Evaluation of Ocean Disposal of Manganese Nodule Processing Waste and Environmental Considerations

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Criteria and Standards Division
Ocean Programs Branch

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Final Report

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EXECUTIVE SUMMARY

A single manganese nodule seabed mining operation is projected to recover approximately 4 million metric tons[a] per year (mty). Processing of these nodules would occur at land-based processing plants. Such a facility will probably be located in coastal areas or have ready access to the ocean for waste disposal. Possible locations could be the western Gulf Coast, southern California, the Pacific Northwest, or Hawaii. The option of land disposal for manganese nodule processing rejects may not be available. The option of ocean disposal may therefore be of great importance to the development of an ocean mining industry.

PROCESSING WASTE

Manganese nodule processing techniques are hydrometallurgical or smelting/hydrometallurgical. These processes rely on chemical leaching of the ground nodule (hydrometallurgical) or smelter matte (smelting/hydrometallurgical) to remove metals such as cobalt, nickel, copper, and molybdenum from the mineral matrix with which they are chemically combined. Processing techniques can also be classified as three- or four-metal processes. Three-metal processes recover copper, cobalt, and nickel as the primary value metals. A four-metal process is designed to also recover manganese. Figure E-1 displays the three- and four-metal processes and their rates of waste production.

The primary waste from nodule processing is a leached residue or rejects from the hydrometallurgical processes and granulated slag from smelting. Volumes of rejects for disposal are estimated at 2.7 to 3.5 x 10^6 mty and 5.8 x 10^5 mty for granulated slag. This volume of rejects would require from 1.8 to 2.4 dumps per day from a 4,900 metric ton capacity barge. One barge of the same size would have to dump every 2.5 days to dispose of the granulated slag. Other types of wastes are produced in a processing plant but their volumes are much less than the rejects. These other waste streams could be added to rejects or treated and disposed of separately. Only the ocean disposal of rejects is evaluated in this report.

Manganese nodule processing rejects will be in the form of a slurry of approximately 42 percent solids and density near 2.0. Particles will be very fine grained. Tests on rejects from one pilot-scale plant showed 50 percent of the solids to be smaller than 6 micrometers (um). Granulated smelter slag is expected to have a much larger particle size, similar to very coarse sand (1.7 mm).

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[a] All values for nodule or reject tonnage are in dry tons unless otherwise noted.

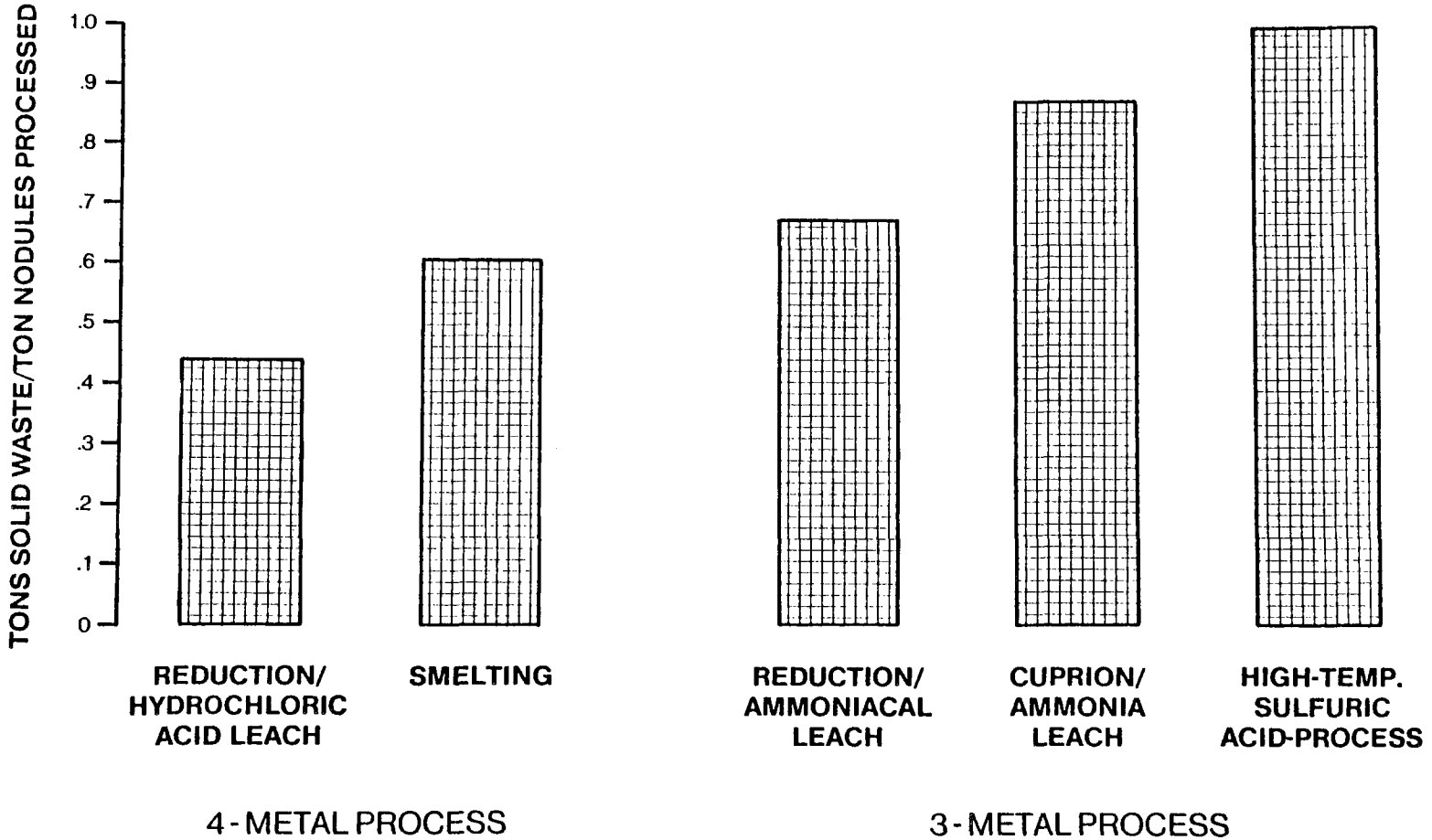


Figure E-1. Waste production rates for alternative manganese nodule processing techniques.

Chemically, the hydrometallurgical rejects will consist mostly of either the carbonate or oxide of manganese, and the oxides of iron, aluminum, and silicon. Granulated slag will be in the form of a vitreous solid. Several heavy metals such as copper, chromium, cadmium, and mercury will also be associated with the rejects, and their potential toxicity is of concern. To be potentially toxic to marine organisms, metals must generally be in a dissolved ionic form. Nearly all the metals associated with the rejects are expected to be chemically combined in the solid phase or adsorbed to particle surfaces. The remaining dissolved metals fraction may exist as dissolved complexes and not as the potentially toxic ionic species. While available evidence supports the above general description of metals partitioning, chemical tests and bioassays of representative rejects will be necessary for qualitative conclusions.

OCEAN DISPOSAL

There are two primary means of disposing of manganese nodule processing rejects to the ocean; pipeline discharge (outfall) and barge dumping. Outfall discharge of rejects requires special siting requirements. The pipe must discharge to a relatively steep slope so that the discharged solids will move downslope and away from the pipe as a density flow. This option is probably feasible only in southern California and Hawaii.

Barged wastes can be dumped through the bottom of the barge or pumped out. The density of the reject slurry in the barge and how it is released will have an important effect on the dispersion and ultimate fate of the rejects. The other major variables are water depth and the density gradient of the water column.

A simplified method has been developed in this report to predict the distribution and concentration of rejects 4 hours after dumping. The 4-hour period was selected because existing regulations call for determination of dilution at the end of 4 hours. A second and perhaps more compelling reason is that to follow advection and dispersion of solids to their point of deposition on the bottom requires the use of a state-of-the-art model and is not amenable to reasonable simplification. The method is useful to describe the behavior of a descending cloud and dilution after 4 hours but should only be used for relative comparisons. With the very fine-grained nature of the solids, much of the material will still be in suspension near the bottom after 4 hours and subject to future transport.

Estimates have been made of the dilution and dispersion of barge dumped sediments using the simplified method. These estimates have been made for nearshore, midshelf, and deepwater areas representative of conditions in the western Gulf of Mexico, southern California, the Pacific Northwest, and Hawaii. For the areas studied, water depths ranged from 44 m (144 ft) to over 3,000 m (9,800 ft). The dilutions after 4 hours range from 37:1 in shallow water to over 50,000:1 in deep water. If all the solids settled from the bottom cloud to the seabed at the end of 4 hours, the areas covered would range from 0.01 km^2 in shallow water to approximately 0.6 km^2 in deep water. As mentioned earlier, however, the full extent of the bottom area

impacted by a dump would be larger but cannot presently be estimated within the scope of this project.

Other disposal concepts which provide a range of containment or dispersal of rejects could be utilized in addition to barge dumping or outfall discharge. A barge or ship can be pumped out and rejects discharged into the ship's wake to achieve maximum dispersion of the waste. Instead of discharging to the surface, the rejects could be shunted through a pipe to a depth below the euphotic zone. This would eliminate the possibility of potential euphotic zone impacts. In water depths less than approximately 200 m, rejects could possibly be shunted directly to the sea floor and provide for maximum containment of rejects.

Rejects could possibly be formed into blocks and dumped nearshore to form an artificial reef. Experiments with wastes from coal-fired power plants suggest that environmental benefits could accrue from the presence of the reef. Blocks of rejects from a three-metal process plant could be more easily recovered if it were later decided to recover manganese. The evaluation of the technical and economic feasibility of this alternative needs extensive study.

CURRENT OCEAN DISPOSAL ACTIVITY

Several waste materials are currently dumped or discharged to marine waters of the United States. In 1979, over 90 million tons of dredged material were dumped at 50 different disposal sites. Also in 1979, nearly 6 million tons of sewage sludge and over 2.5 million tons of industrial wastes were dumped in the Atlantic Ocean.

A total of 232 land-based facilities discharge wastes through outfalls to U.S. coastal waters. These facilities are mostly municipal waste treatment plants, industrial waste treatment plants, and electric generating facilities discharging cooling water. There are also approximately 3,000 offshore oil and gas exploration and production platforms which discharge drilling muds, cuttings, and other wastes.

For the Atlantic, Pacific, and Gulf coasts, over 3 billion gallons of wastewater are discharged each day through marine outfalls. Approximately 360 tons of sewage sludge are discharged each day.

REGULATORY REQUIREMENTS

It appears that current water quality criteria can be met based upon the projected composition of the rejects. Results of chemical analysis of representative processing reject samples are currently not available. The ultimate decision of acceptability for ocean disposal rests with the EPA in the case of ocean dumping. No definitive guidelines exist, however, to determine what degree of biological alteration is acceptable. This is partly because the decision must also be based upon the availability of alternative disposal methods. The final judgement is therefore site specific.

An outfall discharge of manganese nodule processing rejects must currently comply with EPA's regulations for the National Pollutant Discharge Elimination System (NPDES). Discharges to marine waters are addressed specifically by Section 403(c) of the Clean Water Act. As with ocean dumping, the 403(c) regulations do not by themselves provide a definitive answer to the question of what degree of biological alteration is acceptable. The 403(c) regulations must be applied on a case-by-case basis to the facts concerning a particular marine discharge.

There appear to be no absolute regulatory obstacles to the ocean discharge or dumping of manganese nodule processing rejects. It is important to note however that this regulatory evaluation is based upon existing regulations. With commercial scale mining and processing starting in 1988 at the earliest, significant changes in the regulations may occur before they are actually applied to a manganese nodule processing plant.

CHARACTERISTICS OF REPRESENTATIVE DISPOSAL AREAS

The western Gulf of Mexico, the southern California Bight, the Pacific Northwest, and Hawaii are regions where a manganese nodule processing plant might be located by virtue of proximity to the Pacific Ocean nodule mining areas. The physical and biological characteristics of these regions have been evaluated to provide the necessary framework for making general predictions of expected impacts of rejects disposal.

Specific areas have been chosen within each region. The purpose of selecting specific areas is to demonstrate how physical and biological characteristics change with distance from shore and increasing water depth. The areas selected generally represent nearshore, midshelf, and deep water (seaward of the shelf) conditions.

In each of the regions considered, there is typically an offshore-onshore gradient in biological productivity such that nearshore areas are generally most productive. Consequently, most of the major fisheries are located over the continental shelves. Demersal fisheries, which are especially well developed on the continental shelves of the Pacific Northwest and the Western Gulf of Mexico, are particularly vulnerable to adverse impacts of the disposal of manganese nodule processing wastes. Pelagic fisheries, which are the only fisheries in the open ocean, and which are the dominant fisheries over the Hawaiian insular shelf and in the southern California Bight, are less likely to be adversely affected by the disposal of these wastes.

Certain shallow benthic habitats are potentially highly vulnerable to impacts of the marine disposal of manganese nodule processing wastes. These include coral reefs (which are extensively developed in nearshore waters along the Kona coast of the island of Hawaii and exist as well on hard-bottom banks on the outer continental shelf in the western Gulf of Mexico), kelp beds (which flourish in certain nearshore areas of southern California), and other hard-bottom banks having diverse subtidal benthic communities (such as Cortes and Tanner Banks on the seaward portion of the California continental borderland).

The sensitivity of other benthic communities to adverse impacts of the disposal of manganese nodule processing wastes can be expected to vary with the type of natural substrate, the ambient physical/chemical environment, the type of resident organisms, and with the rate of natural sedimentation. Hence, there are important differences in the potential for adverse ecological impacts between regions and between representative disposal areas within each region. This potential for adverse impacts must be evaluated for each area independently, in order to arrive at a decision of the most appropriate disposal site for these wastes.

ENVIRONMENTAL CONSIDERATIONS

Based on a review of the documented effects of marine disposal of mine tailings and other wastes, and on consideration of the limited information on the potential characteristics of manganese nodule processing wastes, it is expected that potential environmental effects of reject disposal may include:

- Effects on primary production
- Direct toxic effects
- Effects on behavior and feeding of marine organisms
- Bioaccumulation
- Effects of substrate alteration
- Intertrophic effects.

Two of these, bioaccumulation and effects of substrate alteration, are expected to be of primary concern because of the potential areal extent of effects, duration of effects, and involvement of commercial/recreational species. Direct toxicity and effects on behavior and feeding have an intermediate significance. The lowest relative significance is associated with effects on primary production and intertrophic effects.

The expected occurrence of potentially toxic metals in manganese nodule processing wastes suggests that bioaccumulation of these metals within marine organisms may be a serious consideration. Organisms may accumulate metals through direct uptake of dissolved forms or through ingestion of contaminated particles. Available evidence indicates that the amount of a metal in the dissolved form is especially important in determining its bioavailability. The metal-binding capacity of the rejects is currently unknown, although the available evidence suggests that it will be high. Further chemical analyses of the wastes would be necessary to evaluate the potential for bioaccumulation of metals by marine organisms. Even if bioaccumulation occurs, however, it is important to note that there is little evidence to suggest that metals can be biomagnified within marine food chains.

An analysis of the effects of the marine disposal of mine tailings, which have characteristics similar to those of the hydrometallurgical process rejects, suggests that benthic (i.e., bottom dwelling) communities may be obliterated by burial under deposits of manganese nodule rejects and that recolonization may be slow due to the unnatural characteristics of these wastes (e.g., change in sediment grain size, lack of organic content, high concentrations of metals). Also, sublethal accumulations of rejects on the sea floor may significantly alter benthic community composition and have effects on marine food chains. Still smaller accumulations of rejects may have negligible effects on benthic communities. The extent of deposition, and therefore the nature of the impacts on benthic communities, may be expected to vary with the receiving environment and with the method of disposal. Of the potentially impacted biotic groups, benthic communities have a higher significance because of the potential for extended exposure to modified or contaminated sediments. Plankton and pelagic fishes are of lesser significance because of limited exposure times, avoidance potential (fishes), and recovery potential (plankton).

Factors important in determining the severity of potential impacts are evaluated in Table E-1. Evaluation of possible disposal options indicates that, considering the relative deposition rates and the potential involvement of commercial/recreational species, the outfall and nearshore dump options would have the greatest potential environmental impacts. The lowest potential impacts are associated with the open ocean disposal options (dump and dispersal). The relative environmental significance of the disposal options varies according to biological and oceanographic characteristics of the four representative disposal sites (Table E-2). For nearshore disposal (outfall or dump), the relative environmental significance is highest in the Pacific Northwest, intermediate in southern California, and lowest in Hawaii. This ranking reflects the general productivity, fisheries potential (especially demersal forms), and available dilution/dispersal in each area. For shelf and deep ocean dispersal options, the four areas have similar levels of environmental significance, except for a higher relative significance for shelf disposal in the western Gulf of Mexico.

It should be emphasized that each of the representative disposal areas has specific environmental characteristics that can potentially alter the relative ranking of disposal options based on generic considerations alone. Moreover, there are most likely considerable differences in sensitivity to impact among organisms associated with each representative disposal area. Unfortunately, these differences in sensitivity are currently not quantifiable. Thus, definitive assessments of potential impacts will require baseline environmental studies, accurate characterization of potential reject materials, and determination of the individual responses of sensitive species to those materials.

TABLE E-1. EFFECTS OF DISPOSAL AREA ON FACTORS RELATED TO POTENTIAL IMPACTS OF WASTE DISPOSAL

Disposal Area	Relative Deposition Rate	Relative Area Affected	Potential Dilution	Relative Organism Sensitivities	Recovery Potential	Trophic Link with Fisheries
Nearshore	High	Limited	Limited	Low	High	High
Shelf	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate to high
Deep ocean	Low	Extensive	High	High	Low	Very limited

TABLE E-2. EVALUATION OF THE ENVIRONMENTAL SIGNIFICANCE OF DISPOSAL AREA OPTIONS WITHIN EACH REPRESENTATIVE DISPOSAL AREA

	Nearshore			
	Outfall	Dump	Shelf	Deep Ocean
Pacific Northwest	4	3	2	1
Southern California	3	3	2	1
Hawaii	2	2	N/A	1
Western Gulf of Mexico	N/A		3	1

Note: Each disposal option is ranked from 1 to 4, with a rank of 4 representing the greatest environmental significance.

1. INTRODUCTION

During the past 15 years, deep ocean manganese nodules have been the focus of a considerable research effort by government, industry, and academia. Much of the interest in manganese nodules stems from their potential as a new source for nickel, copper, cobalt, manganese, and perhaps, molybdenum and other metals. Since the United States relies totally upon foreign sources for nickel, cobalt, and manganese, and imports substantial amounts of copper, development and utilization is of strategic as well as economic significance.

Industry has demonstrated that commercial-scale recovery and processing of deep ocean manganese nodules are technically feasible and is evaluating commercial feasibility. Nodule mining and processing operations are expected to commence as soon as economic and political conditions allow. The provisions of the Deep Seabed Hard Minerals Resources Act allow commercial-scale mining to commence in 1988.

NOAA has been investigating the potential environmental impacts of both deep ocean mining and disposal of manganese nodule processing waste since 1975. NOAA has most recently initiated a cooperative research program on manganese nodule processing waste management in conjunction with the U.S. Bureau of Mines, Environmental Protection Agency Criteria and Standards Division and Office of Research and Development, and U.S. Fish and Wildlife Service. The program consists of three projects:

- Analysis and Characterization of Potential Manganese Nodule Processing Rejects
- State-of-the-Art Assessment of Onshore Disposal of Manganese Nodule Rejects
- Evaluation of Ocean Disposal of Manganese Nodule Processing Waste and Environmental Considerations.

The Analysis and Characterization of Potential Manganese Nodule Processing Rejects project is sponsored by NOAA and is being performed by the Bureau of Mines Avondale Research Center. The objective of this project is to develop chemical and physical characterization of rejects from the types of manganese nodule processing techniques representative of those being developed by industry. Analyses are being performed on rejects generated by pilot-scale processing plants.

The second project, State-of-the-Art Environmental Assessment of Onshore Disposal of Manganese Nodule Rejects, is sponsored by the Bureau of Mines and is being performed by Rogers, Golden, and Halpern. The objectives of this project are to identify state-of-the-art techniques for the onshore

disposal of manganese nodule processing rejects and provide an assessment of regulatory requirements and important environmental concerns at sites representative of those likely to be chosen by industry.

This report presents the results of the third project within the manganese nodule processing waste management program and addresses ocean disposal. Discussion of the following topics is presented:

- Regulatory requirements
- Ocean disposal technologies
- Fate of ocean dumped material
- Current ocean disposal activity
- Characterization of nodule processing rejects
- Comparison of rejects to other wastes
- Physical and biological characteristics of representative disposal areas
- Environmental considerations related to manganese nodule processing rejects disposal
- Research and study requirements for assessing ocean disposal of rejects.

2. LEGAL AND REGULATORY REQUIREMENTS APPLICABLE TO OCEAN DISPOSAL OF MANGANESE NODULE PROCESSING REJECTS

Until the passage of the first environmental legislation in the late 1960s, relatively little governmental or international effort was expended regulating waste disposal in the marine environment. However, increasing public awareness, coupled with political pressures concerning public health and welfare and environmental preservation, led to the passage and ratification of several federal laws and regulations governing waste disposal.

Six major federal environmental laws may apply to manganese nodule processing waste disposal. These are the Federal Water Pollution Control Act (PL 92-500 as ammended), Safe Drinking Water Act (PL 93-253), Clean Air Act (PL 93-319), Resource Conservation and Recovery Act (PL 94-580), Deep Seabed Hard Mineral Resources Act (PL 96-283), and the Marine Protection, Research, and Sanctuaries Act (PL 92-532). All of these laws require permits for disposing, discharging, or dumping wastes into multimedia environments (air, land, surface water, groundwater, and the oceans). However, increasing concern, controversy and research associated with past disposal practices (improper landfilling, midnight dumping) and new innovative technologies (stabilization, encapsulation) have been major factors in the review of several waste management policies. In the United States, many waste management policies are being reviewed and/or re-proposed to consider other disposal options and intermediate trade-offs including but not limited to ocean dumping, marine discharge, waste isolation in stable geologic formations, stabilization, and encapsulation.

If industry elects to dispose of processing wastes in the ocean, it must comply with the two major federal laws governing waste disposal at sea: the Marine Protection, Research, and Sanctuaries Act (for ocean dumping) and the Clean Water Act (for discharge through outfall pipes or discharges from seabed mining vessels, or platforms). Numerous federal laws, such as the Deep Seabed Hard Mineral Resources Act, the National Environmental Policy Act, the Coastal Zone Management Act, the Fish and Wildlife Coordination Act, the Endangered Species Act, the Marine Mammal Protection Act, and the National Historic Preservation Act of 1966 also apply to the ocean disposal of processing wastes but will not be discussed in detail here.

Three key terms used throughout this report include disposal, dumping, and discharge. Disposal is a general term including both dumping and discharge. Dumping is the transportation of wastes from shore, or from any location by a U.S. flag vessel or aircraft, for the purpose of disposal, and the release of such waste into the ocean. Discharge refers to wastes released from a point source, other than a vessel, such as an outfall. For this report, these terms all refer to the ocean environment and are technically defined as follows:

disposal - means the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous wastes into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any water, including groundwaters (40 CFR Part 260.3).

dumping - means a disposition of material: Provided, that it does not mean a disposition of any effluent from any outfall structure to the extent that such disposition is regulated under the provisions of the FWPCA, under the provisions of Section 13 of the River and Harbor Act of 1899, as amended (33 U.S.C. 407), or under the provisions of the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011), nor does it mean a routine discharge of effluent incidental to the propulsion of, or operation of motor-driven equipment on, vessels: Provided further, that it does not mean the construction of any fixed structure or artificial island nor the intentional placement of any device in ocean waters or on or in the submerged land beneath such waters, for a purpose other than disposal, when such construction or such placement is otherwise regulated by Federal or State law or occurs pursuant to an authorized Federal or State program; and provided further, that it does not include the deposit of oyster shells, or other materials when such deposit is made for the purpose of developing, maintaining, or harvesting fisheries resources and is otherwise regulated by Federal or State law or occurs pursuant to an authorized Federal or State program (40 CFR Part 220.2).

discharge - (NPDES) when used without qualification means the "discharge of a pollutant," which means:

> (a)(1) Any addition of any "pollutant" or combination of pollutants to "waters of the United States" from any "point source," or (2) Any addition of any pollutant or combination of pollutants to the waters of the "contiguous zone" or the ocean from any point source other than a vessel or other floating craft which is being used as a means of transportation.
>
> (b) This definition includes additions of pollutants into waters of the United States from: surface runoff which is collected or channelled by man; discharges through pipes, sewers, or other conveyances owned by a State, municipality, or other person which do not lead to a treatment works; and discharges through pipes, sewers, or other conveyances leading into privately owned treatment works.

This term does not include an addition of pollutants by any "indirect discharger."

OCEAN DUMPING

With increasing danger of marine pollution by ocean dumping of waste materials, the President of the United States in April, 1970, directed the Council on Environmental Quality to conduct a study of the problems and alternatives to ocean dumping. This report (Senate Report 92-451, 1971) concluded that although dumping was not a major source of pollution at present, there was an immediate need for urgent action both at national and international levels to prevent the problem of dumping from growing to a great magnitude. As a follow-up to the report, the United States prepared a draft legislation package to regulate the transportation for ocean dumping at an international level. This draft on ocean dumping policy was intended to provide the basis for a global convention on ocean dumping during the United Nations Conference on the Human Environment scheduled for June of 1972.

London Dumping Convention

After much deliberation, an International Conference on Dumping at Sea was held in London from October 30 to November 13, 1972. The conference was attended by 82 states, with 12 other states and various international organizations sending observers. After much debate, the conference adopted a Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (referred to as the London Dumping Convention, the Convention, or LDC) (see Appendix A for a summary of the Convention). Following receipt of the required 15 ratifications or accessions, the London Dumping Convention entered into force on August 30, 1975.

The London Dumping Convention is an international treaty requiring the Contracting Parties to establish national systems to control vessels and aircraft carrying substances leaving their shores for the purpose of being disposed of at sea. It introduced a new element in international law on the environment, in that it is the responsibility of states to prevent damage not only to the environment of other states but also to the environment of areas beyond the limits of national jurisdiction. The Convention requires each signatory state to establish an appropriate authority to issue permits, keep records, and monitor activities. The United States, as a member of the Convention, complies with the mandates and intent of the London Dumping Convention through the guidelines and regulations established by EPA under Title I of the Marine Protection Research and Sanctuaries Act.

Because the Convention was signed when the Third United Nations Conference on the Law of Sea (UNCLOS III) was being prepared and UNCLOS III was to deal with deep sea minerals, the London Dumping Convention did not address at length the dumping of wastes resulting from the processing of seabed mineral resources. Article 210 provides for the development by individual states of rules and regulations for areas and persons subject to its jurisdiction which should be no less effective than any rules developed

collectively by a competent international organization or diplomatic conference. The Law of the Sea Convention is scheduled for signing in Caracas later this year. Many provisions including those dealing with navigation, overflight, the continental shelf, marine research, and the environment are constructive; however, Part XI governing mineral recovery from the deep seabeds appears difficult to approve. Whether under the London Dumping Convention or the Law of the Sea Convention, it is up to the respective signatory state, to make decisions on the dumping of manganese nodule processing wastes.

Marine Protection, Research, and Sanctuaries Act

Statutory Overview--

The Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), commonly known as the "Ocean Dumping Act," was developed to fill regulatory gaps in the protection of the marine environment and public health and welfare. The statute declares "it is the policy of the United States to regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems or economic potentialities" (PL 92-532, October 23, 1972, 33 USC 1401). The Act is to regulate the transportation by any person of material from the United States and, in the case of United States flag vessels, aircraft, or agencies, the transportation of material from a location outside the United States, when in either case the transportation is for the purpose of dumping the material into ocean waters, and the dumping of material transported by any person from a location outside the United States, if the dumping occurs in the territorial seas or the contiguous zone of the United States. The territorial seas are roughly defined as those waters lying within 3 miles of a baseline (roughly the coastline) and the contiguous zone as those waters lying between 3 and 12 miles seaward from the baseline. Thus, the MPRSA mandates the EPA to administer and enforce the regulation of ocean dumping, not only within the territorial seas and contiguous zone, but also within international waters.

Title I of the MPRSA sets forth factors which need to be considered by the Administrator of the EPA in the establishment and application of criteria to be used in the evaluation of permit applications for ocean dumping. These factors include:

A The need for the proposed dumping.

B The effect of such dumping on human health and welfare, including economic, aesthetic, and recreational values.

C The effect of such dumping on fisheries resources, plankton, fish, shellfish, wildlife, shorelines, and beaches.

D The effect of such dumping on marine ecosystems, particularly with respect to

  i the transfer, concentration, and dispersion of such material and its byproducts through biological, physical, and chemical processes;

  ii potential changes in marine ecosystem diversity, productivity, and stability; and

  iii species and community population dynamics.

E The effect of dumping particular volumes and concentrations of such materials.

F The persistence and permanence of the effects of the dumping.

G Appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of requiring use of such alternate locations or methods upon considerations affecting the public interest.

H The effect on alternate uses of the oceans, such as scientific study, fishing, and other living resource exploitation, and nonliving resource exploitation.

I In designating recommended sites, the Administrator shall utilize, wherever feasible, locations beyond the edge of the Continental Shelf (PL 92-532 October 23, 1972).

Under the Act, EPA is authorized to administer and enforce the entire ocean dumping program and to issue permits regulating the dumping of all materials except dredged materials, which are dumped under U.S. Army Corps of Engineers permits issued consistent with EPA's marine environmental impact criteria.

Title III of the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), as amended in 1980, authorizes the Secretary of Commerce with Presidential approval to designate ocean waters as marine sanctuaries for the purposes of preserving or restoring their conservation, recreational, ecological, or aesthetic values. The marine sanctuaries program is intended to prevent indiscriminate multiple use of specific areas that have special values and uses. Site selection criteria for marine sanctuaries include both resource and human-use values in an approach which accurately reflects the intent of Congress in enacting this legislation. Sanctuaries may be designated as far seaward as the outer edge of the continental shelf, in coastal waters where the water ebbs and flows, or in the Great Lakes and their connecting waters. Table 1 gives a listing of the six established marine sanctuaries to date.

TABLE 1. MARINE SANCTUARIES NAMES AND ADDRESSES
(AS OF APRIL, 1982)

Gray's Reef National Marine Sanctuary
(off Sapelo Island, Georgia)
(no manager appointed yet)
Georgia Department Natural Resources
Coastal Resources Division
1200 Glynn Ave.
Brunswick, GA 31523
(912) 264-7289

U.S.S. MONITOR National Marine Sanctuary
(off North Carolina)
Diana Lange, Sanctuaries Coordinator
North Carolina Department Cultural Resources
Division of Archives and History
Underwater Archaeology Branch
P.O. Box 58
Kure Beach, NC 28449
(919) 458-9042

Key Largo Coral Reef National Marine Sanctuary
(off Florida's John Pennecamp State Park)
Florida Department of Natural Resources
Crown Building
202 Blount St.
Tallahassee, FL 32304
(904) 488-1555
(on-site)
John C. Halas, Sanctuaries Biologist
c/o John Pennecamp State Park
U.S. Route 1
MM 102.5 (Oceanside)
P.O. Box 487
Key Largo, FL 33037
(305) 451-2770

Looe Key National Marine Sanctuary
(off Florida Keys)
Florida Department of Natural Resources
Crown Building
202 Blount St.
Tallahassee, FL 32304
(904) 488-1555

TABLE 1. (Continued)

(on-site)
Will Sheftal, Manager
Bahia Honda State Recreation Area
U.S. Route 1, Box 782
Big Pine Key, FL 33043
(305) 872-3253

Channel Islands National Marine Sanctuary
(off Southern California)
(no manager appointed yet)
Channel Islands National Marine Sanctuary
c/o Channel Islands National Park
1901 Spinnaker Dr.
Ventura, CA 93001
(805) 644-8157

Point Reyes-Farallon Islands National Marine Sanctuary
(off north central California)
Peter Gogan, Manager
Point Reyes National Marine Sanctuary
c/o Point Reyes National Seashore
Point Reyes, CA 94956
(415) 663-8017

Regulatory Process--

Regulations promulgated under Title I, Section 102 of the MPRSA were first issued by EPA in 1973. The final ocean dumping regulations were updated by EPA in January, 1977 (Federal Register, January 11, 1977). They are currently being considered for another revision due to advances in scientific knowledge and operational experience.

Existing Regulations--

EPA has set up a regulatory approach to ocean dumping with several levels of control. All materials to be dumped in the ocean require a permit. Except for those wastes generally approved for dumping, all wastes must meet the need, environmental, economic, and social impact criteria set out in 40 CFR Part 227. The burden of proof rests with the applicant to indicate that the disposition of materials seaward of the baseline will not unduly degrade or endanger the marine environment. The criteria used to evaluate proposed dumping are applied on a case by case basis from information available to the applicant, EPA, or the Corps of Engineers.

Specific criteria form the basis for the applicant to show that the proposed disposal of material does not have significant adverse environmental impacts. EPA has established regulations to evaluate materials by categories. Manganese nodule processing wastes are most likely to be classified in one of the following three categories:

1. Prohibited materials (40 CFR Part 227.5) - The dumping of the following materials is prohibited and a permit will not be approved of under any circumstances:

   - High-level radioactive wastes
   - Materials produced or used for radiological, chemical, or biological warfare
   - Persistent inert synthetic or natural materials which may float or remain in suspension in such a manner that might interfere with fishing, navigation, or other uses of the ocean
   - Materials insufficiently described by the applicant to effectively evaluate the application on the basis of the environmental impact criteria.

   It is unlikely that manganese nodule processing rejects will fall into the prohibited category unless the composition and properties of the waste are insufficiently known.

2. Constituents prohibited as other than trace contaminants (40 CFR Part 227.6) - Materials containing the constituents below, which are prohibited other than as trace

contaminants, require detailed characterization and quantification:

- Mercury and its compounds
- Cadmium and its compounds
- Organohalogens
- Oil and greases
- Known or suspected carcinogens, mutagens, or teratogens.

The term "trace contaminants" was initiated to agree with the London Dumping Convention. It is described as those quantities that are in such form and amount that the dumping will not cause significant undesirable effects, including the possibility of their bioaccumulation in organisms. To determine those quantities, bioassay and bioaccumulation testing methods have been developed which are consistent with an ecosystem approach and yield more accurate assessments of the materials impact than comparing total amounts of specific constituents with arbitrary ambient values. Bioassay procedures are used to set the "limiting permissable concentration" that makes up the monitoring parameter for specific constituents.

Trace contaminants listed above, or any other toxic waste (under 40 CFR Part 227.8) cannot exceed its limiting permissable concentrations. The definition of limiting permissable concentration is critical to application of the regulations. Liquid, suspended particulates, and solid phases of the material proposed for ocean dumping each have a limiting permissable concentration for the particular constituent determined by its effect on the marine environment.

The specific bioassay requirements do not apply if the applicant can demonstrate that the constituents are present in a form that is non-toxic and non-bioaccumulative to the marine environment, or will be rapidly rendered so in the marine environment by biological or chemical degradation. EPA has great leeway in the identification of trace contaminants and their allowable concentrations. Potential toxic constituents are dealt with on a case by case basis following bioassay procedures outlined in manuals published by EPA and the Corps of Engineers.

It is likely that disposal of manganese nodule tailings will have to comply with these requirements because nodules are known to contain trace amounts of mercury and cadmium.

These elements are inert in the nodules, but if the processing techniques convert them to soluble compounds or significantly increase their concentration in the solid phase, ocean dumping may be prohibited. Under 40 CFR Part 227.12, "solid wastes consisting of inert natural minerals or materials compatible with the ocean environment may be generally approved for ocean dumping provided they are insoluble above the applicable trace or limiting permissible concentrations and are rapidly and completely settleable, and they are of a particle size and density that they would be deposited or rapidly dispersed without damage to benthic, demersal, or pelagic biota."

Chapter 5 of this report provides a characterization of the manganese nodule processing waste. It is most likely that these wastes would come within the "Strictly Regulated Dumping" category of the London Dumping Convention (see Annex II) and within the "trace constituents" or "other limited materials" categories under the MPRSA.

3. Other limited materials (40 CFR Part 227.7) - Some materials have specific limitations in their concentrations and impacts. They include:

   - Liquid waste constituents immiscible or slightly soluble in water, such as benzene, xylene, carbon disulfide, and toluene, may be present only below their solibility limits in seawater, as long as they do not interact with ocean water to form insoluble materials

   - Radioactive wastes, if not prohibited as high-level radioactive waste, must be safely containerized

   - Wastes containing living organisms are prohibited if the organisms would endanger human or domestic animals health

   - Highly acidic or alkaline wastes require special care which includes demonstrating that the waste cannot change the total acidity or alkalinity of the ocean water by more than 10 percent

   - Biodegradable wastes which consume oxygen may be dumped only in quantities which will not depress normal dissolved oxygen levels by more than 25 percent.

In addition to the above classifications and environmental impact criteria, the applicant must demonstrate the necessity for dumping and potential adverse effects on other uses of the ocean. Other criteria the applicant must meet include:

1. Need for ocean dumping (40 CFR Parts 227.14-227.16) - The applicant must indicate that other options (i.e., landfill, recycle, storage, landfarm, incineration, etc.) and their environmental and economic costs have been considered. The need for ocean dumping will not be considered to have been demonstrated unless it is indicated that there are no practicable alternative locations and methods of disposal or re-use available which have less adverse environmental impact or potential risk to other parts of the environment than ocean dumping. It has been suggested that possible uses of nodule wastes could be landfilling on undesireable land, landfarming and recycling for fertilizer uses. These need to be looked at closely before any permit is approved.

2. Impact or aesthetic, recreational, and economic values (40 CFR Part 227.17) - The applicant must demonstrate that there is no potential for impacting or affecting beaches or shorelines, commercial fishing, or municipalities or other industries.

3. Impact on other uses of the ocean (40 CFR Part 227.20) - It must be shown that the dumping of the nodule wastes has no adverse effects on other uses of the ocean and coastal areas (i.e., scientific research, oil and gas exploration, transportation and navigation). The two major areas of concern here are ocean transportation and fishing.

The objective of these additional criteria is to ensure that there is consideration of economic and social factors in the decision to allow ocean dumping.

EPA's regulatory approach to the ocean dumping program consists of site designation, permitting, and surveillance and enforcement. Site designation includes geographic placement of the site, waste dispersal characteristics and interference with other uses of the ocean. The parameters used in designating, and monitoring dump sites include location, depth, currents water quality, potential accumulation of constituents, past activities at site and existing ambient data both chemical and biological. Both EPA and NOAA (administers Title II of MPRSA, Ocean Research and Monitoring) take the responsibility for researching and monitoring the dump sites. EPA designates site while surveillance, enforcement notice, and safe waste transport responsibilities are under the authority of the U.S. Coast Guard. Responsibilities of other federal departments and agencies involved in the ocean waste disposal program under the MPRSA are shown in Table 2.

Ocean dumping permits are issued by both the Corps of Engineers or EPA (with authority delegated to District Engineers or Regional Administrators, see Table 3) for dredged and nondredged material, respectively. These permits require submission of detailed engineering studies and studies outlining the alternatives to ocean dumping. For material other than dredge spoils, the applicant must also submit a compliance schedule to implement an

TABLE 2. RESPONSIBILITIES OF FEDERAL DEPARTMENTS AND AGENCIES FOR REGULATING OCEAN WASTE DISPOSAL UNDER MPRSA

Department/Agency	Responsibility
U.S. Environmental Protection Agency	Issuance of waste disposal permits, other than for dredged material
	Establishment of criteria for regulating waste disposal
	Enforcement actions
	Site designation and management
	Overall ocean disposal program management
	Research on alternative ocean disposal techniques
U.S. Department of the Army Corps of Engineers	Issuance of dredged material disposal permits
	Recommending dredged material disposal site locations
U.S. Department of Transportation Coast Guard	Surveillance
	Enforcement support
	Issuance of regulations for disposal vessels
	Review of permit applications
U.S. Department of Commerce National Oceanic and Atmospheric Administration	Long-term monitoring and research
	Comprehensive ocean dumping impact and short-term effect studies
	Marine sanctuary designation
U.S. Department of Justice	Court actions
U.S. Department of State	International agreements

TABLE 3. EPA REGIONAL ADMINISTRATIVE OFFICES WITH JURISDICTION OVER SELECTED STATES

Alaska, Oregon, Washington	EPA Region X 1200 Sixth Avenue Seattle, Washington 98101 (206) 442-1220 FTS/339/1220
California, Hawaii	EPA Region IX 215 Fremont Street San Francisco, California 94105 (415) 974-8076 FTS/454/8076
Texas, Louisiana	EPA Region VI 1201 Elm Street Dallas, Texas 75270 (214) 767-7341 FTS/729/7341

environmentally acceptable alternative disposal method before December 31, 1981, or demonstrate that no feasible alternative exists and the waste to be dumped is in full compliance with EPA's criteria by December 31, 1981. The regulations under 40 CFR Part 220.3 describe the six categories of permits. These permit types include:

1. General permits - for disposal of small quantities of material which have minimal adverse environmental impacts when dumped under prescribed conditions.

2. Special permits - for materials that satisfy the criteria, but valid only up to 3 years. Holders of special permits are not subject to the 1981 deadline for cessation of the ocean disposal of harmful wastes. It is most likely that manganese nodule processing wastes would require a special permit for dumping since similar waste types as acid iron wastes and industrial wastes have been approved.

3. Emergency permits - for materials which pose an unacceptable risk relating to human health and for which there is no other feasible alternative. These permits are issued on a limited, case by case basis.

4. Interim permits - these permits which are valid for a maximum of 1 year are issued when the applicant does not demonstrate compliance of the waste with the environmental impact criteria, but can demonstrate that the need for ocean disposal is of greater significance to the public than possible adverse environmental impacts. However, interim permits can not be issued to applicants who were not issued dumping permits before April 23, 1978. Holders of present permits must have a compliance schedule which will ensure either the complete phaseout of the activities by December 31, 1981. Thus, interim permits as presently stated do not apply to the dumping of manganese nodule wastes.

5. Research permits - for dumping material into the ocean as part of a research project, when scientific merit outweighs the potential impacts (i.e., in 1979 a permit was granted for oil dispersant studies). It is possible that initial permits for ocean dumping of nodule processing wastes from pilot plants during feasibility studies will fall under this category.

6. Incineration at sea permits - not applicable.

Applications for any of these permits must include all information necessary to evaluate the application. They must include general information, detailed physical and chemical analyses of the wastes, bioassay or other test results required to apply the impact criteria, the proposed dumpsite, times and amounts of material to be dumped, description of the way

in which this material has previously been disposed of, identification of the process or activity generating the wastes, the method of release of the materials, and an assessment of the environmental impact of the proposed dumping.

According to EPA regulations (40 CFR Part 222.1), "Final action on any application for a permit will, to the extent practicable, be taken within 180 days from the date a complete application is filed." However, the nature of the public review process is such that there is no guarantee that a permit will be granted in that time, if at all. A flow diagram of current permitting procedures for ocean dumping is shown in Figure 1.

Current Status--

The regulatory process has been fairly successful to date relative to the objective of eliminating ocean dumping. Of approximately 150 industrial ocean dumpers in 1973, only 13 remain as of April, 1979 (EPA 1980a). Excluding the Allied Chemical Corporation, NL Industries Incorporated, and E.I. duPont de Nemours, all of the remaining industrial ocean dumpers in the New York Bight and Puerto Rico areas have enforceable compliance schedules within their permits which specify the cessation of ocean dumping by the end of 1981.

So far the EPA has not had to make a permit decision on the economic reasonableness of land-based alternatives. They have been granting or denying permits based upon the environmental criteria. However, the general opinion of the industrial ocean dumpers is that even in a situation where the environmental impact criteria are not met or where a land-based alternative to ocean disposal has a lower overall environmental impact than ocean dumping, economics need to be considered and factored into the decision to grant or deny a permit.

This approach has also been encouraged by the National Advisory Committee on Oceans and Atmosphere (NACOA). A NACOA report entitled "The Role of the Ocean in a Waste Management Strategy, January 1981" states that the ocean is the best disposal option for certain waste material, and that the United States policy should be to dispose of wastes in the most environmentally sound manner, without granting special protection to a particular medium. NACOA further states that even if the risk were somewhat greater for ocean disposal, significantly disproportionate costs could justify the granting of an ocean dumping permit.

This viewpoint was recently supported in a court decision ruling that the Marine Protection, Research, and Sanctuaries Act did not authorize EPA to ban the dumping of New York City sludge in the New York Bight without considering the alternatives to ocean dumping. The District Court ordered that EPA revise its ocean dumping regulations to require a balancing of all the statutory factors including costs and the need for dumping against environmental harm in each case [U.S. District Court for Southern District of New York, City of New York vs. U.S. EPA, 80 Civ. 1677 (ADS), August 28, 1981].

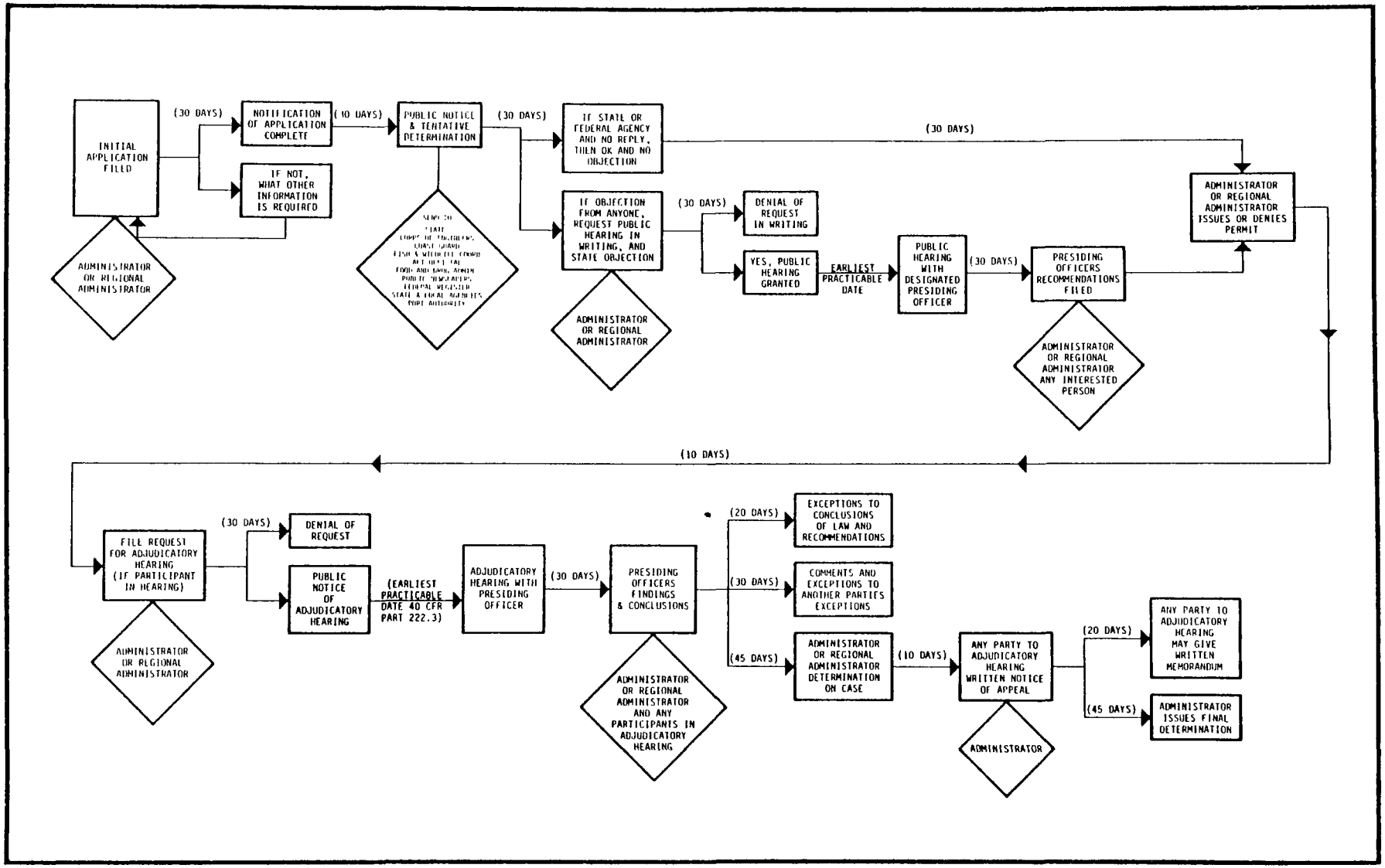


Figure 1. Flow diagram of current permitting procedures for ocean dumping.

OCEAN DISCHARGE

An alternative to ocean dumping or land disposal of manganese nodule processing wastes is the discharge of these materials directly to the ocean by the means of an ocean outfall. An ocean outfall is defined as any point source from which pollutants are discharged into the territorial sea, contiguous zone or the ocean. Ocean discharge of point source pollutants is regulated under the authority of the Clean Water Act (PL 95-217), amending the Federal Water Pollution Control Act (PL 92-500). Section 402 of the Clean Water Act, establishing the National Pollutant Discharge Elimination System, and Section 403 of the Clean Water Act governing ocean discharges, are of primary importance when considering ocean discharge of manganese nodule processing wastes. The Clean Water Act and its associated regulations govern ocean discharges from both land based processing facilities and those facilities discharging at sea through an ocean outfall from either a platform or processing vessel.

Clean Water Act

The Clean Water Act is the principal statutory authority regulating the discharge of pollutants to the navigable waters of the United States (including the territorial sea), the contiguous zone, and the oceans. Section 402 of the Clean Water Act establishes the National Pollution Discharge Elimination System (NPDES) permit program. Section 403(c) addresses specifically the criteria to be used in evaluating NPDES permits for point source discharges to the territorial sea, the contiguous zone and the oceans. The regulations for the NPDES permit program and the criteria for ocean discharge are promulgated under EPA's Consolidated Permit Program and can be found in 40 CFR Parts 122, 124, and 125.

Section 402 - NPDES Permits--

The NPDES permit program is administered either by EPA or by a state agency under an EPA-approved program. Table 4 indicates those states with approved NPDES programs. NPDES requirements under the EPA program and an approved state program are basically the same, but each state should be contacted regarding specific requirements in their regulations and application procedures. A state NPDES program will only apply to discharges within the territorial waters of the state. Discharges to the contiguous zone or oceans could be allowed only under a permit issued by the appropriate EPA region (see Table 5). The appropriate NPDES application forms can be obtained from EPA regional offices or the responsible state agency.

Pursuant to Sections 301, 304(b) and (c), 306(b) and (c), and 307(c) of the Clean Water Act, as amended, New Source Performance Standards (NSPS) and effluent limitation guidelines representing effluent reduction attainable by

TABLE 4. NPDES PERMITTING AUTHORITY

State	State	EPA
Alaska		x
California	x	
Hawaii	x	
Louisiana		x
Oregon	x	
Texas		x
Washington	x	

TABLE 5. NPDES PERMITTING AGENCIES

Alaska	EPA Region X 1200 6th Avenue Seattle, WA 98101 (206) 442-1220 FTS/339/1220
California[a]	Issued by Regional Water Quality Control Boards - Approved by the State Water Resources Control Board State Water Resources Control Board P.O. box 100 Sacramento, CA 95801 (916) 322-8353
	Regional Water Quality Control Boards
	North Coast Region (1) 1000 Coddingtown Center Santa Rosa, CA 95401 (707) 545-2620
	San Francisco Bay Region (2) 1111 Jackson St., Room 6040 Oakland, CA 94607 (415) 464-1155
	Central Coast Region (3) 1122-A Laurel Lane San Luis Obispo, CA 93401 (805) 549-3147
	Los Angeles Region (4) 107 S. Broadway, Room 4027 Los Angeles, CA 90012 (213) 620-4460
	Santa Ana Region (8) 6809 Indiana Avenue Riverside, CA 92506 (714) 684-9330
	San Diego Region (9) 6154 Mission Gorge Rd., Suite 205 San Diego, CA 92120 (714) 286-5114

TABLE 5. (Continued)

Hawaii[a]	State of Hawaii Department of Health Pollution Technical Review Branch 645 Halekauwila St. Honolulu, HI 96813 (808) 548-6410
Louisiana[b]	EPA Region VI 1201 Elm Street Dallas, TX 75270 (214) 767-7341 FTS/729-7341
Oregon[c]	Department of Environmental Quality 522 S.W. Fifth Avenue P.O. Box 1760 Portland, OR
Texas[b]	EPA Region VI 1201 Elm Street Dallas, TX 75270 (214) 767-7341 FTS/729-7341
Washington[c]	Department of Ecology Olympia, WA 98504 (206) 753-0211

[a] EPA Region IX issues NPDES permits for the contiguous zone and oceans off of California and Hawaii.

[b] EPA Region VI issues NPDES permits for the contiguous zone and oceans off of Louisiana and Texas.

[c] EPA Region X issues NPDES permits for the contiguous zone and oceans off of Oregon, Washington, and Alaska.

the application of "best practicable control technology currently available" (BPT), "best available technology economically achievable" (BAT), and "best conventional pollutant control technology" (BCT), have been promulgated for certain industrial categories. Manganese nodule processing is not covered by any of the existing industrial categories or standards. In the absence of existing standards, a NPDES permit will be evaluated using best professional or engineering judgement (BPJ or BEJ). The permitting agency will gather information from available sources to evauate the permit and discharge impacts. The applicant must verify that state water quality standards will be met and that the discharge will be consistent with the state's coastal zone management program.

In the case of a NPDES ocean discharge permit, the applicant must also first meet any more stringent requirements under the 403(c) ocean discharge criteria.

Section 403(c) - Ocean Discharge Criteria--

Section 403(c) of the Clean Water Act provides the statutory authority to establish guidelines for the issuance of National Pollutant Discharge Elimination System (NPDES) permits for the discharge of pollutants from a point source into the territorial seas, the contiguous zone, and the oceans.

Under the Clean Water Act (Section 502) these terms are defined as follows:

- Territorial seas means the belt of the seas measured from the line of ordinary low water along that portion of the coast which is in direct contact with the open sea and the line marking the seaward limit of inland waters, and extending seaward a distance of three miles

- Contiguous zone means the entire zone established or to be established by the United States under article 24 of the Convention of the Territorial Sea and the Contiguous Zone

- Ocean means any portion of the high seas beyond the contiguous zone.

The guidelines are promulgated under Title 40 CFR, Part 125.120-125.124. The regulations were published in the Federal Register on October 3, 1980.

The statutory requirements of Section 403(c) directed the Environmental Protection Agency to promulgate guidelines which would evaluate:

- The effect of disposal of pollutants on human health or welfare, including but not limited to plankton, fish, shellfish, wildlife, shorelines, and beaches

- The effect of disposal of pollutants on marine life including the transfer, concentration, and dispersal of pollutants on their byproducts through biological, physical, and chemical processes; changes in marine ecosystem diversity, productivity, and stability; and species and community population changes

- The effect of disposal of pollutants on aesthetic, recreation, and economic values

- The persistence and permanence of the effects of disposal of pollutants

- The effect of the disposal at varying rates, of particular volumes and concentrations of pollutants

- Other possible locations and methods of disposal or recycling of pollutants including land-based alternatives

- The effect of alternate uses of the oceans, such as mineral exploitation and scientific study.

The regulatory standards and criteria developed under these guidelines charge the permit writing agency with the responsibility of determining whether a proposed discharge will cause "unreasonable degradation." The determination will be based on available information concerning the discharge area and the proposed material to be discharged. The permitting agency may be able to use some mitigating conditions to prevent or ameliorate degradation, or if they can't get enough information to make a determination they shall prescribe a monitoring program that will require the permittee to obtain the needed information. "Unreasonable degradation" of the marine environment is defined (45 FR Vol. 194, p. 65953) to mean:

- Significant adverse changes in ecosystem diversity, productivity and stability of the biological community within the area of discharge and surrounding biological communities,

- Threat to human health through direct exposure to pollutants or through consumption of exposed acquatic organisms, or

- Loss of aesthetic, recreational, scientific or economic values which is unreasonable in relation to the benefit derived from the discharge.

Factors in determining unreasonable degradation to be considered by the permit writing agency include:

- The quantities, composition and potential for bioaccumulation or persistence of the polluants to be discharged in the environment

- The potential transport of such polluants by biological, physical, or chemical processes

- The composition and vulnerability of the biological communities which may be exposed to such pollutants including the presence of unique species or communities of species, the presence of species identified as endangered or threatened pursuant to the Endangered Species Act, or the presence of these species critical to the structure or function of the ecosystem, such as those important for the food chain

- The importance of the receiving water area to the surrounding biological community, including the presence of spawning sites, nursery/forage areas, migratory pathways, or areas necessary for other functions or critical stages in the life cycle of an organism

- The existence of special aquatic sites including, but not limited to marine sanctuaries and refuges, parks, national and historical monuments, national seashores, wilderness areas and coral reefs

- The potential impacts on human health through direct and indirect pathways

- Existing or potential recreational and commercial fishing, including finfishing and shellfishing

- Any applicable requirements of an approved Coastal Zone Management Plan

- Such other factors relating to the effects of the discharge as may be appropriate

- Marine water quality criteria developed pursuant to Section 304(a)(1) of the Clean Water Act (PL 95-217).

Those discharges in compliance with Sections 301(g), 301(h), or 316(a) variance requirements of the Clean Water Act, or in compliance with state water quality standards shall be presumed not to cause unreasonable degradation of the marine environment, for any specific pollutants or conditions specified in the variance or standard.

In order to make the unreasonable degradation determination, the permit writing agency may require from the applicant the following information, as well as any other pertinent information:

- An analysis of the chemical constituents of any discharge

- Appropriate bioassays necessary to determine the limiting permissible concentrations for the discharge

- An analysis of initial dilution

- Available process modifications which will reduce the quantities of pollutants which will be discharged

- Analysis of the location where pollutants are sought to be discharged, including the biological community and the physical description of the discharge facility

- Evaluation of available alternatives to the discharge of pollutants including an evaluation of the possibility of land-based disposal or disposal in an approved ocean dumping site.

Figure 2 illustrates the decision process to be followed by the NPDES permitting agency based upon the agency's determination of unreasonable degradation. A finding of unreasonable degradation compels the agency to revoke an existing permit or to deny a new discharge application. A finding of no unreasonable degradation allows permit issuance or renewal, with any necessary conditions as determined by the permitting agency.

In many cases, it is anticipated that the permitting agency will not have sufficient information to make a conclusive determination of unreasonable degradation based upon existing information. In these cases, no discharge will be allowed to occur unless the permitting agency determines that:

1. The discharge will not cause "irreparable harm" to the marine environment while further evaluation is undertaken

2. There are no reasonable alternatives to the discharge

3. The discharge will comply with certain mandatory conditions.

Permit conditions will require that a discharge of pollutants following dilution as measured at the boundary of the mixing zone not exceed the limiting permissible concentration for the liquid and suspended particulate phases of the waste material as described in Section 227.27(a)(2) and (3), Section 227.27(b) and (c) of the Ocean Dumping Criteria, and not exceed the limiting permissible concentration for the solid phase of the waste material or cause an accumulation of toxic materials in the human food chain as described in Sections 227.27(b) and (c) of the Ocean Dumping Criteria. Additional requirements may include a monitoring program, analysis of bioaccumulative/persistent impact on aquatic life, and performance of liquid or suspended particulate phase bioaccumulation tests. The "mixing zone" is defined under the Ocean Discharge Criteria [40 CFR Part 125.121(c)] as the zone extending from the sea's surface to seabed and extending laterally to a distance of 100 meters in all directions from the discharge point(s), or as

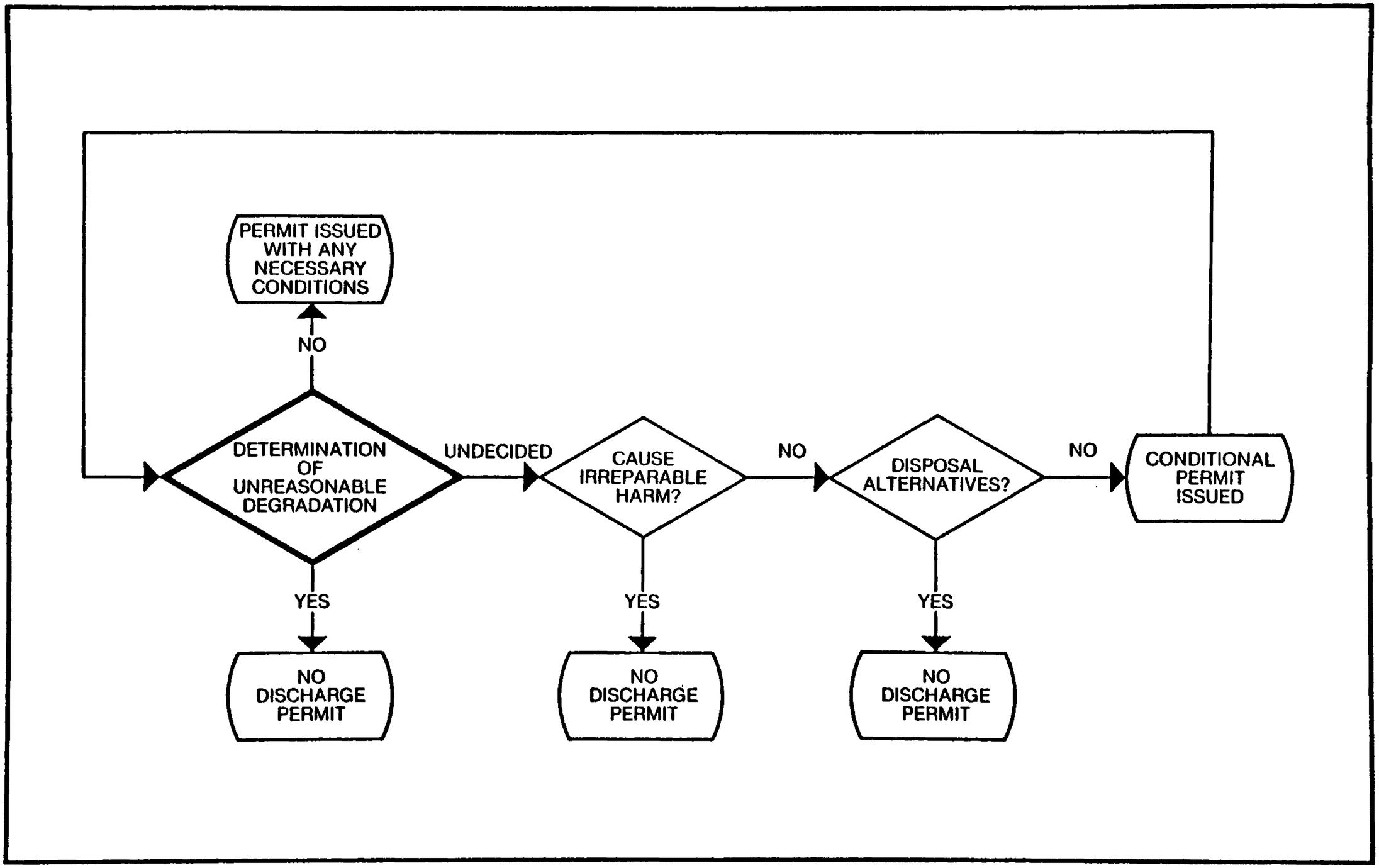


Figure 2. NPDES permit agency decision process for 403(c) evaluations.

the boundary of the zone of initial dilution as calculated by a plume model approved by the director, whichever is greater, unless the director determines that the more restrictive mixing zone or another definition of the mixing zone is more appropriate for a specific discharge. The LPC of the liquid phase is the concentration of the pollutant in the receiving water, after allowances for initial mixing (as defined in 40 CFR Part 227.29), which will not exceed a toxicity threshold of 0.01 of the concentration shown to be acutely toxic to appropriate marine organisms by an EPA approved bioassay procedure. An alternative application factor other than 0.01 can be used in calculating the LPC for liquid phase material if it can be demonstrated to be scientifically supported.

Where the discharge contains suspended particulates and/or solid phase, the applicant will be required to show that the LPC for the suspended particulate and/or solid phase is not exceeded in accordance with Sections 227.27 (b), (c), and (d) of the existing Ocean Dumping Criteria (40 CFR 227). The LPC for these phases is defined as that concentration which will not cause unreasonable acute or chronic toxicity or other sublethal adverse effects based on bioassay results using appropriate marine organisms, or that concentration which will not cause accumulation of toxic materials throughout the human food chain.

Applicants may submit bioassay analyses performed on other wastes in place of bioassay test results on their particular effluent, if the applicant provides documentation to show that the composition of the waste analyzed typifies that which the applicant is discharging or intends to discharge. When the information is not otherwise available, the applicant will be required to determine the LPC in accordance with procedures described in Bioassay Procedures for the Ocean Disposal Permit Program (U.S. EPA 1978), and in Ecological Evaluation of Proposed Discharge of Dredge Material into the Ocean Waters (EPA/COE 1977).

Additional mandatory requirements of an NPDES permit, in those cases where sufficient information is not available to make a conclusive determination of unreasonable degradation, shall include the establishment of a monitoring program to assess the impact of the discharge on water, sediment, and biological quality. Other conditions which may be required of any NPDES ocean discharge permit include bioaccumulation tests, seasonal restrictions, and process modification.

All NPDES permits issued under the 403(c) guidelines can be modified or revoked at any time on the basis of new data indicating that continued discharge may cause unreasonable degradation of the marine environment.

Dischargers applying for an NPDES permit under Section 403(c) must still comply with all other requirements of the Clean Water Act, including applicable technology-based requirements specified by Sections 301, 304, or 306 and water quality based limitations specified by Sections 303 or 307.

OTHER REGULATORY PROGRAMS INVOLVED

The primary statutes applicable to waste disposal at sea have been discussed in detail. However, numerous other federal laws may apply to ocean disposal of processing wastes and may impact project lead times. These laws include the Deep Seabed Hard Mineral Resources Act, the National Environmental Policy Act, the Coastal Zone Management Act, the Fish and Wildlife Coordination Act, the Endangered Species Act, the Marine Mammal Protection Act, and the National Historic Preservation Act of 1966, and merit full consideration at the earliest stages of project planning.

Deep Seabed Hard Mineral Resources Act

The Deep Seabed Hard Mineral Resources Act (Act), the governing domestic law for manganese nodule mining pending ratification of an international Law of the Sea treaty, was enacted in June, 1980, to provide an interim legal framework to facilitate the continued development of deep seabed mining in an environmentally safe and sensitive manner. Congress declared that the purpose of the Act include an assurance that exploration and recovery activities are to be conducted in a manner which will encourage the conservation of the natural resources, protect the quality of the environment, and promote the safety of life and property at sea. The Act authorizes the Administrator of the National Oceanic and Atmospheric Administration (NOAA) to issue licenses for exploration of the deep seabed for manganese nodules after July 1, 1981, and to issue permits for commercial recovery mining beginning no earlier than 1988.

The Act defines commercial recovery to include:

- Any activity engaged in at sea to recover any hard mineral resource at a substantial rate for the primary purpose of marketing or commercially using such resource to earn a net profit, whether or not such net profit is actually earned,

- If such recovered hard mineral resource will be processed at sea, such processing, and

- If the waste of such activity to recover any hard mineral resource, or of such processing at sea, will be disposed of at sea [PL96-283 Sec. 4(1)].

The applicant has the responsibility of submitting a recovery plan for a permit. This recovery plan must address the proposed activities to be carried out during the period of the permit including the methods to be used for disposal of wastes from recovery and processing [PL96-283 Sec. 103(a)(2)(C)].

The Administrator is also responsible under the Act to implement a marine research program to assess the environmental effects of exploration and commercial recovery of deep seabed minerals. Accordingly, NOAA has prepared the Five Year Marine Environmental Research Plan on Seabed Mining

and Processing Waste. Research under the plan is aimed at providing an assessment of environmental impacts of exploration and commercial recovery activities including the at-sea disposal of processing wastes.

NOAA published its final rules on Deep Seabed Mining Regulations for Exploration Licenses on September 15, 1981 (46 FR 45890). The Deep Seabed Mining Final Technical Guidance Document (September, 1981), which provides guidelines for meeting certain environmental requirements in the final regulations, summarizes three categories of information to be submitted with an application for an exploration license:

- Location and boundaries of applicant's proposed license site
- Plans for delineation of features of the exploration area
- Preliminary plans for testing and monitoring.

Additional information that should be submitted within 365 days prior to anticipated mining system tests include:

- Selected environmental characteristics (baseline information)
- Detailed proposed mining system test plans
- Further details on proposed test monitoring plan
- Detailed onshore processing test plans in the U.S., and
- Detailed ocean disposal test plans.

This information will be used by NOAA:

- To assess the environmental aspects of exploration-phase activities in a license application and to prepare site-specific environmental impact statements (EIS). The issuance of a license or permit under this Act is deemed a major federal action under the National Environmental Policy Act of 1969 and an EIS must be prepared for each certified license or permit application. NOAA will be responsible for preparing the EIS which is required to address waste disposal. The Final EIS will then be used as a base for license or permit decisions.
- To develop conditions for each applicant following review of monitoring plans, to validate whether the effects of mining tests agree with the effects predicted in the site-specific EIS and to detect any unforeseen adverse effects

- To further refine estimates of the potential effects of commercial mining, based on system testing, in order to prepare environmentally sound regulations and guidance for commercial recovery under a NOAA's permit

- To relate the new data to objectives of NOAA's Five Year Research Plan on Seabed Mining and Processing Waste Disposal.

Regulations for commercial recovery permits and associated at-sea processing have not yet been issued by NOAA since the Deep Seabed Hard Mineral Resources Act prohibits commercial recovery until January 1, 1988. The commercial mining regulations will eventually explain the applicant's responsibilities for data collection and monitoring. Current exploration parties have indicated that they do not intend to file for commercial recovery permits until at least 1984 (Deep Seabed Mining Report to Congress, December, 1981).

National Environmental Policy Act

The National Environmental Policy Act (NEPA) established an environmental review procedure designed to ensure that public officials make decisions based on an understanding of their environmental consequences. No specific plans or regulations on the maintenance of environmental quality and ecosystems resulted from NEPA, however, federal managers must consider the positive and negative environmental and socio-economic consequences of alternative development decisions including the no-action alternative. The Act requires that the consequences of these decisions be addressed in an Environmental Impact Statement (EIS) from the Federal agency managing "a major Federal action significantly affecting the quality of the human environment."

The regulations define a major Federal action as including "actions with effects that may be major and which are potentially subject to Federal control and responsibility." Such actions include "new and continuing activities including projects and programs entirely or partly financed, regulated or approved by federal agencies, agency rules, regulations, policies or procedures, and legislative proposals." It is anticipated that at least one EIS will be required for the federal actions which will be associated with the development of a deep ocean manganese nodule processing project. The issue of waste disposal will certainly need to be addressed.

Coastal Zone Management Act

The Coastal Zone Management Act (CZMA) of 1972 affirms a national interest in the effective management, beneficial use, protection and development of the coastal zone. It created a program of federal grants to help the states manage their coastal resources on shore and within the 3 mile limit or territorial seas. The Act can be viewed as a benefits program to foster more coherent and effective action by each state to assure that the multiple interests in the amenities and resources of their coastal zones are balanced and protected from new developments.

Under the CZMA, the term coastal zone means the coastal waters and the adjacent shorelands strongly influenced by each other and in proximity to the shorelines of the several coastal states, and includes, transitional and intertidal areas, salt marshes, wetlands, and beaches. The zone extends in the Great Lakes waters, to the international boundary between the U.S. and Canada and, in other areas, seaward to the outer limit of the U.S. territorial sea. The zone extends inland from the shorelines only to the extent necessary to control shorelands, the uses of which have a direct and significant influence on the coastal waters (PL94-370, 90 Stat. 1013, July 26, 1976).

The CZMA also authorizes the Secretary of Commerce to make grants to any coastal state for the purpose of: (1) acquiring, developing, or operating estuarine sanctuaries, to serve as natural field laboratories in which to study and gather data on the natural and human processes occurring within the estuaries of the coastal zone, and (2) acquiring lands to provide for access to public beaches and other public coastal areas of environmental, recreational, historical, aesthetic, ecological, or cultural value and for the preservation of islands. The sanctuaries are owned and managed by the individual states, and are kept as undisturbed as possible so researchers can study the naturally functioning system and also be able to use the areas as controls against which to measure ecological changes in other estuaries.

At present there are twelve estuarine sanctuaries in operation and several in the planning stages. The national program is administered by the Estuarine Sanctuary Program Office, Office of Coastal Zone Management; a component of the National Oceanic and Atmospheric Administration of the Department of Commerce. Table 6 lists the twelve estuarine sanctuaries currently in operation.

CZMA has a bearing on any proposed activity in coastal waters and adjacent shorelands. Section 307(c) requires that after a state's coastal zone management program has been approved "any applicant for a required Federal license or permit to conduct an activity affecting land or water uses in the coastal zone" must provide a certification that the proposed activity complies with the states approved program. This "federal consistency provision" provides states with approved programs a significant amount of control over projects requiring federal permits.

All the states considered in this study, except for Texas, have federally approved CZM programs currently in place (Table 7). The applicant will be required to get the approval of the responsible agency and a "consistency certification" for any activity affecting the coastal zone. This gives the states and local governments a significant amount of influence over deep seabed mining related activities.

TABLE 6. ESTUARINE SANCTUARY NAMES AND ADDRESSES
(AS OF APRIL, 1982)

Chesapeake Bay
Dr. Sarah Taylor
Chesapeake Bay
Department Natural Resources
Tawes State Office Building
Anapolis, MD 21401
(301) 269-2786

Jobos Bay, Puerto Rico
Jose Gonzalez-Livoy
Department Natural Resources
Box 5887
Puerta de Tierra
San Juan, PR 00906
(809) 722-5501

Tijuana River, California
Sue Hansch
California Coastal Commission
631 Howard St., 4th Floor
San Francisco, CA 94105
(415) 543-8555

Sapelo Island, Georgia
Margaret Melton, Estuarine Sanctuary Coordinator
Department of Natural Resources
Coastal Resources Division
1200 Glynn Avenue
Brunswick, GA 31520
(912) 264-7218

South Slough, Oregon
Dr. Delane Munson, Manager
South Slough Estuarine Sanctuary
P.O. Box 5417
Charleston, OR 97420
(503) 888-9015

Waimanu, Hawaii
Richard Poirirer
Department of Planning and Economic Development
P.O. Box 2359
Honolulu, HI 96804
(808) 548-3047

TABLE 6. (Continued)

Old Woman Creek, Ohio
Eugene Wright, Manager
Old Woman Creek Estuarine Sanctuary
2005 Cleveland Rd., East
Huron, OH 44839
(419) 433-4601

Dr. David Klarer, Sanctuary Biologist
Old Woman Creek Estuarine Sanctuary
2005 Cleveland Rd., East
Huron, OH 44839
(419) 433-4601

Rookery Bay, Florida
Dr. Kris W. Thoemke, Manager
Rookery Bay Estuarine Sanctuary
No. 10 Shell Island Road
Naples, FL 33942
(813) 775-8845

Apalachicola River/Bay, Florida
Mr. Woodward Miley II, Manager
Apalachicola River/Bay Estuarine Sanctuary
57 Market St.
Apalachicola, FL 32320
(904) 653-8063

Elkhorn Slough, California
Kenneth S. Moore, Manager
Elkhorn Slough Estuarine Sanctuary
1454 Elkhorn Road
Watsonville, CA 95076
(408) 728-0560

Padilla Bay, Washington
Mr. Milt Martin
Department of Ecology
Mail Stop PV-11
Olympia, WA 90854
(206) 549-6287

Narragansett Bay, Rhode Island
Mr. Gary Bannon, Manager
Narragansett Bay Estuarine Sanctuary
Department of Environmental Management
83 Park Street
Providence, RI 02903
(401) 277-2776

TABLE 7. STATE AGENCIES RESPONSIBLE FOR COASTAL ZONE MANAGEMENT PLANS

California	California Coastal Commission 631 Howard Street, 4th Floor San Francisco, California 94105 (415) 543-8555
Oregon	Land Conservation and Development Commission 1175 Court Street N.E. Salem, Oregon 97310 (503) 378-4097
Washington	Department of Ecology State of Washington P-V-11 Olympia, Washington 98504 (206) 459-6000
Hawaii	Department of Planning and Economic Development P.O. Box 2359 Honolulu, Hawaii 96804 (808) 548-3042
Alaska	Department of Community and Regional Affairs Pouch B, Room 213 Community Building Juneau, Alaska 99801 (907) 465-3541
Louisiana	Department of Transportation and Development Coastal Management Section P.O. Box 44245 Capital Station Baton Rouge, Louisiana 70804 (504) 342-7591
Texas	No approved state plan

Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act was enacted for the purpose of recognizing the vital contribution of our wildlife resources to the Nation, the increasing public interest and signficance thereof due to the expansion of our economy, and to provide that wildlife conservation shall receive equal consideration and be coordinated with other features of water-resource development programs. The Act authorizes the Secretary of the Interior to provide assistance to, and cooperate with federal, state, local, public, or private agencies and organizations in the development, protection, rearing, and stocking of all species of wildlife, resources, and their habitats, in or effecting controlling losses from disease or other causes and in minimizing damages. According to Section 5 of the Act, the Secretary of the Interior, through the Fish and Wildlife Service and the Bureau of Mines, is authorized to make any investigations as deemed necessary to determine the effects of domestic sewage, mine, petroleum, and industiral wastes, and other polluting substances and report the findings to Congress. For any waste disposal in the oceans, consultation with the Fish and Wildlife Service of the Department of the Interior and the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration is necessary to ensure compliance with their guidelines and policies for alleviating dangerous and undesirable effects of the proposed action.

Endangered Species Act

The Endangered Species Act of 1973 was enacted to protect and conserve endangered and threatened species and their critical habitats. The Act vests in the Secretary of the Interior and the Secretary of Commerce broad regulatory authority to list species determined to be endangered or threatened, and to designate the critical habitats of such species. It also imposes an affirmative duty on federal agencies to promote the conservation of endangered or threatened species of fish, wildlife, or plants. The Secretary may enter into a cooperative agreement with any state which establishes and maintains an adequate and active program for the conservation of endangered or threatened species of fish, wildlife, or plants.

Prior to submitting any permit associated with ocean disposal activities, the applicant will need to ensure that the activities to be authorized will not jeopardize the continued existence of any listed species or destroy or modify a designated critical habitat of such species. However, if activities related to the construction of a marine terminal, offshore mooring point, pipelines, or actual disposal of wastes will have the likelihood to have effects on endangered species or critical habitats, the prospects of obtaining a permit will be greatly reduced. Consideration of endangered or threatened species and critical habitats warrants strict attention in the early project planning stages. Coordination with the Department of Interior, Department of Commerce (National Oceanic and Atmospheric Administration, National Marine Fisheries Service) and appropriate state agencies will help avoid lengthy project delays regarding threatened or endangered species.

Marine Mammal Protection Act

The Marine Mammal Protection Act of 1972 was enacted to protect marine mammals, establish a Marine Mammal Commission, and to maintain marine mammal's significance as a functioning element of the marine ecosystem. The Secretary of Commerce is given responsibility for whales, porpoises, seals, and sea lions, and the Secretary of Interior is given responsibility for all other marine mammals. Any activities which result in the indirect "taking" of marine mammals requires that an "incidental taking" permit be obtained from the National Marine Fisheries Service under the authority of the Secretary of Commerce. Any interference with marine mammals or any actions having an adverse effect on their habitat resulting from disposal operations may raise the question of whether they constitute an "incidental taking" which requires a permit. Consultation with local National Marine Fisheries Service representatives and appropriate state agencies concerning the proposed action should take place early to avoid lengthy delays due to marine mammal conservation and protection programs.

National Historic Preservation Act

The National Historic Preservation Act of 1966 established a program for the preservation of additional historic properties throughout the Nation. The Act authorizes the Secretary of the Interior to maintain a natural register of districts, sites, buildings, and objects significant in American history, architecture, archeology and culture. The Act imposes a duty on federal licensing agencies to consider the effect on historic sites of the proposed activity. If there is any effect on historic or archaeological sites, all activities must be reviewed and commented on by the Advisory Council on Historic Preservation. If a determination warrants further action, the Preservation of Historical and Archaeological Data Act of 1974 authorizes the Secretary of the Interior to take any action deemed necessary to recover and preserve significant historical or archaeological data threatened by activities at such sites. This is a sensitive issue and may cause extensive delays and a possible ending of the proposed activity if it is not considered early in the site selection process for waste disposal.

CONCLUSIONS

Federal environmental legislation governing ocean disposal of manganese nodule processing wastes consists primarily of two acts: the Clean Water Act (CWA) which regulates ocean discharges, and the Marine Protection, Research, and Sanctuaries Act (MPRSA) which regulates ocean dumping. It appears that the ocean need not be excluded from waste management strategies for the disposal of manganese nodule processing wastes based upon close review of both statutes and their existing regulations.

Characterization studies of manganese nodule processing wastes indicate that the wastes can meet the environmental criteria and permit requirements for "strictly regulated dumping" and "trace constituents and other limited materials" for ocean dumping, in addition to meeting some of the stringent state water quality standards for point source discharges.

3. OCEAN DISPOSAL TECHNOLOGIES

This chapter discusses present and potential ocean disposal technology and the resulting fate of material. Because the method of disposal can significantly influence the fate of material, each method is considered separately. The application to manganese nodule processing rejects of three basic methods of ocean disposal are considered; ocean dumping, pump out of ships or barges at sea, and ocean outfalls. Each disposal method discussion is followed by a brief discussion of the fate of solids disposed of by that method. In the case of ocean dumping from a barge, a simplified procedure has been developed which can be used to estimate solids transport and dispersion. A detailed technical discussion of the procedures and their limitations are described in Appendix B. These procedures are used in Chapter 6 to estimate the fate of waste materials discharged to representative disposal areas. These estimates are very approximate, and should be used only to qualitatively differentiate dumping strategies and locations. Many of the technical difficulties are discussed in Appendix B.

DISPOSAL TECHNOLOGY

Conventional technology for the disposal of wastes in the ocean employs bottom dump barges, split hull barges, ocean outfalls, and specialized sludge dumping ships. Much of this technology is adaptable to the disposal of manganese nodule processing wastes.

Ocean Dumping

Approximately 90 percent of the waste tonnage dumped at sea in 1979 was dredged material dumped by barge or hopper dredge. Both types of vessels release their load through the bottom of the vessel. Bottom dump barges and hopper dredges are partitioned into a number of compartments, each fitted with a set of bottom doors. The bottom door system usually consists of a pair of doors (port and starboard) running the length of each compartment and hinged along the outboard edges so that they open downward.

The barge is towed to the dump site by a tugboat. When the barge is in position to dump, the bargeman releases each set of doors. He first releases the hopper at either the bow or stern and then releases the hopper at the opposite end. The alternating pattern is continued until the last hopper is discharged in the midships area. This procedure prevents the vessel from going far out of trim during a dumping cycle. The total unloading time for a manually operated barge consists of the time to release and dump one hopper and to walk back and forth over the deck route. According to Johanson et al. (1976), a 3,060 m^3 (4,000 yd^3) barge releases and dumps a single hopper in 1 min with a time of 6 min required to empty the entire barge.

The bottom dump barge is being replaced by the split-hull or clamshell barge. Although still in use, a limited survey of barge manufacturers revealed that bottom dump barges are no longer being manufactured in the United States. New barges specifically designed for ocean disposal of manganese nodule processing waste would probably be of the split-hull design. Split or clamshell barges are designed with hulls that hinge open to release the load through the bottom. Figure 3 shows a 2,294 m^3 (3,000 yd^3) split-hull barge in open and closed configuration.

The split-hull design eliminates practically all of the manual effort, and it empties the entire load in one operation. One lever controls the hydraulic piston which rotates the hull open to release the load over the entire hopper length. When opened, the hull is held open by buoyant forces. When closed, hydrostatic pressure acts to keep the hull closed.

The split-hull dumping sequence is illustrated in Figure 4. The time required to empty is only a few seconds. The opening of the barge can be stopped at any position to regulate the rate of material discharge.

The split-hull barge is more versatile than the conventional bottom-dump. If maximum dispersion of the waste is desired, the hull opening can be controlled. The split-hull can be opened quickly (in seconds as opposed to 6 min) to achieve maximum concentration of the waste.

The barges illustrated in Figures 3 and 4 are Manitowoc "Hydro-Dump" barges. Standard sizes range from 153 m^3 (200 yd^3) to 3,060 m^3 (4,000 yd^3). Specifications for the largest standard size are presented below:

Size	3,060 m^3	4,000 yd^3
Approximate capacity	4,900 metric tons	5,400 tons
Length overall	72 m	236 ft
Length beam	16.2 m	53 ft
Depth midship	6.4 m	21 ft
Loaded draft	6.0 m	20 ft
Light draft (closed)	1.2 m	4 ft

Barges of greater capacity could be designed and built. The largest barges currently being built in the United States are designed for carrying liquids and exceed 55,000 dwt.

A single manganese nodule processing plant is estimated to generate from approximately 2.7 to 3.5 million metric tons per year of hydrometallurgical rejects. This represents approximately 550 to 700 dumps from the largest standard-sized barge (4,900 metric tons). Assuming 300 working days per year, dumps would occur at a rate of from 1.8 to 2.4 dumps per day.

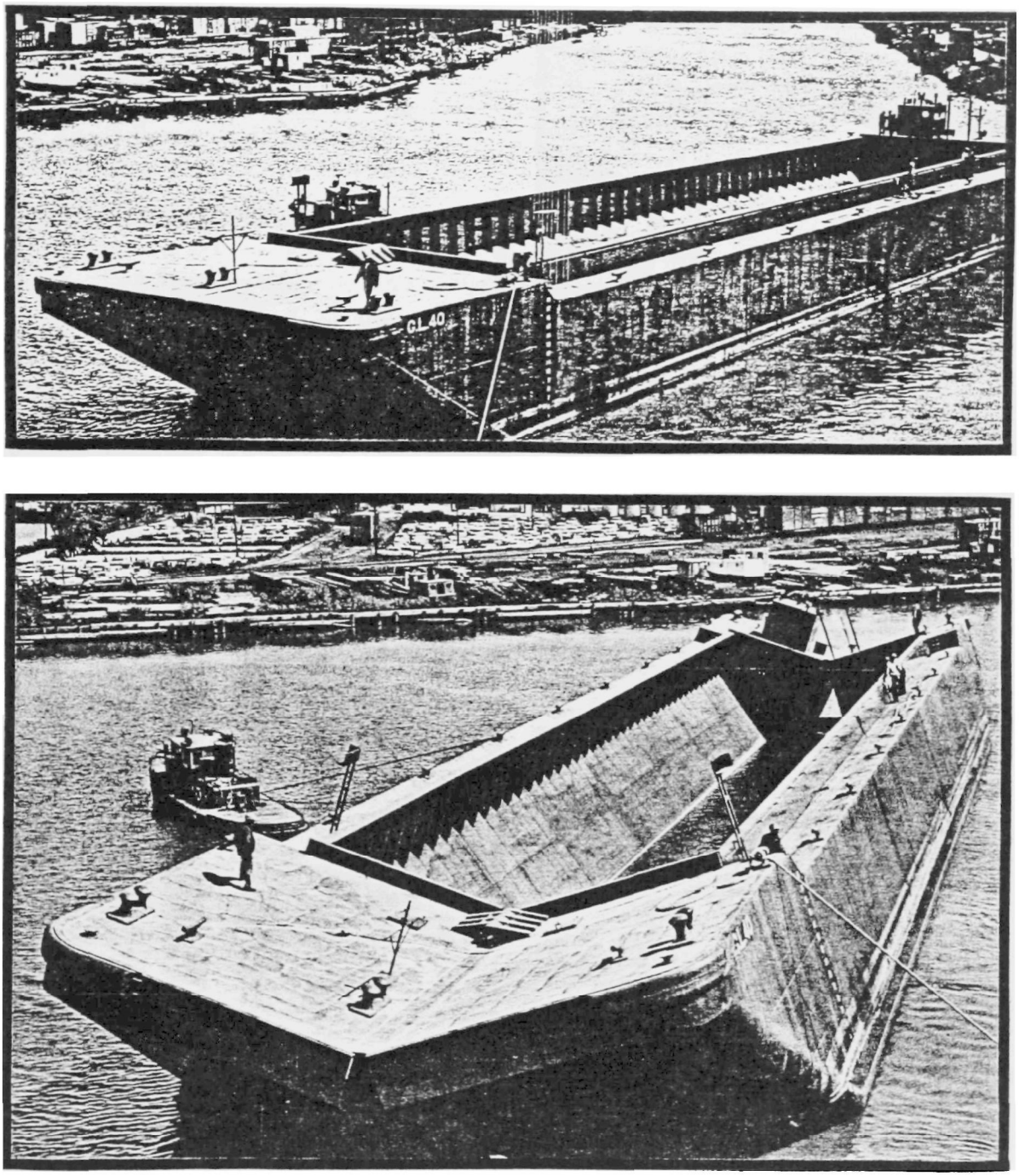


Figure 3. A split-hull bottom dump barge in open and closed configuration.

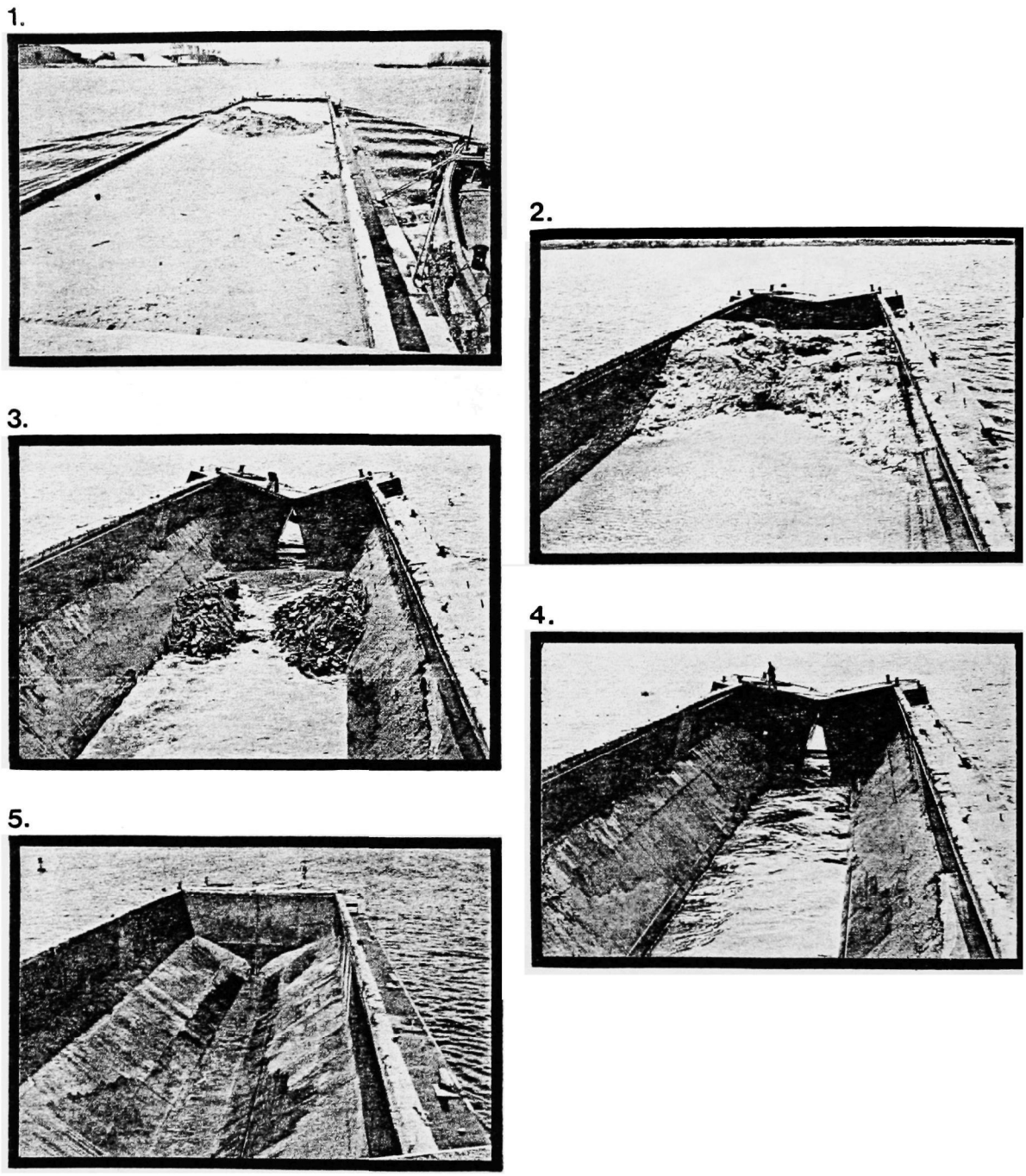


Figure 4. The dumping sequence of a split-hull barge.

FATE OF OCEAN DUMPED MATERIAL

Barge Dumping

Disposal of waste material into the ocean using barges results in dumps of relatively short duration ranging from a few seconds for a split hull barge to several minutes for a hopper barge. The discussions which follow consider only instantaneous dumps in water deep enough for the dump material to be considered as a hemispherical cloud. A schematic representation of an instantaneous dump is presented in Figure 5. Dumps in relatively shallow water where the duration of release is comparable to the time required for the cloud to impact the bottom are described elsewhere (see Barnard 1978). If the water depth is not sufficiently great, the plume of waste material impacts the bottom before equilibrium of the plume and the surrounding seawater is reached and surges along the bottom.

The physical processes which govern the behavior of the dumped material in deep water are divided into 3 phases: the convective descent, the dynamic collapse, and the passive diffusion. The division of the processes into these three phases is found in the modeling efforts of Koh and Chang (1973) and Brandsma and Divoky (1976), and is schematically illustrated in Figure 6. The plume can be represented as a hemispherical cloud. During the convective descent, the cloud falls at a rate determined primarily by its total mass and size and entrains ambient water. The sizes of the particles which compose the solid portion of the cloud are of secondary importance during this phase. The downward force on the cloud is its negative buoyancy, which decreases as it entrains ambient water. The resisting forces are primarily due to drag. The dynamic collapse phase occurs when the cloud has entrained sufficent water to reach the point where density of the cloud equals that of the surrounding water. Due to its downward momentum, the cloud continues to fall past the level of neutral buoyancy entraining water which results in the cloud becoming positively buoyant. The successive buoyancy changes produce a rise and fall oscillation about the position of neutral buoyancy. These oscillations cause the cloud to flatten and behave more and more as individual particles. The passive diffusion phase begins at this point. The particles are advected by local currents and dispersed laterally by horizontal diffusion. The particles settle at a rate determined by their fall velocity and any vertical currents. If the particle size is small enough, vertical diffusion will alter the particles' rate of descent. These motions continue until the particle settles on the sea floor.

There are basically two types of fate for material discharged by instantaneous dump. The falling cloud can be trapped at some depth in the water column, and is eventally transported and diffused by horizontal currents while the particles fall at their respective fall velocities. The other possibility is that the cloud will impact the bottom. The resulting surge will spread out radially, and eventually will be transported horizontally by the ambient currents until the particles settle on the seafloor.

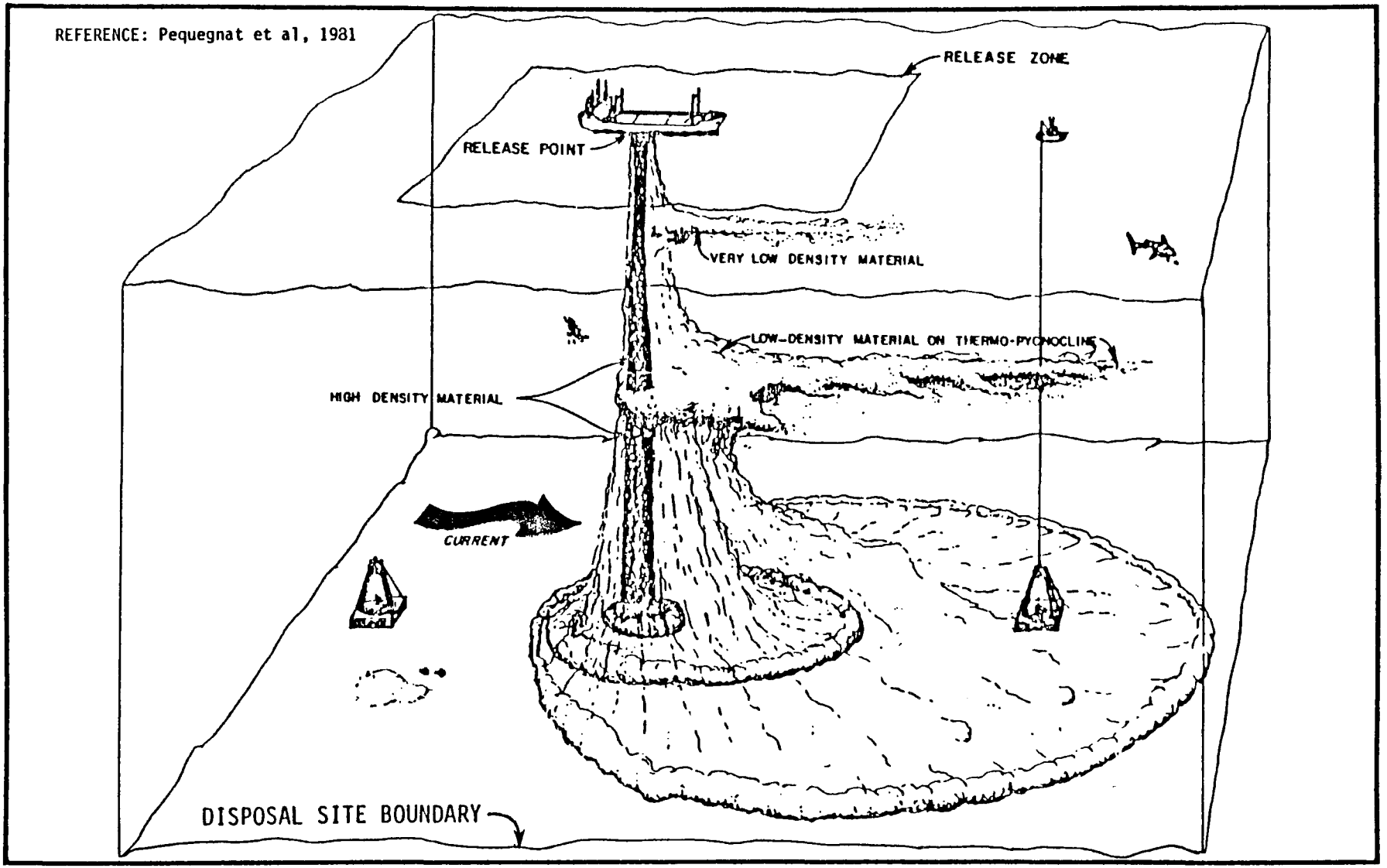


Figure 5. Schematic representation of ocean dumping.

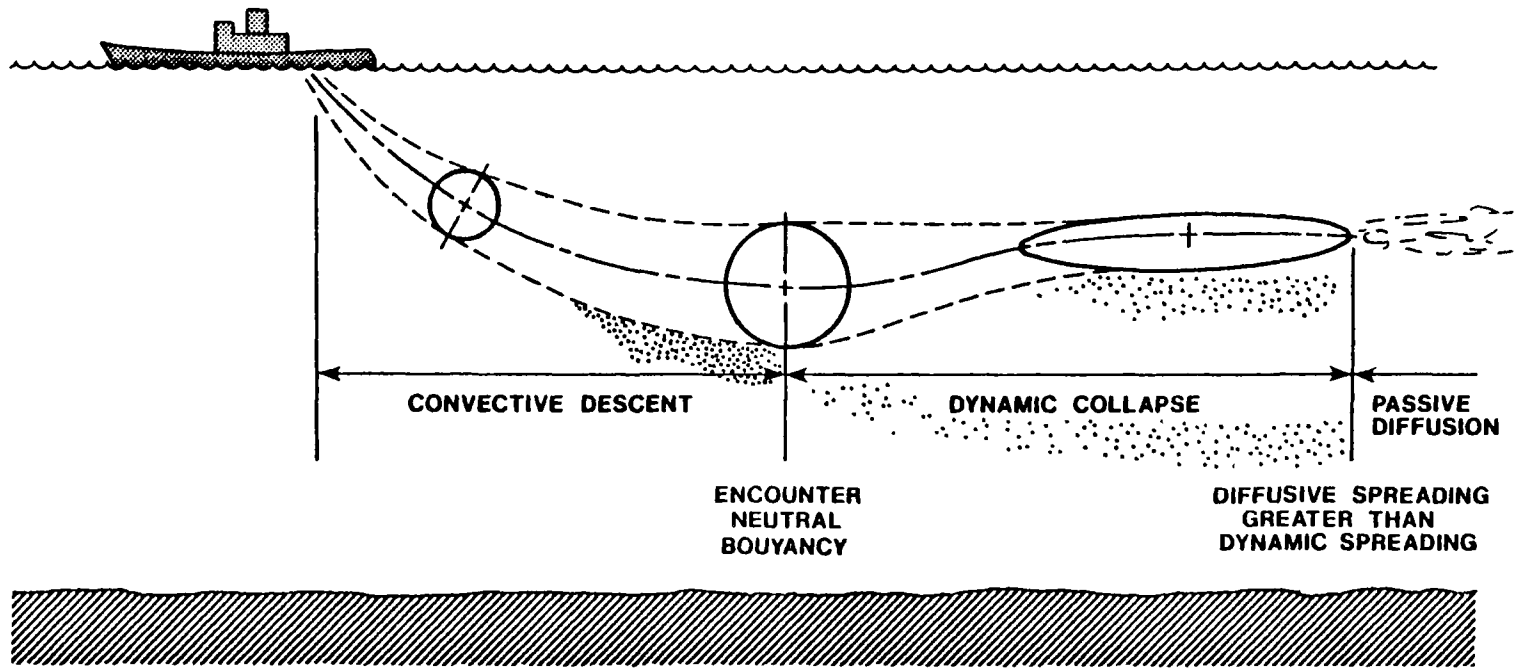


Figure 6. Idealized discharge from moving vessel.

A method to determine the area as well as the average concentrations, or height (if the cloud impacts the bottom) at 4 hours time is described in Appendix B. The method is very approximate and is useful only to give rough qualitative comparisons between alternative disposal procedures. A discussion of the technical difficulties with the method is contained in Appendix B. Several figures are presented below which summarize the predictions. Also discussed is an example computation. Figure 7 shows the horizontal area covered by an instantaneously dumped cloud after 4 hours as a function of trapping level and initial dump volume. Figure 8 shows the dilution achieved after 4 hours. For initial cloud densities equal 1.4 g/cm^3 and 2.0 g/cm^3 Figures 9 and 10 give the thickness of the sediment layer if the solids suspended in the dump cloud were to fall uniformly in the horizontal cloud area after 4 hours time.

As an example suppose 1,000 m^3 having bulk density equal 1.4 g/cm^3 is discharged in oceanic waters having depth 250 m (820 ft) and constant normalized density gradient $\varepsilon = 1 \times 10^{5}/m$ ($3.1 \times 10^{-6}/ft$). The equation for the trapping level d_{max} contained in Appendix B shows that the dump cloud reaches its equilibrium level (trapping level) 212 m (696 ft) below the surface. Using Figure 7, the area equals 0.034 km^2 and using Figure 8, the dilution is 1,300. The average material thickness, using Figure 9, is 5 mm. If the solid material in the cloud had a density equal 3.4 g/cm^3 and no particles have diameters greater than 121 um, then the largest particles will fall no more than 1.4 m (4.6 ft) after the dump cloud reaches the trapping level.

Surface and Subsurface Dispersal

An alternative to dumping processing waste from a barge is to pump the material out, discharging the slurry to the surface or to greater depth. By pumping out the barge, bottom dump capability is no longer needed. Existing vessels or barges, such as ore carriers, could be modified for slurry pump out capability to dispose of the manganese nodule processing waste. The transport ships used to convey manganese nodules from the mining site to the processing plant could also be designed to discharge the waste at sea.

The maximum possible dispersion of the waste could be achieved by pumping the waste slurry into the wake of a moving barge or ship as it traverses a course of many miles. This technique is currently used to dispose of acid wastes at the New York Bight acid waste dump site (NOAA 1975). The disadvantage of this method is that the waste achieves the maximum residence time in the euphotic zone where it may impact phytoplankton and zooplankton populations.

This problem can be avoided by discharging the slurry through a pipe extending downward below the euphotic zone to depths of 50 to 100 m (160 to 320 ft). This concept, referred to as shunting, is used in the offshore oil and gas industry to minimize dispersion of drilling muds and cuttings. U.S. Army Corp of Engineers has also evaluated this concept for accurate placement of dredged material into offshore borrow pits (Johanson et al., 1976).

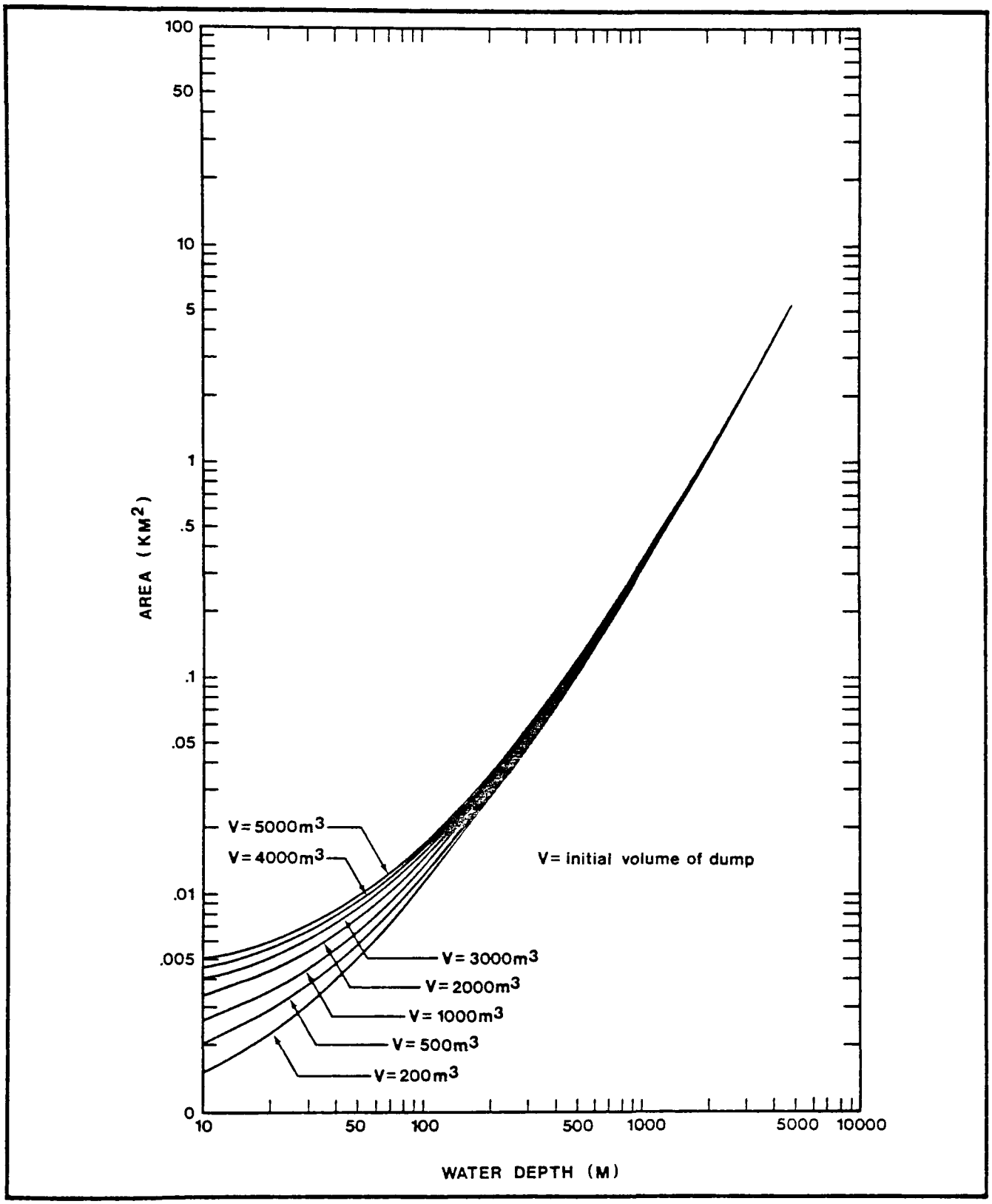


Figure 7. Horizontal area covered by instantaneous dump cloud 4 hours after dumping as a function of trapping level.

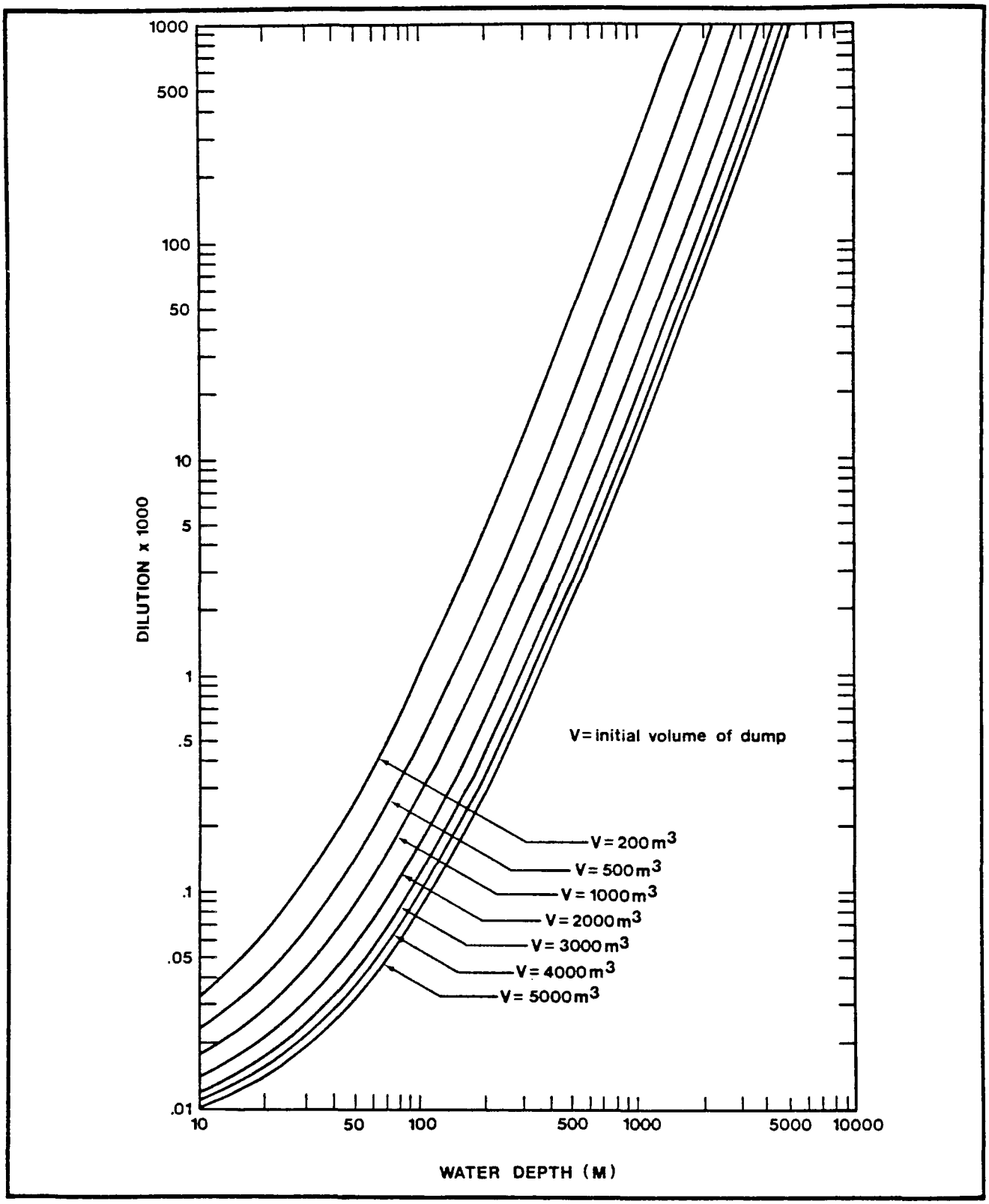


Figure 8. Dilution achieved by instantaneous dump cloud 4 hours after dumping as a function of trapping level.

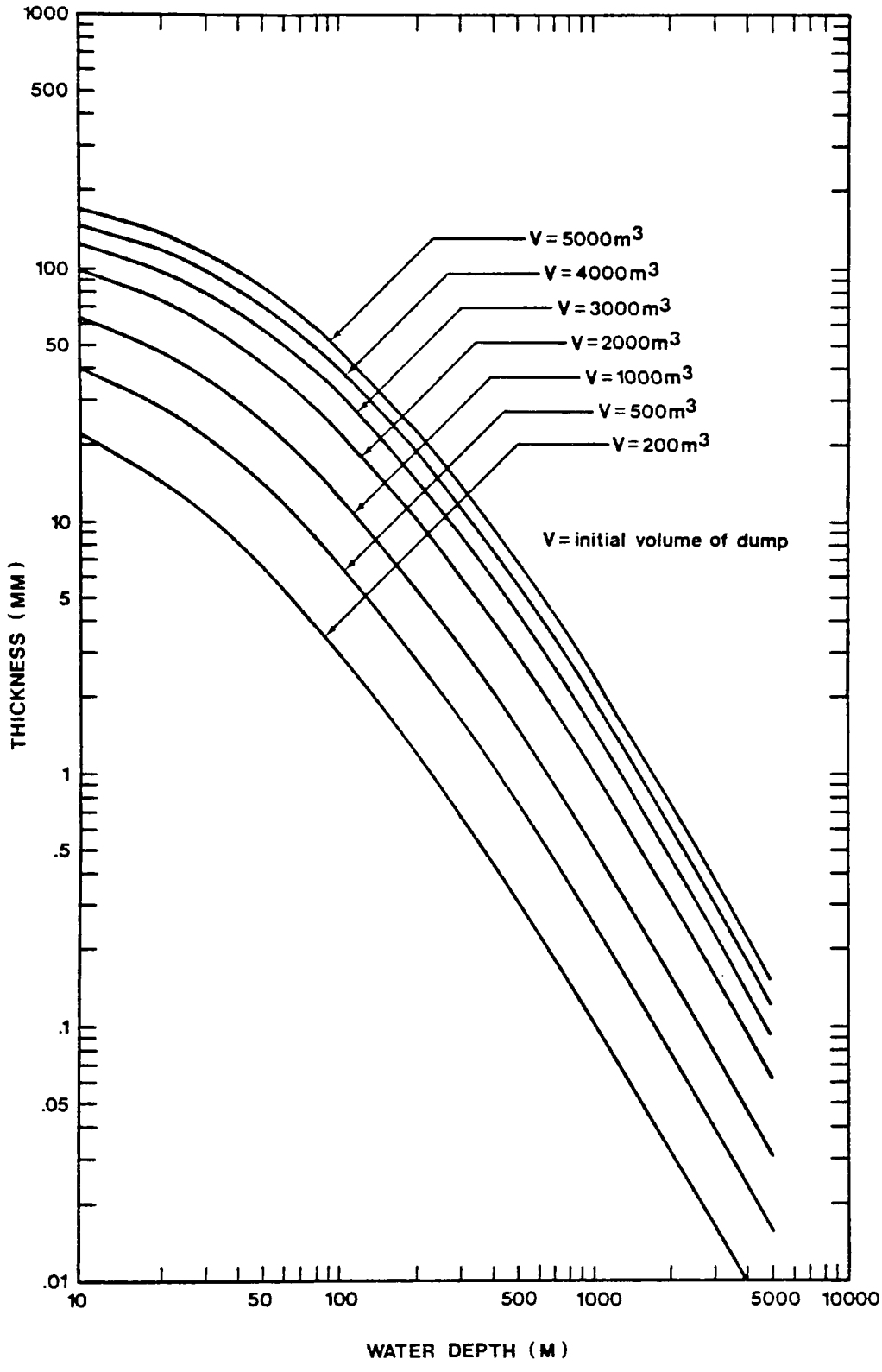


Figure 9. Thickness of sediment layer if the solids suspended in the dump cloud were to fall uniformly in the horizontal cloud area after 4 hours time (initial cloud density = 1.4 gm/cm^3).

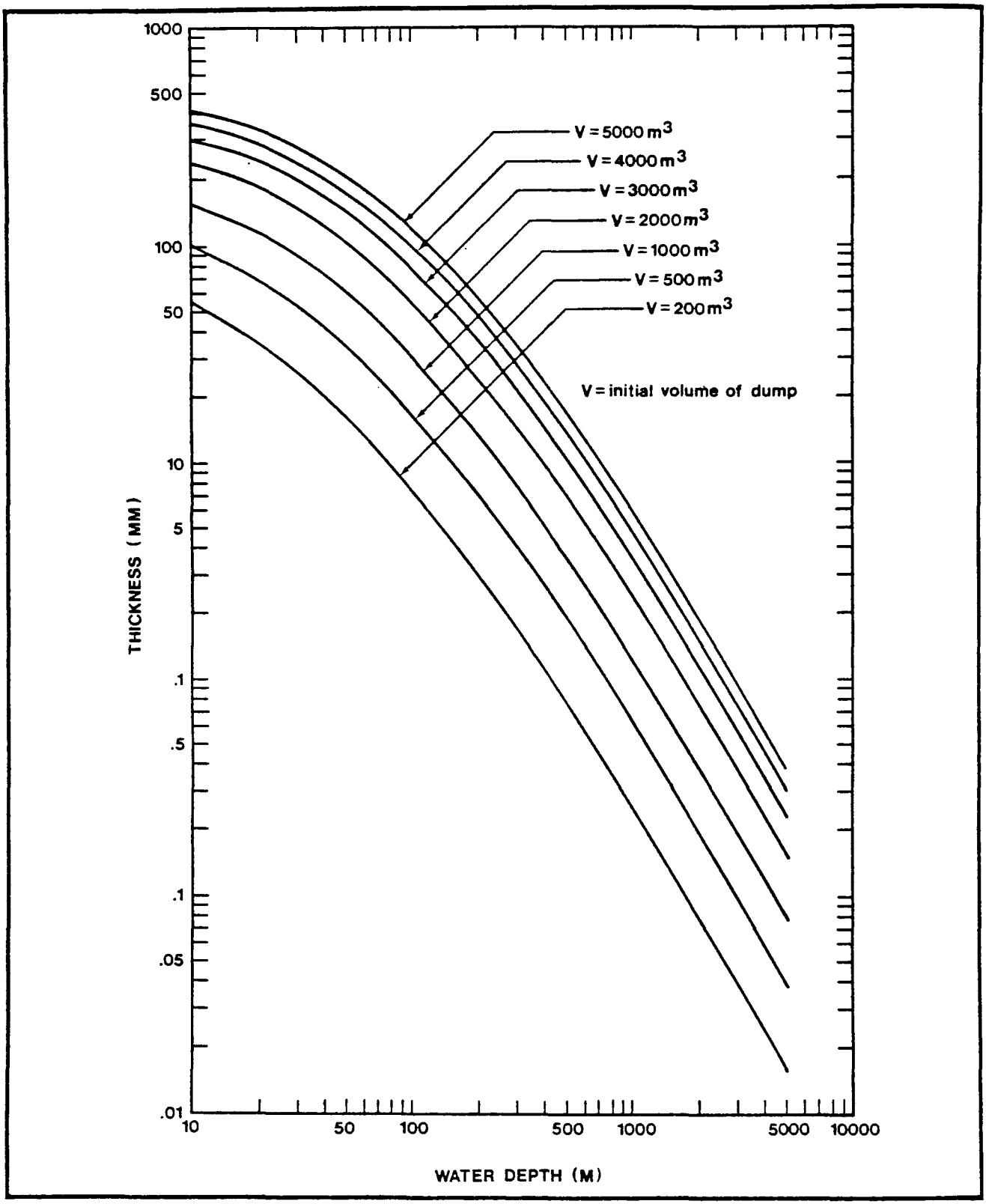


Figure 10. Thickness of sediment layer if the solids suspended in the dump cloud were to fall uniformly in the horizontal cloud area after 4 hours time (initial cloud density = 2.0 gm/cm^3).

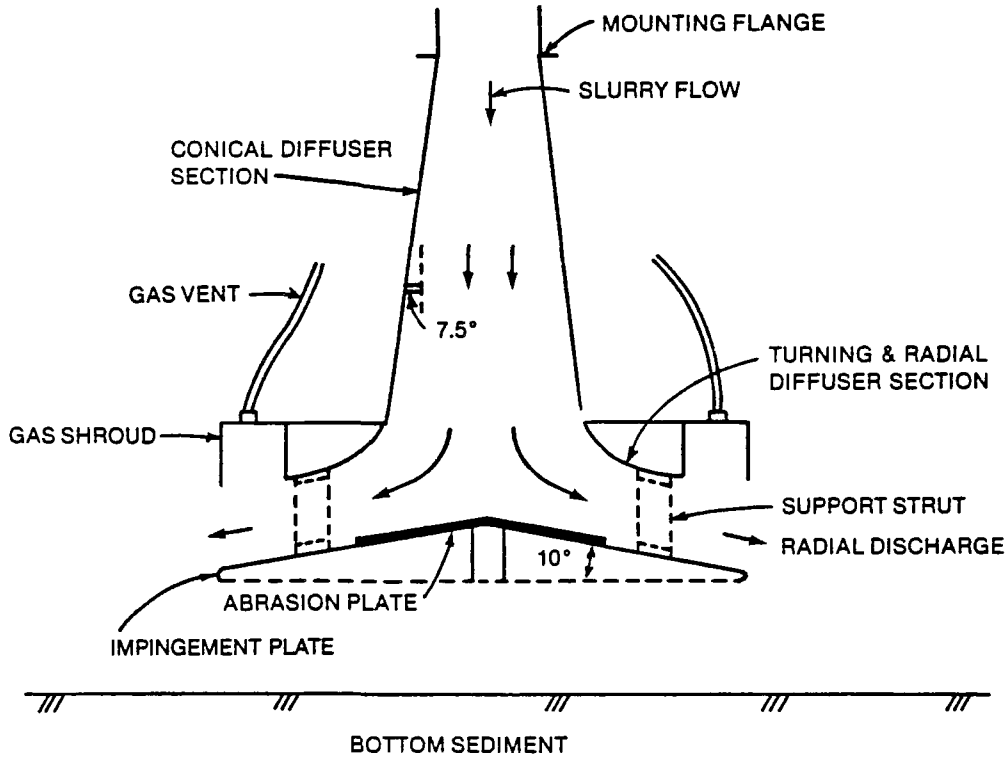
Other examples of barge pump-out capability exist. These include self loading and unloading, bulk and liquid barges in the 7,000 to 20,000 dwt range and pump-out barges commonly used in Europe to unload and pump ashore dredged material from transport barges (Johanson et al., 1976).

An additional concept which can be added to the pump down technique is the use of a diffuser plate at the end of the discharge pipe. The purpose of the diffuser, developed by the U.S. Army Corps of Engineers (Barnard 1978), is to minimize the momentum and energy of the discharge as it exits the pipe. The diffuser, shown in Figure 11, thus reduces the dispersion of the slurry. The material will basically fall out the diffuser rather than act as a turbulent jet.

The diffuser concept is most applicable to pump down in relatively shallow water, approximately 60 m (200 ft). The diffuser could be placed on the bottom, if flexible pipe can be used, or maintained at a safe distance above the bottom at the end of a rigid pipe string. The material creates clouds around the diffuser from which particles would settle individually. The buoyant liquid fraction could however rise to the surface or to some level of neutral buoyancy.

The farfield behavior of material continuously discharged into the sea from a pipe aboard a ship is similar to the passive diffusion stage of dumped material. The nearfield behavior is different in that the initial flow is similar to a jet and not a single cloud. The flow of a buoyant jet into an ambient fluid is well known (Koh and Brooks 1975) and a number of computer models exist, which predict the level of neutral buoyancy of the resulting plume (see Teeter and Baumgartner 1979 for example). Particle-laden jets appear to entrain water less efficiently (Ditmars and McCarthy 1975) and, hence, the level of neutral buoyancy for a particle-laden jet will be greater than that of a negatively-buoyant jet. In most present ship discharges of this type, the end of the pipe is close to the water surface. Thus, prediction of the trapping level depends on the wake of the ship as well as location and orientation of the pipe (see Brandsma and Wu 1980). Regardless of the complexities of the flow near the exit pipe, the jet plume reaches equilibrium quickly. From a distance, the resulting cloud looks like a continuously generated pulse source. This can be approximated by an exponential function (Lavelle and Oztergut 1981). Advective transport in the open ocean is primarily horizontal. Horizontal currents commonly have speeds measured in cm/sec. Since 1 cm/sec = 0.864 km/day, a waste field would likely be advected a number of km/day. Vertical advective transport is ignored, although vertical currents during periods of upwelling may influence the fall velocity of very small diameter particles.

Predictions of the convective descent phase of a jet depend on enough parameters so that a method as simple as the method for instantaneous dumps is not possible. In Appendix B, the farfield model of Brooks' is used to obtain some passive dispersion results.



REFERENCE: Barnard 1978

Figure 11. Submerged diffuser.

Marine Outfalls

Occasionally outfalls are used to dispose of waste material in slurry form. There are basically two possible strategies for discharging wastes through an outfall into marine waters. One is to make the discharge mixture have a specific gravity greater than seawater, while the other is to make the mixture have a specific gravity less than seawater. These possibilities are schematically shown in Figure 12. Heavier-than-water slurries must be discharged on a sloping seabed to ensure that the settled material moves downslope away from the outfall and does not accumulate at the outfall site. This method has been used in a number of locations. The Hyperion sludge outfall in Santa Monica Bay discharges municipal waste sludge at the head of a submarine canyon. An outfall in Rupert Inlet on Vancouver Island, B.C., discharges mining waste into a fjord (Evans et al., 1979). Other examples are described in Chapter 5 of this report. Properly designed, this method offers a number of advantages. The movement of the material is independent of the water column density structure. Impacts are restricted to the benthic environment. Only bottom currents affect the motion of the material. Problems can develop however. At Hyperion, internal waves can cause surges in the submarine canyon which can transport material from the outfall diffuser upward and onto the shelf. Deep water upwelling at a sill in Rupert Inlet occasionally transports solids up into the water column. In both examples, the diffuser is in relatively deep water [on the order of 61 m (200 ft) or more]. Hence, oscillatory bottom currents due to wind waves are not likely to resuspend settled solids unless the waves are high and have long periods.

Some care must be used in the design of the outfall. If the flow behaves as a turbidity current, then gravity causes the current to seek the greatest possible depths. Energy losses due to friction can stop the current on a mild slope. However, sufficient mounding will induce slumping and further movement. If the initial discharge velocities are too high, a portion of the turbidity current may separate from the seabed and form a cloud in the water column. Once formed, this cloud would be advected and dispersed by the ambient ocean currents. This situation occurs in Alice Arm, British Columbia, where mine tailings are discharged near the head of a fjord (Burling et al., 1981). Burling et al. (1981) suggests that the cloud may be caused by a hydraulic jump occuring in a supercritical discharge. The mechanics of separation do not appear to be understood at present. Clouds may also separate from the turbidity current due to the positive buoyancy of the fluid in the slurry (usually fresh water) with respect to the ambient seawater. Thus, it appears that flows which initially have as small a water content as possible and discharged slowly may avoid the problem of cloud formations. Physical simulation of slurry jet discharges are needed to develop an understanding of their behavior.

The procedure of discharging mining wastes in mixtures which have specific gravities less than that of saltwater appears to be impractical and has evidently never been attempted in the U.S. The advantage of such a scheme would be that the discharge plume is trapped in the water column and advected away from the diffuser site by the ambient currents. Aside from the high turbidity levels which would occur near the trapping level of the

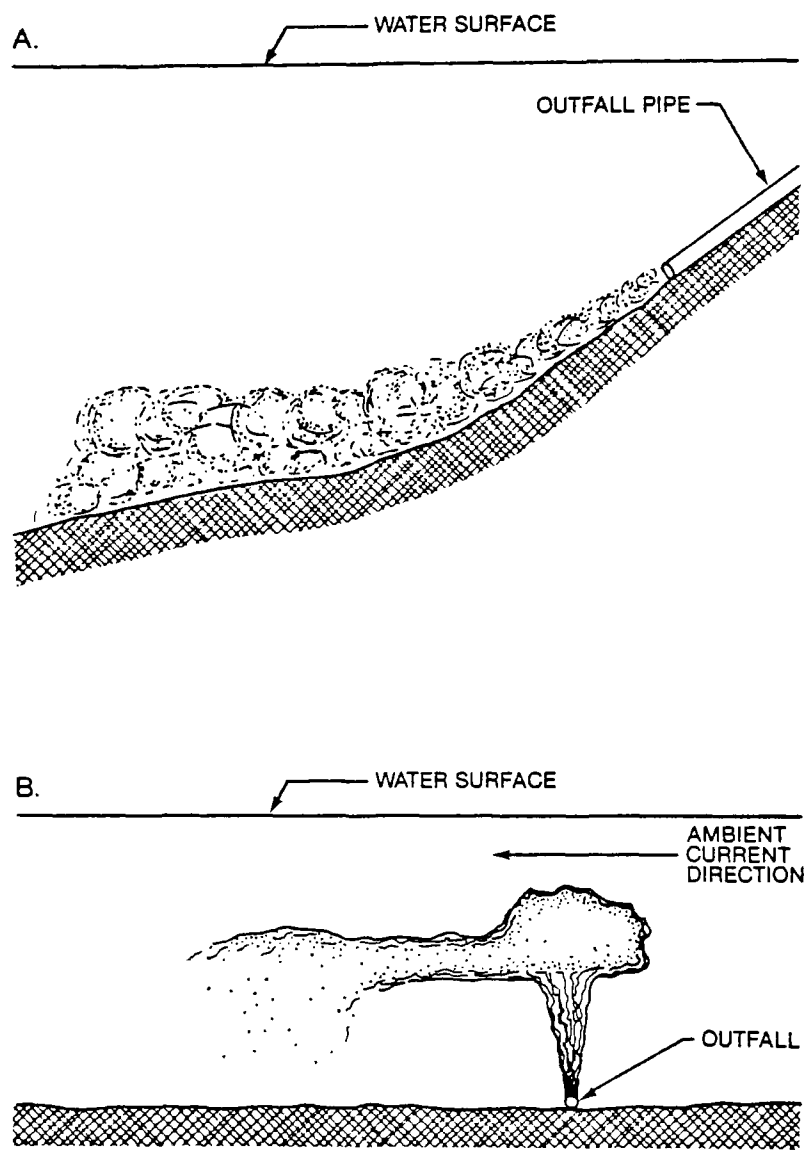


Figure 12. A) Negatively buoyant discharge on a sloping bottom.
B) Positively buoyant discharge on a horizontal bottom.

wastefield, the principal problem is the amount of fresh water required to reduce the specific gravity of the slurry to less than that of seawater.

ADDITIONAL CONCEPTS

Block Formation

As previously noted, the particle size of dumped rejects has a very important influence on their eventual fate. Very small particles, in the micrometer range, settle very slowly and can be widely dispersed. Particles in the millimeter size range settle relatively quickly. If the concentration of the waste within a small area of the seabed is desired, this could be done by artifically increasing the particle size. For example, rejects formed into brick-size blocks would sink very rapidly and remain in distinct piles on the bottom.

Other advantages accrue in addition to rapid sinking. The particle surface area of the blocks in contact with seawater is extremely small compared to unmodified rejects. The opportunity for potentially toxic constituents to exchange from the reject solids to the ambient seawater is therefore greatly reduced. The second potential advantage is that rejects in large blocks could be placed as an artificial reef. Such reefs could actually enhance biological communities on the continental shelf.

The idea of forming waste material into blocks and forming reefs has been investigated by Woodhead et al. (1979). Experimental reefs were formed of fly ash and scrubber sludge from coal-fired power plants at a site located approximately 1.3 km (2 mi) south of Fire Island, New York. Woodhead et al. (1979) found that the blocks of power plant waste retained their physical integrity in seawater and did not appreciably erode or dissolve. Extensive tests showed no adverse effects to marine organisms.

A final advantage may exist in the ability to recover the disposed of rejects. Rejects generated by the "three-metal" processes still contain potentially valuable quantities of manganese. Blocks deposited in shallow water [less than 90 m (200 ft)] may be much more feasible to recover than a deposit of untreated rejects.

The technical and economic feasibility of forming blocks with rejects is not known. Substantial work would be necessary to determine the feasibility of this alternative.

Capping

Once a deposit of manganese nodule rejects is in place on the seabed it may be possible to cover (or cap) the deposit with uncontaminated sediments. This would prevent long term impacts of the deposit. For example, if it was found that benthic organisms were concentrating undesirable compounds from the reject deposit, a cap of clean sand could be dumped on top of the rejects to isolate the rejects from the organisms. This concept is currently being evaluated by the Corps of Engineers, New York District (Suszkowski 1982).

Approximately 764,500 m^3 (1,000,000 yd^3) of contaminated dredged material were deposited in approximately 21 m (70 ft) of water at the New York Bight mud dump site. Approximately 1,530,000 m^3 (2,000,000 yd^3) of clean sand was then deposited to form a 0.6 m- (2 ft-) thick cap over the contaminated sediment (Suszkowski 1982). The New York District is currently performing studies to determine the effectiveness of the capping technique.

Capping may be an effective technique to isolate manganese nodule processing rejects, if required, in shallow water [less than approximately 300 m (1,000 ft)]. The ability to control the placement of dumped, or pumped down, material decreases as water depth increases. The amount of cover material required to cover a reject deposit in deep water may prove prohibitive.

The capping technique may also prove useful in reverse. Manganese nodule processing rejects may prove to be suitable as a cover material. In this case, rejects could be used to bury and isolate potentially harmful wastes such as highly contaminated dredged material or low-level radioactive wastes.

4. CURRENT OCEAN DISPOSAL ACTIVITY

Untreated municipal wastewater was probably the first material to be discharged to the ocean in any large quantities. The earliest type of material dumped in the ocean was dredged material from harbor entrance channels. Regulation of this form of dumping began in 1888, primarily because of concerns of possible interference with navigation. New York City began dumping sewage sludge at a site 19 km (12 mi) outside the harbor in the 1920s. Ocean dumping of industrial wastes in significant quantities began on the Pacific and Atlantic Coasts in the 1940s and on the Gulf Coast in the 1950s. As with dredged material, where regulations existed concerning municipal sludge and industrial wastes, the primary concern was not over environmental impacts, but with constraints on navigation (Wastler 1981).

Since World War II, the U.S. government has disposed of obsolete or unserviceable equipment, ammunition, rocket fuels, and other unsalvageable war materials in deep waters off the U.S. coasts. Generally the material is transported by barges and ships and dumped over the side. However, within the last 20 years, gutted World War II cargo ships are loaded with material and sunk in water with depths over 1,800 m (6,000 ft) (Wastler 1981).

The Atomic Energy Commission disposed of limited quantities of packaged radioactive waste materials between 1946 and 1967 (Wastler 1981). In most cases the material was packaged in 55-gal steel drums. Four principal radioactive waste disposal sites were utilized. Two sites were in the Pacific Ocean near the Farallon Islands, with depths of about 914 m (3,000 ft) and 1,700 m (5,600 ft). Two sites in the Atlantic Ocean had depths of 2,800 m (9,200 ft) and 3,800 m (12,500 ft), and were located 193 km (120 mi) and 322 km (200 mi) off the Maryland-Delaware coasts, respectively (EPA 1979).

Nearly 300 ocean dump sites have been used historically, mostly for dredged materials. Public interest in the effects of materials disposed of at these sites was aroused in 1969 - 1970 due to incidents involving the disposal of chemical warfare agents. Simultaneously, studies completed by several universities and NOAA identified potentially adverse effects of industrial waste and sewage sludge disposal in the New York Bight. The Council on Environmental Quality reported in 1970 to the President and identified poorly regulated waste disposal as a potential marine environmental danger (EPA 1980b).

Subsequent chapters of this report evaluate the potential impacts of reject disposal at generalized locations (i.e., mid shelf, shelf edge, and deep ocean) within western Gulf of Mexico, southern California, Pacific Northwest, and Hawaii regions. It should be noted that interim and final designated disposal sites exist nearshore in each of these regions for disposal of dredged material (Table 9). These sites are not specifically addressed in this report. They are theoretically, however, potential disposal sites for manganese nodule processing rejects. The possibility of using these sites to dispose of materials other than dredged material is not known.

WASTE QUANTITIES AND DISPOSAL SITES

Ocean Dumping

Approval of ocean dumping sites is the responsibility of EPA. Presently, 142 disposal sites have been designated - 12 for municipal and industrial wastes and 130 for dredged materials (Smith 1981). All sites except the incineration site in the Gulf of Mexico are designated as interim approved, based primarily on historical use. The Gulf of Mexico at sea incineration site was given final designation in 1976, for a 5-yr period of use. Final designation was given to an incineration at sea site in the Pacific Ocean near Johnston Island for disposal of the herbicide Agent Orange; however, the period of use was for only 3 months in 1977.

In 1979, all ocean dumping of materials other than dredged material occurred at sites in the Atlantic Ocean, with the exception of a single site in the Pacific Ocean where 998 tons of abandoned vehicles and equipment were dumped near Kwajalein Island under a special permit. Table 8 shows the location, principal waste types, and status of ocean disposal sites. The two sites in the Pacific Ocean are located near Johnston and Kwajalein Islands. The sites which have received the greatest use include the sewage sludge sites in the New York Bight and off Maryland (the Philadelphia sludge site) and the industrial waste sites off New York (deepwater dumpsite 106 and the New York/New Jersey acid waste dumpsite), Puerto Rico (near Arecibo), and on the Gulf Coast (the Galveston site and Mississippi River site). The Mississippi River, Galveston, New York/New Jersey acid waste, and the Philadelphia sludge sites have been abandoned (Anderson et al., 1979). The only sites still in use for municipal and industrial wastes are the Puerto Rico chemical waste site, deepwater dumpsite 106, the New York Bight, and the Gulf incineration site (NOAA 1980; Anderson et al., 1979). Dumping at these remaining sites is scheduled to decrease. Of the four industrial permittees at the deepwater dumpsite 106, three are scheduled to cease ocean disposal by the end of 1981. The remaining permittee, Du Pont-Grasselli, will be permitted to continue because the waste complies with current EPA criteria and because no viable land-based alternative is available (EPA 1980b). Dumping of municipal sewage sludge at deepwater dumpsite 106 may also be curtailed, depending on capacity and health considerations at the New York Bight site.

The 130 dredged material disposal sites granted interim status by EPA are scattered along the Atlantic, Gulf, and Pacific coasts. Efforts currently underway are developing environmental impact statements to enable permanent designation of 50 ocean disposal sites (COE 1980). These 50 sites were the only sites receiving dredged material in 1979. Table 9 indicates the latitude and longitude of these sites. The most active site is the Southwest Pass dredged material disposal site located in the Gulf of Mexico. Other large-scale active disposal sites are the Mud Dump site in the New York District and sites at the mouth of the Columbia River in the Portland District (COE 1980). Although four coastal districts (Seattle, Norfolk, Baltimore, and Philadelphia) reported no dredged material ocean disposal activities in 1979, dredged material dumping is expected to continue utilization of ocean disposal sites in the future.

TABLE 8. OCEAN DUMPING SITES FOR MUNICIPAL AND INDUSTRIAL WASTES

Site	Location	Primary Use	Status (as of July 1982)
1. Region II Sludge (NY Sludge Site)	40°22'30"N to 40°25'00"N 73°41'30"W to 73°45'00"W	Municipal sewage sludge	Still in use
2. Region II Industrial Wastes Site (Galveston Site)	27°12'00"N to 27°28'00"W 94°28'00"N to 94°44'00"W	Industrial wastes	Interim approved (never used)
3. Region II Industrial Wastes Site ("106" Site)	38°40'00"N to 39°00'00"N 72°00'00"W to 72°30'00"W	Industrial wastes	Interim approved
4. Region III Sludge Site (Philadelphia Sludge Site)	38°20'00"N to 38°25'00"N 74°10'00"W to 74°20'00"W	Municipal sewage sludge	Terminated December 1980
5. Region III Acid Site (DuPont Site)	38°30'00"N to 38°35'00"N 74°15'00"W to 74°25'00"W	Acid wastes	Terminated December 1980
6. Region II Acid Site (NY Acid Site)	40°16'00"N to 40°20'00"N 73°36'00"W to 73°40'00"W	Acid wastes	Final approved
7. Region VI Industrial Wastes Site (Mississippi River Site)	28°00'00"N to 28°10'00"N 89°15'00"W to 89°30'00"W	Industrial wastes	Terminated
8. Region I Industrial Wastes Site	43°22'30"N to 40°25'00"N 73°41'30"W to 73°45'00"W	Industrial wastes	Terminated
9. Region II Industrial Wastes Site (Puerto Rico Site)	19°10'00"N to 19°20'00"N 66°35'00"N to 66°50'00"W	Industrial wastes	Terminated September 1981
10. Region II Construction Debris Site (NY "Cellar Dirt" Site)	40°23'00"N, 73°49'00"W 0.6 nautical mile radius	Construction or demolition debris	Proposed for final approval

TABLE 8. (Continued)

11.	Region VI Gulf of Mexico Ocean Incineration Site	27°06'12"N, 93°24'15"W 26°32'24"N, 93°15'30"W 26°19'00"N, 93°56'00"W 26°52'40"N, 94°04'40"W	At-sea incineration	Final approved
12.	Region II Wrecked Vessel Dump Site (NY "Wreck" Site)	40°10'00"N, 73°42'00"W 0.5 nautical mile radius	Wrecks	Terminated
13.	Region I Industrial Wastes	42°25'42"N, 70°35'00"W 1 nautical mile radius	Industrial wastes	Terminated
14.	Region IV Industrial Waste Site	31°46'00"N, 80°30'00"W 31°47'06"N, 80°29'00"W 31°48'00"N, 80°30'30"W 31°46'30"N, 80°32'00"W	Industrial wastes	Terminated (never used)
15.	Region II Wood Incineration Site	40°00'00"N to 40°04'20"N 73°41'00"W to 73°38'10"W	Incineration of wood	Interim approved
16.	Headquarters Herbicide Orange Incineration Site	15°45'N to 17°45'N 171°30'W to 173°30'W	Incineration of herbicide orange	Terminated
17.	Region IX Kwajalein Ocean Dumping Site	08°47'N, 167°36'W	Waste material from Kwajalein Missile Range	Terminated
18.	Region II Alternate Sewage Sludge Site	40°10'30"N to 40°13'30"N 72°40'30"W to 72°43'30"W	Sewage sludge	Interim approval, not used yet
19.	Region IX San Nicholas Site	San Nicholas Basin	Drilling fluids	Final approval (still in use)

Sources: EPA (1977), Ramsey (1982), and 40 CFR Part 228.12.

TABLE 9. DREDGED MATERIAL OCEAN DISPOSAL SITE LOCATIONS AND DISPOSED YARDAGES FOR CALENDAR YEAR 1979

#	NORTH LATITUDE in degrees(°) minutes(') and seconds(")	WEST LONGITUDE in degrees(°) minutes(') and seconds(")	SITE NAME/DISTRICT LOCATION	TOTAL CUBIC YARDS	TOTAL TONS
			ATLANTIC OCEAN SECTION		
1.	43 34 06	70 01 48	Portland/New England Division, ME	196,069	264,693
2.	42 25 54	70 34 55	Marblehead/New England Division, ME	91,800	123,930
3.	40 21 48	73 51 28	Mud Dump/New York, NY	8,289,746	10,610,869
4.	40 32 30	73 54 00	Rockaway/New York, NY	97,349	124,606
5.	40 35 06	73 47 06	East Rockaway/New York, NY	43,213	55,312
6.	33 50 00	78 02 30	Wilmington/Wilmington, NC	138,836	194,370
7.	34 40 00	76 41 00	Morehead City/Wilmington, NC	204,846	286,724
8.	33 11 18	79 07 20	Georgetown/Charleston, SC	136,978	232,863
9.	32 05 40	80 35 30	Port Royal/Charleston, SC	17,015	28,925
10.	32 38 06	79 49 21	Charleston/Charleston, SC	746,977	1,269,860
11.	31 57 55	80 46 58	Savannah/Savannah, GA	239,468	362,511
12.	31 02 35	81 17 40	Brunswick/Savannah, GA	57,456	86,978
13.	27 35 49	82 51 75	Tampa/Jacksonville, FL	647,000	960,794
14.	27 35 32	82 54 42	Tampa/Jacksonville, FL	1,147,800	804,483
15.	27 35 41	82 52 36	Tampa/Jacksonville, FL	665,413	988,138
16.	27 35 58	82 49 39	Tampa/Jacksonville, FL	555,895	825,504
17.	27 09 58	80 09 30	St. Lucie/Jacksonville, FL	57,246	85,010
18.	26 46 00	79 58 55	Palm Beach/Jacksonville, FL	48,048	71,351
19.	30 42 00	81 19 05	Fernandina/Jacksonville, FL	2,663,505	5,035,305
20.	30 21 30	81 18 34	Jacksonville/Jacksonville, FL	47,148	70,015
Atlantic Ocean Subtotal	20 sites			16,091,808	23,382,241
			GULF OF MEXICO SECTION		
1.	30 11 18	88 58 24	Gulfport/Mobile, AL	723,962	1,020,786
2.	30 11 54	88 33 06	Pascagoula/Mobile, AL	235,968	332,715
3.	30 10 00	88 07 42	Mobile/Mobile, AL	360,047	507,666
4.	29 28 53	89 08 08	Brenton Sound/New Orleans, LA	2,933,239	3,535,859
5.	28 54 24	89 26 03	Southwest Pass/New Orleans, LA	21,602,793	22,811,434
6.	29 15 00	91 27 00	Atchafalaya/New Orleans, LA	6,250,890	7,405,750
7.	29 44 30	93 20 40	Calcasieu Site "C"/New Orleans, LA	6,820,000	7,273,530
8.	29 27 00	93 44 00	Sabine-Neches/Galveston, TX	630,708	728,468
9.	29 29 00	93 45 00	Sabine-Neches/Galveston, TX	237,740	274,590
10.	29 32 00	93 47 00	Sabine-Neches/Galveston, TX	651,652	752,658
11.	29 36 00	93 49 00	Sabine-Neches/Galveston, TX	58,080	67,082
12.	29 17 00	94 38 00	Galveston/Galveston, TX	3,839,190	3,870,516
13.	28 54 00	95 17 00	Freeport/Galveston, TX	312,390	483,267
14.	28 24 00	95 19 00	Matagorda/Galveston, TX	539,891	919,974
15.	26 34 17	97 16 12	Mansfield Site 1-A/Galveston, TX	364,534	572,065
16.	26 04 00	97 08 00	Brazos Site-1/Galveston, TX	859,209	1,945,969
Gulf of Mexico Subtotal	16 sites			46,420,293	52,022,324
			PACIFIC OCEAN SECTION		
1.	37 45 00	122 35 00	San Francisco/San Francisco, CA	968,661	1,430,410
2.	40 45 44	124 15 42	Humboldt/San Francisco, CA	588,892	879,830
3.	33 37 06	118 17 24	Los Angeles/Los Angeles, CA	12,425	18,637
4.	42 02 00	124 16 00	Chetco/Portland, OR	44,230	71,653
5.	43 21 59	124 22 45	Coos Bay Site-"E"/Portland, CA	806,785	1,306,992
6.	43 22 44	124 22 18	Coos Bay Site-"F"/Portland, CA	1,220,897	1,977,853
7.	42 07 54	124 27 04	Coquille/Portland, OR	82,800	134,136
8.	46 15 00	124 06 00	MCR Site-"E"/Portland, OR	5,134,048	8,317,158
9.	46 14 00	124 11 00	MCR Site-"B"/Portland, OR	89,082	144,313
10.	44 01 32	124 07 37	Siuslaw/Portland, OR	246,563	399,432
11.	43 40 00	124 14 18	Umpqua/Portland, OR	317,132	513,754
12.	44 36 03	124 06 04	Yaquina/Portland, OR	378,191	612,669
13.	64 30 40	165 25 52	Nome/Anchorage, AK	13,000	22,000
14.	21 14 30	157 54 30	Honolulu,Honolulu, HI	399,000	591,271
Pacific Ocean Subtotal	14 sites			10,301,706	16,420,108
TOTAL (All Sections)	50 sites			72,813,807	91,824,673

Source: COE 1980.

The type and quantities of materials being dumped in the ocean under EPA permits are shown in Table 10 for the years 1973-1979. It is evident from Table 10 that the Pacific Ocean disposal sites have had infrequent use over the 7-year period represented. The same is generally true for the Gulf of Mexico sites, particularly in 1978 and 1979. The Atlantic Ocean sites receive the vast majority of ocean dumped industrial and municipal wastes. Although no trend is apparent in the total amounts of material dumped at the Atlantic sites over the years, reported quantities for 1980 and 1981 are expected to be less than previous years as permittees are phased out.

Dredged materials for dumping result from COE maintenance dredging activities, newly authorized projects, and from COE permittees. Table 11 indicates the quantity of dredged material disposed of at sites inside and outside the 3-mile limit in 1979 (COE 1980). Disposal of material from COE projects occurred using both COE and private contracted vessels.

Ocean Discharge

The Federal Water Pollution Control Act (FWPCA), also known as the Clean Water Act, governs all discharges of pollutants into U.S. waters by outfalls. Administration and implementation of the FWPCA is the responsibility of EPA. Final regulations concerning ocean discharges were published on October 3, 1980, and became effective 30 days later. These 403(c) ocean discharge criteria are applied to all applicants for National Pollutant Discharge Elimination System (NPDES) permits involving new or continuing discharges.

Of the 62,400 NPDES permittees nationwide, there are 232 land-based dischargers with outfalls emptying into U.S. coastal waters. These ocean discharges include 102 municipal wastewater treatment plants, 74 industrial treatment plants, 25 steam electric plants, and 31 federal facilities. In addition to these land-based ocean dischargers, there are about 3,000 offshore oil and gas exploration and production platforms which require discharge permits (NACOA 1981).

The volume of municipal wastewater discharged to the ocean is extremely large compared to ocean dumping. In southern California coastal waters alone, over 1 billion gallons of treated wastewater are discharged per day (NACOA 1981). For the Atlantic, Pacific, and Gulf coasts, over 3 billion gallons of wastewater are discharged through marine outfalls each day. Sewage sludge is also discharged through outfalls by Boston and Los Angeles. The Los Angeles Hyperion plant discharges sewage sludge at the rate of about 160 tons per day. An average of about 200 tons per day of sewage sludge from the Deer and Nut Island treatment plants in Boston is currently discharged to President Roads. Ocean discharge of sewage sludge was originally scheduled to end by December 31, 1981. However, because the city of Los Angeles is unable to comply with this date, a recent court order has extended the deadline. The Hyperion plant must cease discharging sludge by 1985.

TABLE 10. TYPES AND AMOUNTS OF OCEAN DISPOSAL (IN APPROXIMATE TONS) 1973-1979 (EXCLUDES DREDGED MATERIAL)

Atlantic Ocean

Waste Type	1973	1974	1975	1976	1977	1978	1979
Industrial waste	3,642,800	3,642,000	3,322,300	2,633,200	1,783,600	2,548,000	2,577,000
Sewage sludge	4,898,900	5,010,000	5,039,600	5,270,900	5,134,000	5,535,000	5,932,000
Construction and demolition	973,700	770,400	395,900	314,600	379,000	241,000	107,000
Solid waste	0	0	0	0	100	0	0
Explosives	0	0	0	0	0	0	0
Incinerated (wood)	10,800	15,800	6,200	8,700	15,100	18,000	36,000
Incinerated (chemicals)	0	0	0	0	0	0	0
TOTALS	9,526,200	9,438,200	8,764,000	8,227,400	7,311,700	8,342,000	8,652,000

Gulf of Mexico

Waste Type	1973	1974	1975	1976	1977	1978	1979
Industrial waste	1,408,000	937,700	119,600	100,300	60,200	173	0
Sewage sludge	0	0	0	0	0	0	0
Construction and demolition debris	0	0	0	0	0	0	0
Solid waste	0	0	0	0	0	0	0
Explosives	0	0	0	0	0	0	0
Incinerated (wood)	0	0	0	0	0	0	0
Incinerated (chemicals)	0	12,300	4,100	0	17,600	0	0
TOTALS	1,408,000	950,000	123,700	100,300	77,800	173	0

Pacific Ocean

Waste Type	1973	1974	1975	1976	1977	1978	1979
Industrial waste	0	0	0	0	0	0	0
Sewage sludge	0	0	0	0	0	0	0
Construction and demolition debris	0	0	0	0	0	0	0
Solid waste	240	200	0	0	0	0	998
Explosives	0	0	0	0	0	0	0
Incinerated (wood)	0	0	0	0	0	0	0
Incinerated (chemicals)	0	0	0	0	12,100	0	0
TOTALS	240	200	0	0	12,100	0	998

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TABLE 11. DREDGED MATERIAL DISPOSED OF IN 1979

	Inside 3-mi Limit		Outside 3-mi Limit	
	Cubic Yards	Grand % Total	Cubic Yards	Grand % Total
COE Programs				
Corps vessel	31,548,482	43.3	8,747,066	12.0
Contract vessel	13,672,357	18.8	14,767,641	20.3
COE Permits				
103 Authority	0	0.0	4,078,261	5.6
NET TOTAL	45,220,839	62.1	27,592,968	37.9

Source: COE 1980.

Except for drilling muds and cuttings discharged to offshore waters, wastes discharged from current NPDES permitted outfalls have little similarity to manganese nodule processing waste. Existing outfalls are designed to discharge liquids (mostly buoyant). The chemical and physical characteristics of solids associated with discharges such as sewage or sewage sludge differ greatly from manganese nodule rejects. This is primarily because of the high organic content of sewage solids. Wastes considered to be most analogous to manganese nodule processing rejects are mine tailings. Mine tailings are not currently discharged to U.S. waters although it is being planned for a mine near Ketchikan, Alaska. The discharge of mine tailings to marine waters is employed most widely in British Columbia, Canada. The comparison of the physical and chemical characteristics of other wastes to manganese nodule processing wastes is presented in Chapter 5. Appendix C presents a detailed discussion of available information on mine tailings discharges to marine waters. A comparison of observed impacts of mine tailings discharges is presented in Chapter 7.

5. CHARACTERIZATION OF NODULE PROCESSING REJECTS AND WASTES AND COMPARISON TO OTHER WASTES

The complex composition of manganese nodules makes the development of efficient processing and extraction technology a critical factor to the viability of commercial manganese nodule mining. Nickel, copper, and cobalt, the metals generally agreed to be of primary economic importance, account for approximately 3 percent of the dry weight of an ore-grade nodule. These metals are not present as discrete minerals but are disseminated throughout the nodules in the manganese oxide and iron oxide phases. For this reason, the value metals are not amenable to physical concentration, and require extraction processing of the entire ore volume.

The ferro-manganese oxide matrix of nodules effectively scavenges trace elements from the ocean. During metallurgical processing these trace constituents must be either recovered as product, treated as impurities in products, or relegated to the process wastes. Although trace elements occur as inert compounds in manganese nodules, some are considered potentially toxic or hazardous in ionic forms. In developing a metallurgical process to economically extract value metals from nodules, the chemical forms and fates of potentially toxic elements also require attention.

The majority of nickel, copper, and cobalt currently being produced comes from sulfide ores processed in smelting operations utilizing well-established extractive metallurgy. Some nickel and cobalt are produced from laterites, silicate, and iron oxide deposits in which the value metals are distributed throughout the mineral matrix, similar to manganese nodules, and cannot be physically beneficiated. Reduction of the laterite oxide matrix by pyrometallurgical or hydrometallurgical processes is required before the nickel and cobalt can be recovered.

A summary of the state of knowledge of nodule processing methods and resulting waste characteristics is provided in this section. This summary is followed by a comparison to similar wastes, mining waste, dredged material, and drilling muds and cuttings, which are currently disposed of in marine waters. Throughout, the reader should note that a commercial-scale processing will produce several discrete waste streams in addition to the solids which remain after all the value metals have been extracted. These other waste streams are described in this report but are not considered to be part of the waste for which ocean disposal is being evaluated. These other waste streams are relatively small in volume compared to the processing rejects. It is assumed in this report that the design of the processing plant will allow for separation and treatment of these wastes independently of reject handling. Separate treatment versus disposal with the rejects is an option which should be evaluated during the feasibility studies for individual processing plants.

It is important to note also that the data on chemical composition of rejects from the various nodule processing schemes are based upon two primary sources. These are the Dames and Moore studies (1977a and b) and data from chemical analysis of rejects from a CUPRION-ammonia leach processing pilot plant supplied by the Bureau of Mines, Avondale, Maryland. The Dames and Moore values are theoretical in nature and represent a mass balance of inputs to the plant among all wastes, products, and process chemicals leaving the plant. These results are therefore not expected to be completely representative of wastes from a pilot or operational plant. The analytical results for the CUPRION-ammonia leach process are similarly not expected to agree with the Dames and Moore mass balances or to be truly representative of rejects from an operational processing plant.

SUMMARY OF EXTRACTION PROCESSES

In a comprehensive study of nodule processing activities contracted by NOAA (Dames & Moore, Vol. I, 1977), five processing alternatives were identified as the most likely options for first generation plants. Three of these, reduction-ammonia leach, CUPRION-ammonia leach, and high temperature sulfuric acid leach, are designed to recover three metals: nickel, copper, and cobalt. Two systems, reduction-hydrochloric acid leach and smelting-sulfuric acid leach, are capable of four metal recovery: nickel, copper, cobalt, and manganese. All but the smelting-sulfuric acid leach option are hydrometallurgical (chemical leaching) processes, while the last includes a pyrometallurgical (smelting) step.

Four general steps can be identified for each of the five processing schemes discussed in this section:

- Separation of the value metals from the iron-manganese oxide matrix
- Isolation of the value metals from each other and recovery
- Retrieval of reagents utilized in the extraction, and
- Waste disposal.

In the following discussion, the principal components of each process are first summarized and then described in more detail.

All of the processes except the reduction/hydrochloric acid leach have analogous processes already in existence to which they can be compared. The wastes generated by the hydrochloric acid leach process can only be characterized in a qualitative sense whereas much of the waste generated by the other processes can be dealt with in more quantitative terms.

The majority of the wastes (85-95 percent) generated by the reduction-ammonia leach, CUPRION-ammonia leach, and high temperature sulfuric acid leach consist of leached rejects or slag and leached rejects for the smelting-sulfuric-acid leach process. The physical and chemical characteristics of these rejects are inferred from analogous existent

processes. The wastes generated by metals separation and purification of nodules are quite different than those for conventional mineral deposits because of the unique chemical nature of deep sea manganese nodules. The susceptibility of the leaching of potentially toxic elements from rejects discharged in the marine environment appears to be low while the stability of the chemical constituents of the lime boil solids and electrowinning sludges generated in the separation and purification steps are unknown.

REDUCTION-AMMONIA LEACH

The reduction-ammonia leach process (Figure 13) consists of a carbon monoxide reduction step followed by solubilization of the value metals in an ammonia solution. Copper and nickel are separated from the pregnant liquor by liquid ion exchange and removed as electrowon cathodes. Cobalt is precipitated as a sulfide which is reduced to form cobalt metal.

Prior to reduction, the nodules are dried at 175° C by direct contact with combustion gases and ground to approximately 200 um. The hot nodule fragments are transferred to the reduction step where they contact carbon monoxide produced by coal gasification at 625° C. The overall reduction-oxidation reaction is:

$$(1) \qquad MnO_2 + CO \longrightarrow CO_2 + MnO$$

The reduction of manganese breaks down the matrix structure of the nodules, enabling solubilization of the metals. The nodules are cooled with a water spray and the carbon dioxide produced in reduction step (1) is reacted with the nodule slurry to form manganese carbonate. Oxygen introduced into the system forms an insoluble iron oxide precipitate which is added to the manganese carbonate tailings. After leaching the slurry with a solution of ammonia and carbon dioxide, the tailings are separated from the solution in a series of thickeners, washed, stripped of excess ammonia by steam, and sent to waste containment. The solvent phase (pregnant liquor) now contains much of the copper, nickel and cobalt originally present in the nodules.

The pregnant liquor passes through a counter-current liquid ion exchange circuit where copper, nickel, and small amounts of cobalt and ammonia are removed from the solution. To prevent buildup in the circuit, cobalt and ammonia are periodically removed by precipitation with hydrogen sulfide and washing with ammonium sulfate, respectively. Nickel and copper are stripped selectively from the ion exchange liquid by varying the strength of the electrolyte and recovered as electrowon cathodes. The effluent leach solution is subjected to several processes, including sulfide precipitation, oxidation, and solids separation, in order to remove remaining copper, nickel, and zinc prior to cobalt recovery by reduction with hydrogen gas.

Much of the ammonia and steam produced are recycled through the process. Ammonia and ammonium carbonate are recovered after steam stripping of the tailings by condensation. Ammonium sulfate used in the ion exchange washing and generated in the purification of cobalt is reacted with slaked lime. Ammonia is recovered from this mixture by steam stripping, leaving gypsum (calcium sulfate) as a waste product.

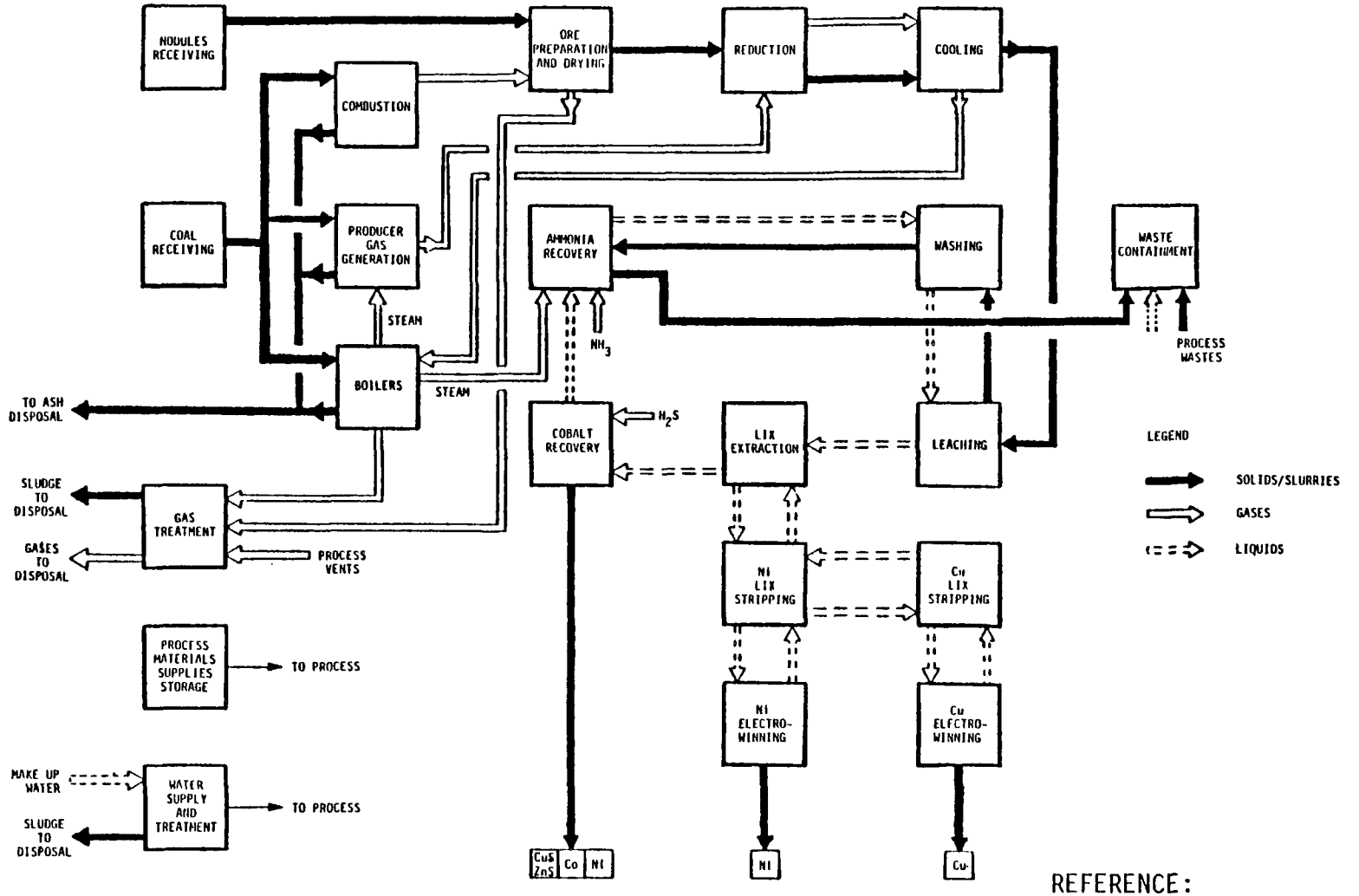


Figure 13. Reduction/ammoniacal leach process.

The waste streams produced by this process include: the rejects slurry, lime boil (gypsum) slurry, ash from combustion, sludges from gas scrubbers, degraded organics recovered from the ion exchange circuit, spent carbon from nodule reduction, electrowinning sludges, and plant runoff.

Processing alternatives which would influence the volume or composition of the waste streams include: a low temperature hydrometallurgical reduction (the CUPRION process described in the next section) and production of ammonium sulfate by crystallization which would reduce gypsum production by 18,500 tons/yr, and increase ammonia requirements by 4,300 tons/yr.

CUPRION-AMMONIACAL LEACH

The CUPRION/ammoniacal leach process (Figure 14) is quite similar to the reduction-ammonia leach process except that the initial nodule reduction step is performed in solution at low temperature by cuprous ion. Cuprous ion is regenerated by reaction with carbon monoxide. Reduction proceeds by the following reactions:

(2) Reduction: $2Cu(I) + Mn(IV) \longrightarrow 2Cu(II) + Mn(II)$

(3) Regeneration: $2Cu(II) + CO + H_2O \longrightarrow 2Cu(I) + CO_2 + 2H^+$

The reduced nodule slurry passes through a series of thickeners with the overflow being recycled. The thickened slurry is subjected to an oxidizing ammonia leach in which iron forms a hydroxide precipitate which is added to the manganese carbonate rejects. Liquid-solid separations are made in thickeners which provide added residence time for ammonia leaching. Off-gases are scrubbed for ammonia recovery and the tailings are washed and passed to waste containment. The pregnant liquor passes to liquid ion exchange, where the remainder of the process is identical to the reduction-ammonia leach metals purification scheme previously discussed.

The waste streams produced by this process include: the rejects slurry, lime boil slurry, ash from combustion, sludges from gas scrubbers, degraded organics recovered from the ion exchange circuit, electrowinning sludges, and plant runoff. The major difference in the wastes produced by the CUPRION and reduction-ammonia leach processes is in the amount of fuel-related waste products. The initial low temperature nodule reduction step of the CUPRION process consumes less fuel than the reduction-ammonia leach process, with a concomitant decrease in the production of ash and gas scrubbing sludges.

Process alternatives include a pyrometallurgical reduction (reduction-ammonia leach detailed in the previous section) and the production of ammonium sulfate by crystallization which would reduce gypsum production by 21,500 tons/yr and increase ammonia requirements by 5,000 tons/yr.

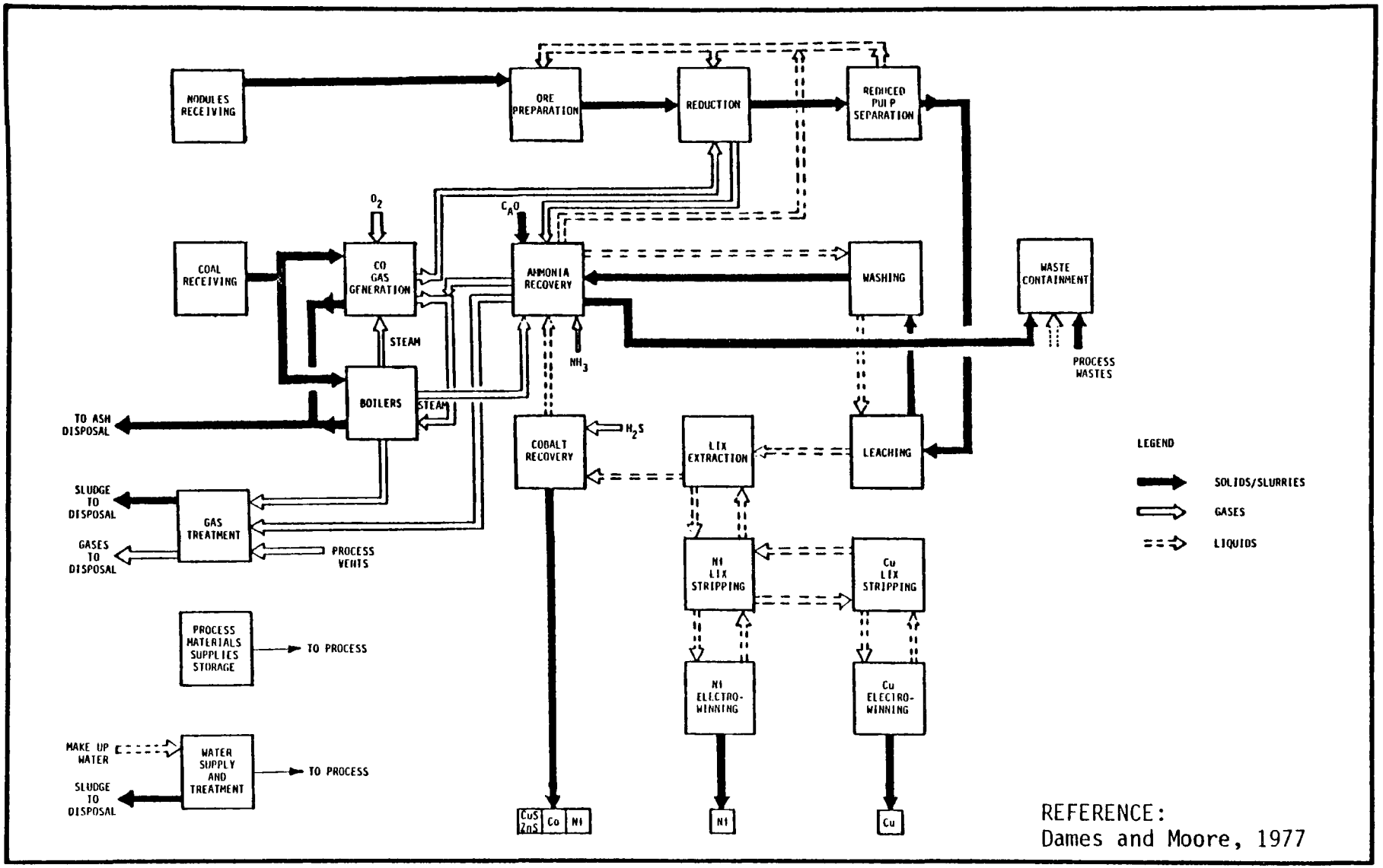


Figure 14. Cuprion/ammoniacal leach process.

HIGH TEMPERATURE SULFURIC ACID LEACH

The high temperature sulfuric acid leach (Figure 15) consists of a high temperature and pressure solubilization of the ground nodules. Nearly all of the value metals are extracted into the sulfuric acid solution. Copper and nickel are recovered from solution by liquid ion exchange followed by electrowinning. Cobalt is recovered from the raffinate by precipitation with hydrogen sulfide and reduction by hydrogen gas.

Nodules are ground to approximately 200 um, mixed into a slurry with recycled pregnant leach liquor, and heated to 245^{o} C. The hot slurry contacts a 30 percent sulfuric acid solution at 35 atm pressure. After dissolution of the value metal, the slurry passes through a heat exchange step where the temperature is lowered to 50^{o} C and waste heat is recovered.

Unreacted solids are separated from the slurry and washed of value metals, the washings being added to the pregnant liquor. Limestone (calcium carbonate) is added to the solution phase to adjust pH. This results in precipitation of gypsum (calcium sulfate) which is removed in clarifiers. The gypsum is washed of value metals and sent to waste containment. The neutralized pregnant liquor flows to the copper ion exchange circuit.

The ion exchange process selectively removes copper and nickel from the pregnant liquor. At acidic pH, copper is extracted by the ion exchange medium. Adjustment of pH to more basic values, by the addition of ammonia, allows nickel extraction in a second ion exchange circuit. The effluent passes to cobalt recovery. The copper and nickel are stripped from their respective ion exchange circuits by electrolyte that has been depleted of the metals in the electrowinning process. The nickel ion exchange medium is stripped of ammonia by washing and reaction with sulfuric acid. Prior to electrowinning, the pH and conductivity of the electrolyte from the nickel ion exchange circuit are adjusted with boric acid and sodium sulfate, and dissolved organic materials are removed by absorption on activated carbon. Copper and nickel are both recovered as electrowon cathodes.

Cobalt, and unextracted copper, nickel, and zinc are removed from the nickel ion exchange raffinate by sulfide precipitation. The precipitate is separated in a clarifier and pressure leached with air to preferentially dissolve cobalt and nickel sulfides. The zinc and copper sulfides are separated and sold as minor products. The remaining nickel/cobalt solution is further processed with ammonium sulfate to remove nickel. Cobalt is separated by evaporation, crystallization, and selective redissolution in a strong ammonia solution, and recovered by hydrogen gas reduction. The raffinate from the cobalt recovery is then reacted with slaked lime to recover ammonia added as ammonia and ammonium sulfate.

Waste streams generated in the sulfuric acid leach process include: rejects slurry, combustion ash, gas scrubber solids, lime boil solids, spent carbon from activated carbon adsorption, degraded organics from the liquid ion exchange circuits, and electrowinning sludges.

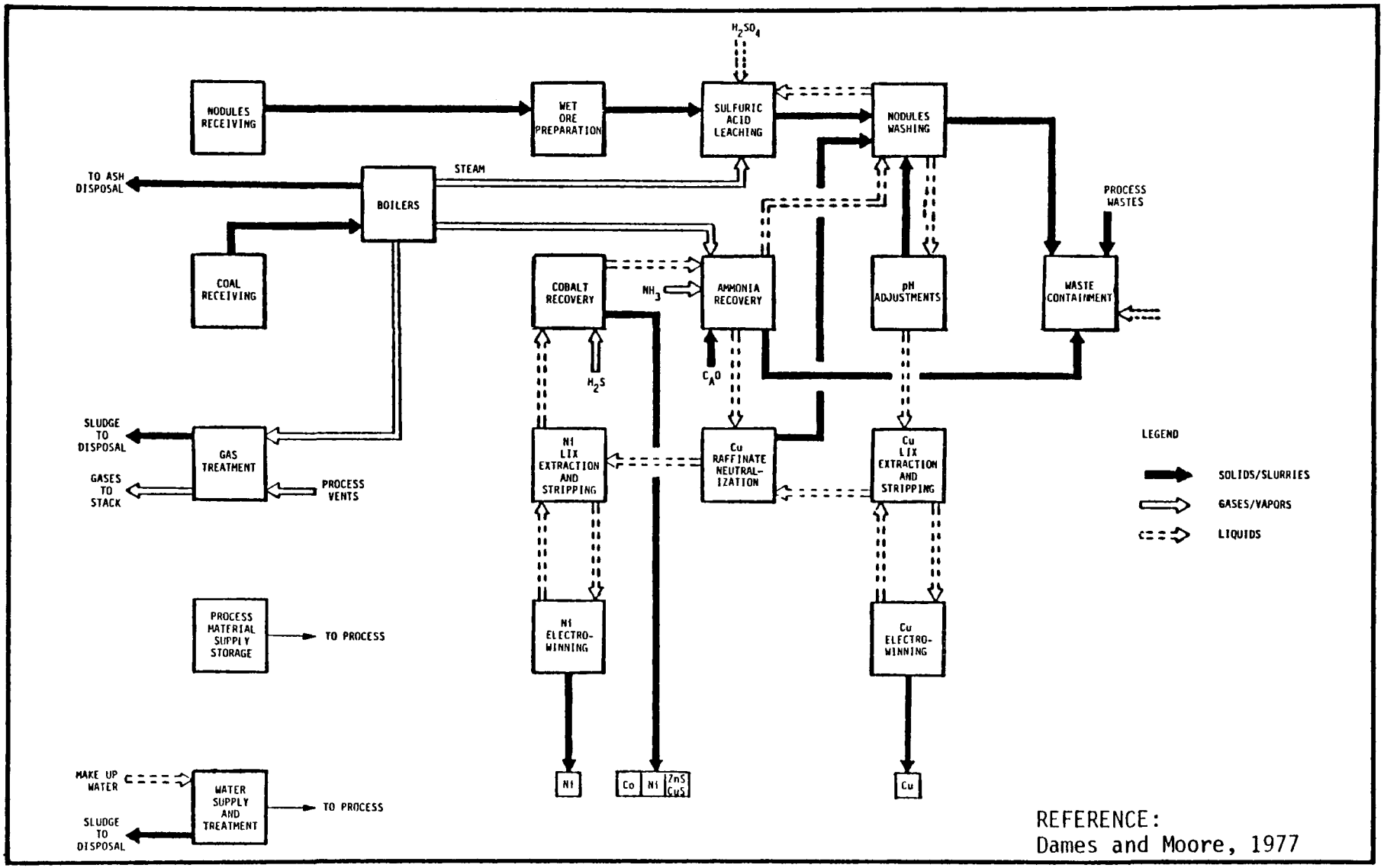


Figure 15. High temperature sulfuric acid leach process.

Process alternatives include the elimination of the oxidation/pH adjustment of the copper raffinate wih ammonia prior to nickel extraction if an extraction reagent could be found to selectively remove nickel in the presence of cobalt. Another alternative would be the recovery of ammonium sulfate by crystallization which would reduce gypsum production and increase the ammonia requirement.

REDUCTION-HYDROCHLORIC ACID LEACH

The hydrochloric acid leach process (Figure 16) is based on the reduction of manganese dioxide by the following reactions:

$$(4) \qquad MnO_2 + 2HCl \longrightarrow Mn(OH)_2 + Cl_2\ (g)$$

$$(5) \qquad Mn(OH)_2 + 2HCl \longrightarrow MnCl_2 + 2H_2O$$

The formation of soluble manganese chloride also releases copper, nickel, and cobalt from the nodule matrix. In this process, copper and nickel are selectively separated by liquid ion exchange and recovered as electrowon cathodes. Cobalt is separated by solvent extraction, deposited as a sulfide precipitate, and subsequently selectively leached into solution and reduced by hydrogen gas to form cobalt powder. Manganese can be recovered from the raffinate by several processes including evaporation of the solution to produce an impure manganese chloride.

The chemical reduction of the manganese nodule matrix, reactions 4 and 5, is carried out on ground (approximately 200 um) and dried nodules at a temperature of 500^{0} C. Solubilization of the iron content of the nodules by the formation of iron chloride is minimized by a water spray which converts ferric chloride to insoluble ferric hydroxide. The prevention of iron solubilization is important to the subsequent separation and recovery of the value metals. Unreacted HCl is recovered for recycle and chlorine gas (generated in reaction 4) is recovered, after drying by passage through concentrated sulfuric acid, as a salable byproduct.

After the high temperature reduction step, metal chlorides are brought into solution in HCl. Copper is extracted from this solution (pregnant liquor) using a liquid ion exchange medium. After separation of the copper loaded organic phase from the metal-chloride solution from the ion exchanger using strong sulfuric acid, the resulting copper sulfate solution is sent to electrowinning producing cathode copper. The copper depleted sulfuric acid solution is recycled to remove more copper from the ion exchange media.

The copper depleted chloride solution is neutralized with sodium hydroxide and mixed with an organic solvent which selectively removes cobalt from the solution. The cobalt is recovered by stripping it from the organic solvent with recycled process water, precipitating it as cobalt sulfide with hydrogen sulfide, and reducing it to cobalt powder with hydrogen gas.

Nickel is removed from the cobalt and copper-depleted chloride solution using a liquid ion exchange media. The nickel is stripped from the ion exchange media with depleted electrolyte from nickel electrowinning which

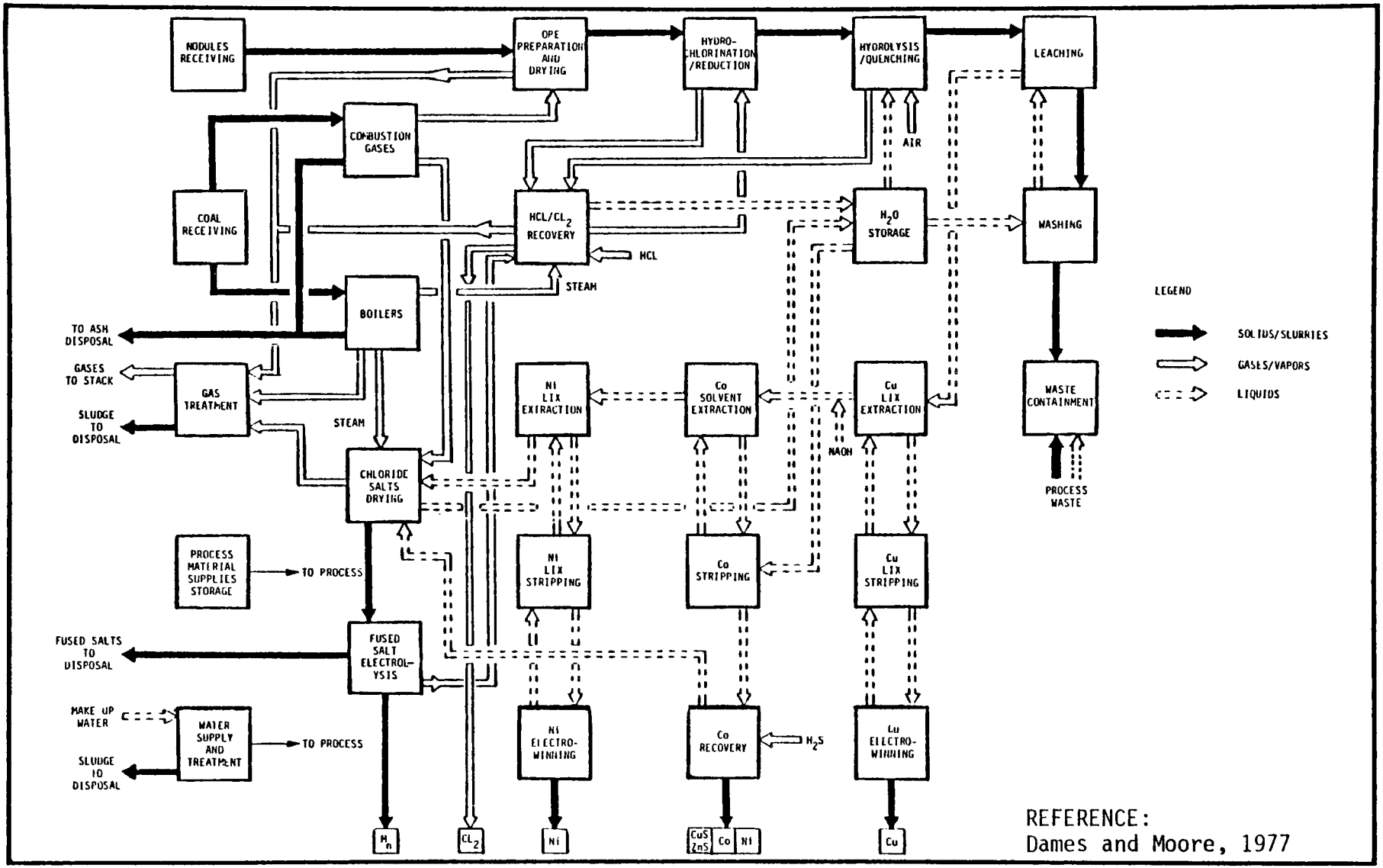


Figure 16. Reduction/hydrochloric acid leach process.

contains nickel sulfate in solution as well as some sodium sulfate as an additive and recovered from the nickel-sulfate solution as an electrowon cathode.

The remaining manganese chloride solution which has been stripped of copper, cobalt, and nickel can be dried to form impure manganese chloride. The manganese can be purified in a high temperature electrolysis furnace where it is separated in a pure molten form that can be cast into molds.

Because there are no close terrestrial analogs to the reduction/hydrochloric acid leach process it is difficult to accurately characterize the wastes produced. Comparison to the ferric chloride leaching of copper sulfide ore indicates the potential for production of large amounts of hydrous slimes which are difficult to settle and stabilize. The largest waste stream will be fused salts which remain after purification of manganese. Very little is known about the characteristics of these salts including their solubility or susceptibility to leaching of potentially toxic elements into the aqueous environment. Due to the lack of analogous systems to which this process can be compared there will be no quantitative analysis of the various waste streams.

SMELTING-SULFURIC ACID LEACH

The smelting-sulfuric acid leach is a combined pyro- and hydrometallurgical process (Figure 17) in which the iron and manganese oxides are reduced at high temperature. The reduced nodules are converted to a molten alloy in an electric furnace. Subsequent reoxidation of the molten alloy and addition of coke and gypsum form two separable phases: a slag containing manganese and iron oxides and a sulfide matte containing the copper, nickel, and cobalt. Copper and nickel are recovered from the matte following dissolution in sulfuric acid by ion exchange and electrodeposition. Cobalt is recovered from the raffinate by precipitation with hydrogen sulfide. A ferromanganese alloy can also be recovered from the slag.

Prior to reduction, the nodules are dried and ground to approximately 200 um. The dried nodules are mixed with coke and fed into a fluid-bed roaster for reduction by carbon monoxide. The reduced nodules are smelted with silica flux in an electric furnace at 1,425^{o} C. The alloy phase contains iron, nickel, copper, cobalt, and minor amounts of manganese, while the slag is mainly composed of manganese, iron, and silica/calcium in the proper ratio to maintain fluidity. Iron and manganese in the alloy are removed to the slag by oxidation with oxygen gas. After separation of the slag and alloy phases, the latter is mixed with calcium sulfate and coke to form sulfides of the value metals.

The sulfide matte containing the value metals is quenched in a granulation unit and formed into a slurry. The slurry is leached with sulfuric acid at 150 psi and 110^{o} C. The leachate, which now constitutes the pregnant liquor, is separated from the residue by filtration. The residue is removed to waste treatment. The pregnant liquor is pH adjusted with calcium carbonate, resulting in the formation of calcium sulfate.

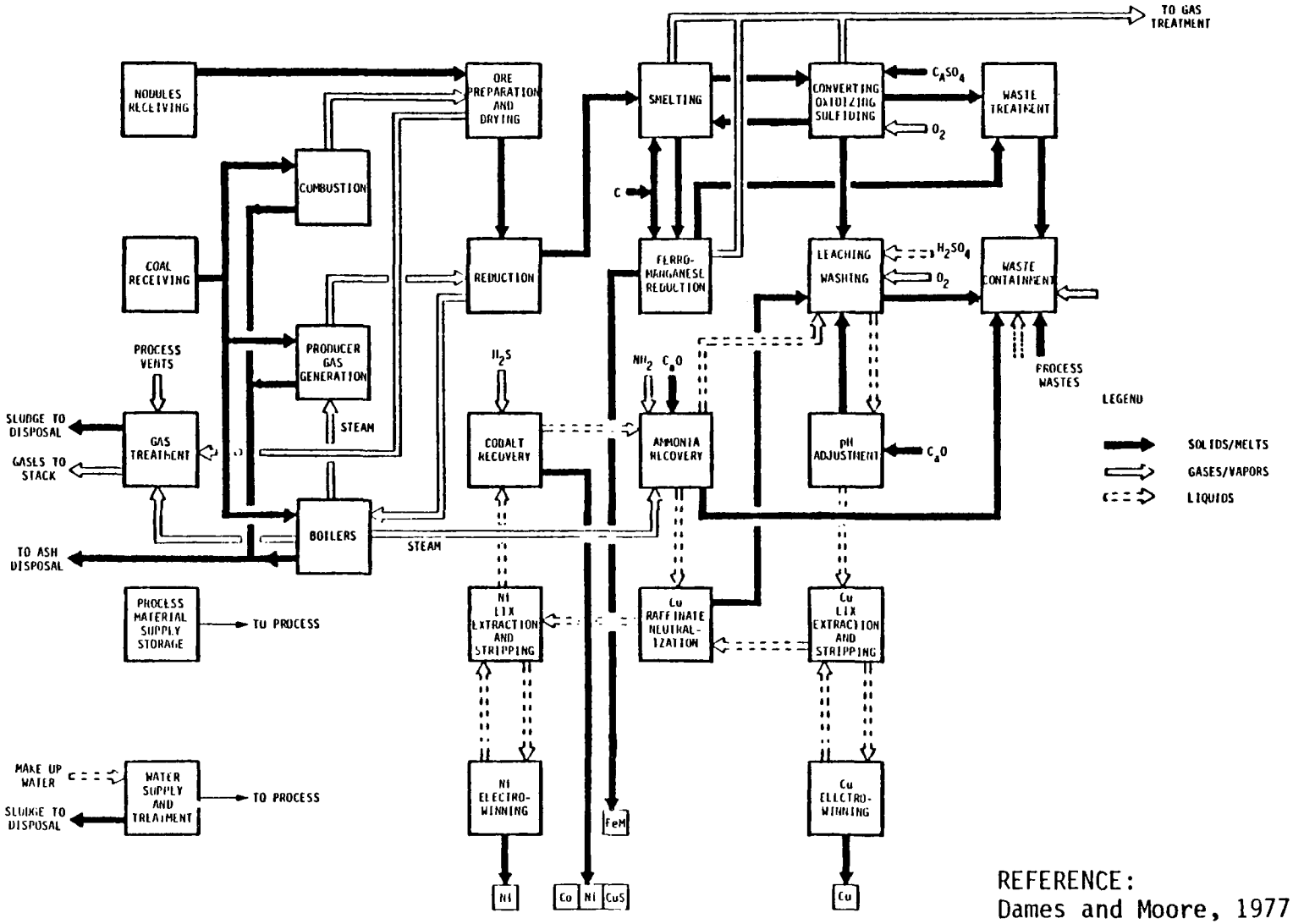


Figure 17. Smelting process.

Copper is removed from the solution by contact with an organic ion exchange reagent. The organic medium is stripped of copper by contacting it with depleted electrolyte from copper electrowinning. The nickel-rich raffinate from the copper electrowinning process is then treated with ammonia to raise the pH and oxidized to keep cobalt in solution prior to extraction of nickel by liquid ion exchange.

Oxidation and pH adjustment cause the precipitation of iron, manganese, magnesium, and aluminum initially extracted from the matte and carried in the raffinate. Because precipitation under these conditions results in the formation of hydrous slimes, the solution must be filtered. The solids are sent to disposal.

The remainder of the process including nickel and cobalt recovery is identical to that described for the sulfuric acid leaching process. Copper and nickel are sold as electrowon cathodes and cobalt is recovered as a sulfide precipitate followed by hydrogen reduction. Additionally, the slag may be further processed to obtain a saleable ferromanganese product.

The waste streams produced by the smelting process include: leached rejects and gypsum in slurry form from matte digestion, hydrous precipitates (slurried), lime boil solids, granulated slag (slurried), gasification slag (slurried), combustion ash, gas scrubber solids (slurried), smelting dust, spent carbon, degraded organics, and electrowinning sludges.

Most alternatives in this process were eliminated as not adding significant benefits. The greatest impact on waste production would stem from the possible need to generate electrical power on-site to run the furnaces. This would significantly increase the quantities of combustion ash and gas scrubber solids produced.

WASTE STREAMS

Five process wastes have been evaluated: reduction-ammonia leach, CUPRION-ammonia leach, high temperature sulfuric acid leach, reduction-hydrochloric acid leach, and smelting-sulfuric acid leach. With the exception of the reduction-hydrochloric acid leach, the waste streams produced by each of these processes are similar in many respects. Where sufficient data are available, similar waste streams from each process will be compared on the basis of both physical and chemical characteristics.

Rejects

All of the processes considered discharge some form of reject in slurry form. Rejects from the reduction-ammonia leach and CUPRION processes should be quite similar in character since the nodules for both are originally ground to the same size and are treated with the same lixiviant, ammonia. Rejects from the sulfuric acid leach and the smelting process will each have different qualities. Rejects from the sulfuric acid leach process result from the extraction of ground nodules with sulfuric acid. Although the smelting process also utilizes sulfuric acid as a lixiviant, the rejects arise from the extraction of the sulfide matte phase.

The reject waste stream comprises approximately 95 percent of the total generated solids for both the reduction-ammoniacal leach and CUPRION processes. The rejects are only approximately 85 percent of the total solids generated by the high temperature sulfuric acid leach process because of a higher lime boil solids production from the neutralization of excess sulfuric acid. Smelting produces a small amount of matte rejects (1 percent of solid wastes) because most of the waste solids are separated as slag prior to leaching. The granulated slag comprises approximately 85 percent of the total solid waste for this process and may be further processed to recover ferromanganese or discharged as a waste product.

The physical characteristics of the rejects (Table 12) tend to be similar for the processes evaluated. The waste streams range from 43 - 50 percent solids by weight and from 1.8 - 2.0 g/cc in bulk density. Also shown are the yearly estimated solid and liquid fraction discharges, assuming a nodule input of 3.7×10^6 mty for the hydrometallurgical processes and 1.25×10^6 mty for the smelting process. As discussed later, McKibbin (1981) has found the particle size of rejects from the CUPRION process to be very small; 50 percent are less than 50 um.

The chemical characteristics of the rejects discharged (Table 13) are estimated for both the major and minor constituents. The pH of the waste products will be adjusted to between 6.5 and 8.0 prior to discharge. An additional concern may be the presence of reduced manganese (MnII). In seawater, MnII may be oxidized to Mn IV by reaction with oxygen. While Table 13 indicates that 12.5 percent of the hydrometallurgical rejects may be MnII, most of the reduced manganese will probably be present as a solid. Table 18, shown later, also suggests that only a very small fraction of the manganese would be in the dissolved state. Thus, oxygen consumption does not apear to be a major concern. The oxygen consumption could easily be measured on a representative sample of the waste.

The environmental impact of the potentially toxic metals in nodule rejects disposed of in the ocean is determined by their availability to the marine environment. It is expected that nearly all the metals will be bonded to the solid phase or complexed and only extremely small percentages will be in an ionic form. The Extraction Procedure (EP) toxicity test discussed later for the CUPRION/ammoniacal extraction confirms the low release of metals from tailings generated in this process. Similar low dissolved concentrations can be inferred for tailings produced by the reduction-ammonia leach process. The granulated slag produced by smelting tends to be vitreous in nature and would be expected to be stable with respect to leaching. Insufficient data exist for evaluating the leaching of the high temperature sulfuric acid tailings.

Changes in some of the physical characteristics of the waste streams, e.g., solids concentration, may result from attempts to promote better settling characteristics when production actually is implemented. Assessment of chemical characteristics can also be updated and improved as wastes from pilot processes are generated and analyzed.

TABLE 12. PHYSICAL CHARACTERISTICS OF REJECTS

	Reduction/ Ammonia Leach	CUPRION/ Ammonia Leach	Sulfuric Acid Leach	Smelting Matte	Smelting Granulated Slag
Nature	slurry	slurry	slurry	slurry	granular
Weight Percent Solids[a]	45	47	50	43	79
Density (g/cc)	1.8-2.0[f]	1.9[e]	1.8	1.8-2.0[f]	N.D.
Dry Solids Specific Gravity	N.D.	3.19[e]	N.D.	N.D.	N.D.
Grain Size[a] (um)	<74	<74	<44	<44[f]	>1,700[f]
Solids Discharge[a] (mty)	2.7×10^6 [b]	3.5×10^6 [b]	3.5×10^6 [b]	7.3×10^3 [c, d]	5.8×10^5
Liquids Discharge[a] (mty)	3.3×10^6 [b]	3.9×10^6 [b]	3.5×10^6 [b]	9.7×10^3 [c, d]	1.5×10^5
(mgy)	870	1,000	930	2.6	40

[a] Calculated from Dames & Moore 1977, Vol. III.

[b] Based on 3.7×10^6 mty nodule input.

[c] Leached rejects mixed with gypsum.

[d] Based on 1.25×10^6 mty nodule input.

[e] Bureau of Mines analysis of leached rejects.

[f] Estimate.

N.D. = No data.

TABLE 13. CHEMICAL CHARACTER OF REJECTS[a] AND PERCENT OF ORIGINAL INPUT

	Element	R/A Leach	CUPRION/ Ammonia Leach	H_2SO_4 Leach	Smelting Matte Rejects	Smelting Granulated Slag
Major Constituents in Percent	MnII[b]	12.5[c] (50)	12.5 (50)	(50)	--	25 (100)
	MnIV	12.5 (50)	12.5 (50)	(50)	--	--
	Fe	8.5 (100)	8.5 (100)		--	8.5 (100)
	Al	2.7 (100)	2.7 (100)		ND[d]	ND
	Si	6.8 (100)	6.8 (100)		ND	ND
Potentially Toxic Constituents (ppm)	Ba	4,645 (100)	3,600 (100)	3,610 (100)	--	6,474 (100)
	La	1,680 (90)	1,400 (95)	744 (50)	--	2,669 (100)
	V	418 (90)	300 (80)	36 (10)	--	353 (50)
	Cr	10.5 (90)	8 (90)	8.1 (90)	--	8.7 (55)
	Ag	0.35 (10)	0.3 (10)	0.28 (10)	202 (50)	-- --
	Cd	2.3 (10)	2 (10)	--	12.8 (1)	14.6 (45)
	As	29 (50)	33 (70)	4.5 (10)	565 (10)	8 (10)
	Sb	31.4 (90)	25 (90)	2.7 (10)	390 (10)	--
	Tl	23.2 (10)	33 (20)	90 (50)	128 (1)	146 (45)
	Pb	523 (90)	411 (90)	409 (90)	2,906 (5)	368 (45)

[a] All values calculated from Dames and Moore (1977, Vol. III).

[b] Estimated worst case of unoxidized Mn.

[c] Upper value is concentration in rejects (in percent or ppm). Value in parentheses is the percentage of the original concentration in nodules present in the waste.

[d] ND = no data.

Additional Waste Streams

Manganese nodule processing plants will generate wastes other than rejects and slag, although the magnitude of these additional wastes will be small by comparison. Some of these wastes have physical and chemical properties which may be unique to nodule processing and are yet to be well defined. These include: lime boil waste, electrowinning sludges, and degraded organics from the ion exchange circuit. Other wastes such as fly ash from coal combustion, water softening sludges, and plant runoff are common to many industrial and manufacturing plants.

Lime boil solids constitute from about 1 percent of the total waste rejects for the reduction-ammonia leach, CUPRION/ammoniacal leach, and smelting processes to approximately 15 percent of the total waste for the high temperature sulfuric acid leach. Grain size and slurry solids content of lime boil solids appear to be similar to those of the reject slurry for the high temperature sulfuric acid process (Table 14).

The concentrations of several potentially toxic constituents in the lime boil waste streams are high (Table 14); however, their availability to leaching is not presently known. Only thallium, in the reduction ammonia and CUPRION/ammonia processes, and antimony, in the high temperature sulfuric acid leach, are removed to the lime boil wastes in a proportion greater than 10 percent of their original nodule concentration.

Electrowinning sludges (Table 15) account for less than 0.1 percent of the total wastes generated, yet they tend to concentrate heavy metals. The high lead concentrations result from the use of lead anodes in the electrowinning process. At present, more detailed physical and chemical characteristics of this waste stream are not available. No data exist on the nature of the ion exchange circuit degraded organics which are a small fraction of the wastes.

Wastes produced from coal combustion are not unique to nodule processing; however, they constitute up to 3 percent of the solid wastes generated (Tables 16 and 17). Smelting produces a smaller output of combustion wastes than the other processes because a portion of the ash is incorporated into the slag. The smelter output also does not reflect the possible on-site generation of electricity to run the high temperature furnaces. Solids density for fly ash is approximately 2.5 g/cc and mean particle diameters are approximately 5 um (Davison et al., 1975).

The pathways of toxic elements through coal-fired plants are well documented in the literature (Klein et al., 1975; Anderson and Smith, 1977; Kaakinen et al., 1975; Gladney et al., 1978; Cox et al., 1978; Dreesen et al., 1977; and, Davison et al., 1975). Because fly ash is not unique to nodule processing, and its properties are well documented, it will not be discussed in detail.

The levels of wastes generated from nodule processing activities will be dependent upon the use of recycle technologies, which are discussed below. There is also the possibility for later recovery of other value

TABLE 14. PHYSICAL AND CHEMICAL CHARACTERISTICS OF LIME BOIL SOLIDS

Physical Characteristics

	Reduction/ Ammonia Leach	CUPRION/ Ammonia Leach	High Temp. Sulfuric Acid Leach	Smelting Lime Boil + Neutral-ization
Nature	slurry	slurry	slurry	slurry
Percent Solids[a]	14	14	52	60
Grain Size (um)	N.D.	N.D.	<53[b]	N.D.
Solids Discharge[a] (mty)	2.1×10^4	2.1×10^4	6.2×10^5	7.2×10^4
Liquids Discharge[a] (mty)	1.3×10^5	1.3×10^5	5.7×10^5	5.9×10^4
(mgy)	34	34	150	16

[a] Calculated from Dames & Moore 1977, Vol. III.

[b] Estimated.

N.D. - No data.

Chemical Characteristics

	Waste Concentration (ppm) (Percent of Original Nodule Input)			
Element	Reduction/ Ammonia Leach	CUPRION/ Ammonia Leach	High Temp. Sulfuric Acid Leach	Smelting (Neutrali-zation precipitate)
Ba	-	-	-	-
La	11,000 (1)	12,265 (5)	-	-
V	1,400 (2)	2,670 (5)	7.3 (0.4)	82 (0.7)
Cr	60 (4)	126 (8)	-	-
Ag	-	-	-	-
Cd	200 (7)	222 (7)	-	-
As	-	-	-	904 (7)
Sb	-	-	45.8 (20)	315 (4)
Tl	17,000 (60)	16,832 (60)	5.2 (0.6)	504 (1)
Pb	22 (0.03)	45 (0.06)	-	-

1977, Vol. III.

TABLE 15. PHYSICAL AND CHEMICAL CHARACTERISTICS OF ELECTROWINNING SOLIDS

Physical Characteristics

	Reduction/ Ammonia Leach	CUPRION/ Ammoniacal Leach	High Temp. Sulfuric Acid Leach	Smelting
Nature	sludge	sludge	sludge	sludge
Grain size	N.D.	N.D.	N.D.	N.D.
Discharge[a] (mty)	8.0×10^2	8.0×10^2	8.4×10^2	1.2×10^2

[a] Calculated from Dames & Moore 1977, Vol. III.

N.D. = No data.

Chemical Characteristics

	Waste Concentration (ppm) (Percent of Original Nodule Input)			
Element	Reduction/ Ammonia Leach	CUPRION/ Ammoniacal Leach	High Temp. Sulfuric Acid Leach	Smelting
Ba	-	-	-	-
La	-	-	-	-
V	1,230 (0.02)	791 (0.05)	9,880 (0.6)	23 -
Cr	20 (0.05)	20 (0.05)	26.6 (0.07)	-
Ag	283 (2)	262 (2)	-	-
Cd	1,613 (2)	1,742 (2)	3,496 (5)	162 (0.1)
As	920 (0.5)	1,100 (0.5)	1,728 (1)	325 (0.08)
Sb	108 (0.1)	120 (0.1)	754 (0.7)	157 (0.06)
Tl	6,467 (0.8)	6,966 (0.8)	4,028 (0.5)	760 (0.05)
Pb	18,600	19,600	-	-

Source: Dames & Moore 1977, Vol. III.

TABLE 16. PHYSICAL CHARACTERISTICS OF GASIFICATION ASH, COMBUSTION ASH, AND OFF-GAS SCRUBBER SOLIDS

	Nature	Percent Solids	Grain Size[a] (um)	Solids Discharge[b] (mty)	Liquids Discharge[b] (mty)	(mgy)
Reduction/ Ammonia Leach						
Gasification	slurry	20	N.D.	4.7×10^4	1.9×10^5	50
Combustion	solid	100	$\bar{x} \sim 5$	1.3×10^4	-	
Scrubber	slurry	20	$\bar{x} \sim 5$	2.4×10^4	9.5×10^4	25
CUPRION/ Ammoniacal Leach						
Gasification	slurry	5	N.D.	4.0×10^4	7.6×10^5	200
Combustion	solid	100	$\bar{x} \sim 5$	3.3×10^4	-	
Scrubber	slurry	20	$\bar{x} \sim 5$	2.4×10^4	9.5×10^4	25
High Temperature Sulfuric Acid Leach						
Gasification	slurry	N.A.	N.A.	N.A.	N.A.	
Combustion	solid	100	$\bar{x} \sim 5$	3.3×10^4	-	
Scrubber	slurry	20	$\bar{x} \sim 5$	1.2×10^4	5.0×10^4	13
Smelting						
Gasification	slurry	10	N.D.	1.4×10^3	1.3×10^5	3.4×10^7
Combustion	solid	100	$\bar{x} \sim 5$	4.7×10^3	-	
Scrubber	slurry	20	$\bar{x} \sim 5$	9.5×10^3	3.8×10^4	1.0×10^7

[a] From Davison et al. 1974.

[b] Calculated from Dames & Moore 1977, Vol. III and assumes 3.7×10^6 mty nodules processed by hydrometallurgical methods and 1.25×10^6 mty by smelting.

N.D. = no data.

N.A. = not applicable.

$\bar{x}$ = mean grain size.

TABLE 17. CHEMICAL CHARACTERISTICS OF COMBUSTION ASH (FLY ASH)[a]

Al%	12.7
As	58
Cd	1.85
Co	41.5
Cr	127
Cu	133
Fe%	6.2
Hg	0.127
La	82
Mg%	1.8
Mn	496
Ni	98
Pb	75
Se	10.2
Sr	1,700
Ti	7,400
U	235
Zn	216

[a] Values in mg/kg unless otherwise noted.

Source: Klein et al. (1975) and Ondov et al. (1975).

metals such as molybdenum. The outputs derived here assume no recycling of waste products and fixed nodule input rates.

UPDATE OF NOAA'S 1977 EVALUATION

Hubred (1980) provides an updated review and comprehensive bibliography of the literature and patents which exist on manganese nodule processing and extractive metallurgy. The bulk of this literature addresses the processing scenarios favored by the four major ocean mining consortia; however, very little of this material deals directly with process wastes.

As part of the Deep Seabed Hard Mineral Resources Act (PL 96-283), enacted on June 28, 1980, NOAA was required to prepare a marine environmental research plan for deep seabed mining. The resulting 5-year program assigned waste disposal research a high priority. As part of this program, the Bureau of Mines Avondale Research Center, with support from the Spokane Research Center, has initiated a NOAA sponsored project entitled "Analysis and Characterization of Potential Manganese Nodule Processing Rejects." Although the mining industry has conducted tests of various processing options, rejects from these tests cannot be considered representative because they have been small-scale batch runs with frequent system adjustments. Large-scale runs which would simulate commercial operations have not yet been conducted and therefore characteristic process reject material is not presently available. The first phase of the Bureau of Mines project is to predict the characteristics of wastes from each of the five processing options considered most likely in early commercial operations.

The initial phase of the Bureau of Mines study included several analyses of a sample of steam-stripped rejects from a CUPRION process pilot plant run made by Kennecott Copper Corporation in 1973. These rejects indicate the general physical and chemical behavior of the material but are not considered to be representative of the commercial process. The primary reasons for non-representation given by Kennecott were:

- The rejects were produced from a pilot plant operation that was purposely varied throughout the course of the campaign so that the rejects were not produced under optimum conditions.
- Leaching of nickel, copper, and cobalt from the ore was below that which will be achieved commercially, so that residual concentrations of these metals in the rejects may be higher than will be obtained.
- The rejects were batch steam-stripped, while commercially this will be done in a continuous manner using lime addition. Lime treatment was not used during the batch operations.
- Batch steam-stripping was not optimum nor complete so that residual ammonia concentration in solution is well above that rejected commercially.

- The rejects have been aging since 1973 which may have caused changes in the nature of the rejects.

- Kennecott plans to recover molybdenum from the liquor associated with the rejects and this procedure was not carried out on the reject sample sent.

Tests conducted on this material by the Bureau of Mines included elemental analysis, evaluation of engineering properties, and an EPA Extraction Procedure (EP) Toxicity Test. Table 18 is an analysis of the reject material. Engineering property tests conducted by Bureau of Mines' Spokane Research Center are presented in Table 19. The chemical and physical characteristics of CUPRION reject material is in general agreement with those predicted in Tables 12 and 13. To assess element availability, an EPA leachate experiment based upon the EP Toxicity Test outlined in the May 19, 1980, Federal Register was performed on the CUPRION reject material. The results (Table 20) indicate that the leached amounts were well below the permissible limits for silver, arsenic, barium, cadmium, chromium, mercury, lead, and selenium. Other potentially important metals, especially copper, were not analyzed because criteria for other metals, including copper, are not specified in this test.

Additional work during phase one of Bureau of Mines' research project study of processing rejects has resulted in the preparation of three draft reports. These reports describe the mineralogical and elemental characteristics of Pacific manganese nodules (Haynes, Law, and Barron 1981), review the most feasible process flowsheets for first generation process plants (Haynes and Law 1981a), and predict the physical and chemical characteristics of nodule processing reject waste material (Haynes and Law 1981b). The latter two reports were primarily based upon the 1977 study contracted by NOAA (Dames and Moore 1977b), but unlike previous work, they attempt to predict the probable forms of elements present in processing wastes. This information is necessary for assessing the potential toxicity of reject material.

WASTE RE-UTILIZATION CONSIDERATIONS

An assessment of wastes associated with manganese nodule processing cannot be complete without a discussion of the potential for reduction of these wastes. Modern recycling and co-generation practices can be included in the processing design, enhancing recovery efficiency, reducing pollution hazards, and generating useful byproducts.

Japan's smelting industry best indicates the range of waste utilization alternatives (Dresher and Rodolff 1981). In newer plants, secondary copper extraction from slag and flue dust augments copper recovery to better than 95 percent. Slag is sold for cement manufacture. Up to 97 percent of the sulfur released, collected as sulfur dioxide gas, is converted to sulfuric acid in plants adjacent to the processor. For example, Mitsubishi's Naoshima smelter produced 3.5 to 7 tons of sulfuric acid per ton of copper recovered, while sulfur emissions were kept below one-half the regulation

TABLE 18. ANALYSIS OF REJECT MATERIAL FROM A PILOT PLANT TEST OF THE CUPRION PROCESS[a]

Element	Solid		Liquid
	Percent	ppm	ppm
Ag		70.0	<0.05
Al	2.37		<0.5
As		54.8	0.025
B		410.0	6.06
Ba		50.0	0.27
Be		10.0	<0.01
Ca	1.60		2.96
Cd		49.0	<0.05
Co	0.180		0.10
Cr		140.0	<0.1
Cu	0.119		<0.05
Fe	6.35		<0.05
Hg		0.018	<0.0003
Mg	2.03		4.82
Mn	32.19		<0.02
Mo		190.0	62.9
Ni	0.28		<0.2
Pb		413.0	<0.01
Sb		38.2	<0.018
Se		1.2	<0.031
Si	0.16		22.4
Sr	0.398		0.34
Tl		158.0	0.11
V	0.067		0.06
Zn	0.11		<0.04

[a] These rejects are not representative of the commercial process but do give an indication of the general physical and chemical behavior of the material.

Data supplied by U.S. Bureau of Mines, Avondale, MD.

TABLE 19. ENGINEERING PROPERTIES OF REJECT MATERIAL FROM A PILOT PLANT TEST OF THE CUPRION PROCESS[a]

Slurry density	- 1.9, 41.8 percent solids by weight (56.5 ft^3/ton)
Specific gravity, dry solids	- 3.19
Grain size	- 100 percent passing 74 um (200 mesh) 50 percent passing 6 um 0 percent passing 1 um
Atterberg limits	- 45 percent liquid 41.2 percent plastic 3.8 plasticity index ML (lean silt) soil classification
Permeability	- 8.46 x 10^{-6} cm/sec at 95 percent maximum density
Maximum density	- 90.1 lb/ft^3
Water content at maximum density	- 32 percent
Triaxial shear strength	- 38 degrees friction angle 5 psi cohesion
Settled density, column test,	
30 days without bottom drain	- 42.8 ft^3/ton (24 percent reduction)
with bottom drain	- 37 ft^3/ton (35 percent reduction)

[a] These rejects are not representative of the commercial process but do give an indication of the general physical and chemical behavior of the material.

Reference: McKibbin (1981).

TABLE 20. RESULTS OF AN EP TOXICITY TEST PERFORMED ON REJECTS FROM A PILOT TEST OF THE CUPRION[a] PROCESS BY THE BUREAU OF MINES AVONDALE RESEARCH CENTER

Element	Leached, ppm	Maximum Limit, ppm
Ag	0.3	5.0
As	0.004	5.0
Ba	4.4	100
Cd	0.06	1.0
Cr	0.14	5.0
Hg	0.019	0.20
Pb	0.6	5.0
Se	0.002	1.0

[a] These rejects are not representative of the commercial process but do give an indication of the general physical and chemical behavior of the material.

Data supplied by U.S. Bureau of Mines, Avondale, MD.

allowance. Gypsum is a product of stack lime scrubbing which is used in agriculture and in construction as wallboard. Use of smelter byproduct gypsum allowed Japan to cease gypsum mining entirely in 1978.

In the United States, waste re-utilization prospects are being investigated. The feasibility of ocean disposal of fly ash and scrubber sludge from coal-fired power plants as artificial reef blocks has been studied (Woodhead et al., 1979). The blocks were found to be stable in an ocean environment, with no toxic effects on the biological communities which they supported. In Hawaii, the utilization of manganese nodule processing wastes as a volcanic soil conditioner is being investigated (Jenkins et al., 1980). Slag could be used as road-bed material and in other construction applications. It is also suggested that the scavenging nature of manganese nodules may make the rejects suitable for stabilizing radioactive wastes.

The specific process utilized in manganese nodule extraction determines the chemical and physical nature of the waste products and limits which waste re-utilization procedures can be applied. Inclusion of such practices may ultimately impact the final assessment of the acceptability of nodule processing wastes for ocean disposal.

SUMMARY OF PROCESS TECHNOLOGIES

Four of the proposed manganese nodule processing systems have been considered to be the most likely for first generation processing plants. These four: reduction-ammonia leach, CUPRION-ammoniacal leach, high temperature reduction-sulfuric acid leach, and smelting-sulfuric acid leach have been tested in small-scale pilot tests by the major ocean mining consortia. Data on large-scale system performance have been largely theoretical. Based upon information provided in the Dames and Moore, EIC study (Dames and Moore 1977b), waste streams have been identified and characterized for each of the four processes (Tables 12 through 17). From these data there appear to be only minor differences in the wastes from the reduction-ammonia leach and CUPRION-ammoniacal leach processes. Wastes and reject materials from these systems are summarized below and in Tables 21 through 23.

CUPRION- and Reduction-Ammonia Leach Processes

Rejects--

A fine-grained slurry with a bulk density of 1.8 to 2.0 gm/cc, 45 to 50 percent solids, pH 6.5 to 8.0 with reduced manganese (MnII) present as $MnCO_3$ solid. Trace element content is high, but most are in insoluble forms or appear to be tightly bound and not readily leached. Rejects account for approximately 95 percent of the solid waste generated by these processes.

Lime Boil Solids--

A fine-grained slurry consisting primarily of gypsum (calcium sulfate) with a high liquid fraction (86 percent). These wastes may contain considerable amounts of lanthanum, vanadium, chromium, cadmium, and thallium.

TABLE 21. CHARACTERISTICS OF CUPRION- AND REDUCTION-AMMONIA WASTE STREAMS

	Form	Bulk Density (g/cc)	Percent Solids	Percent of Total Solid Waste	Metals Present	Availability of Toxicants	Comments
Leached Tails	Slurry	1.8-2.0	45-50	∿95	All incoming	Relatively Unavailable	
Lime Boil Solids	Slurry	ND	∿14	∿1.0	La, V, Tl, Cr, Cd	Unknown	
Electrowinning Sludge	Sludge	ND	ND	<<0.5	Pb, Cd, Tl, As	Unknown	
Combustion Rejects	Slurry	∿1.3[a]	20[a]	∿2.0	All incoming plus others	Relatively Unavailable	Bulk density and percent solids do not include discharge of combustion ash generated as a solid.

[a] For gas scrubber and gasification rejects only.

TABLE 22. CHARACTERISTICS OF HIGH TEMPERATURE SULFURIC ACID WASTE STREAMS

	Form	Bulk Density (g/cc)	Percent Solids	Percent of Total Solid Waste	Metals Present	Availability of Toxicants	Comments
Leached Tails	Slurry	∿1.8	∿50	∿85	All incoming	Relatively Unavailable	
Lime Boil	Slurry	ND	∿52	∿15		Unknown	
Electrowinning Sludge	Sludge	ND	ND	<<0.5	Pb, V, Cd, Tl, As	Unknown	
Combustion Rejects	Slurry	∿1.3[a]	20[a]	∿1.0	All incoming plus others	Relatively Unavailable	Bulk density and percent solids do not include combustion ash generated as a solid.

[a] For gas scrubber and gasification rejects only.

TABLE 23. CHARACTERISTICS OF SMELTING WASTE STREAMS

	Form	Bulk Density (g/cc)	Percent Solids	Percent of Total Solid Waste	Metals Present	Availability of Toxicants	Comments
Leached Matte Tailings	Slurry	1.8-2.0	∿43	1-2	Ag, As, Sb, Tl, Pb	Unknown	
Granulated Slag	Slurry	ND	∿79	∿85	Most incoming	Unavailable	
Lime Boil Solids	Slurry	ND	60	∿10	As, Sb, Tl	Unknown	
Electrowinning Sludge	Sludge	ND	ND	<<0.5	Pb, Cd, As, Sb, Tl	Unknown	
Combustion Rejects	Slurry	∿1.3[a]	10-20[a]	∿4.0	All incoming plus others	Unavailable	Bulk density and percent solids do not include combustion ash generated as a solid.

[a] For gas scrubber and gasification rejects only.

Combustion Ash and Gas Scrubber Solids--

Principally spent carbon and dusts from nodule reduction (slurry) and combustion ash from steam generation (solid), these wastes are typical of many other industrial processes.

Electrowinning Solids--

This sludge from the electrowinning extraction circuit is small in total amount, but may contain elevated concentrations of lead and cadmium from spent anodes.

High Temperature Sulfuric Acid Leach

The slurry will consist of sulphate salts and oxides of aluminum, silicon, iron, and manganese. This reject material will be neutralized to pH 6.0 to 6.5 prior to disposal. The volume of rejects and lime boil solids together are slightly greater than the volume of nodules input.

Rejects--

A slurry with fine-grained solids similar to CUPRION and reduction ammonia rejects. This reject material will be neutralized to pH 6.0 to 6.5 prior to disposal. Trace element content is high but solubility is probably very low. Considerable reduced manganese may be present in the liquid fraction.

Lime Boil Solids--

Due to the reagent requirements for pH adjustment of acidic spent liquors, this waste stream discharges more material than the other process options (15 percent of the total solids); however, it remains similar in physical and chemical characteristics.

Electrowinning Solids--

Similar to the other processes, this sludge represents a small percentage of total wastes discharged, but may contain high levels of several heavy metals.

Combustion Ash and Gas Scrubber Solids--

Characteristics of this waste are similar to those for the ammonia processes.

Smelting-Sulfuric Acid Leach

Smelting-sulfuric acid leach differs from the other process options in that it includes a pyrometallurgical step with separation of the ore into slag and matte.

Rejects--

Two distinct rejects must be considered here, smelting matte and slag. Both are rejected as a slurry, but the matte is fine-grained material similar in nature to the high temperature sulfuric acid tailings. The slag accounts for the bulk of the rejected material and consists of a coarse, granulated slurry. The majority of the trace constituents considered potentially toxic are in the slag fraction where they are expected to be bound in the inert, vitreous solids phase.

Lime Boil Solids--

Much of this slurry is from the acid neutralization step following sulfuric acid leaching and metal extraction. This material is similar to that of the high temperature sulfuric acid wastes, but since only the smelting matte is leached, discharge amounts are lower.

Electrowinning Solids--

Similar to the sludges from the other processes but of lower volume and trace element content (the majority of the trace elements are in the slag).

Combustion Ash and Gas Scrubber Solids--

Similar to other processes but less volume as much of the spent carbon from the reduction-smelting step is incorporated into the slag.

Preliminary data indicate that rejects from the three hydrometallurgical processes considered and slags from smelting are fairly resistant to leaching of potentially toxic metals. As discussed in Chapter 7, metals in ionic form are generally of greatest environmental concern. It is clear that the majority of trace metals associated with slags and rejects will be chemically bound in solid mineral phases and not as dissolved ionic species. Concentrations of metals in the dissolved state as shown in Tables 18 and 20 are relatively low and most dissolved metals may be complexed and therefore not in an ionic form. The detailed nature of trace element partitioning in rejects can only be determined from further tests of representative wastes. The other nodule processing waste streams such as the lime boil solids, degraded ion exchange liquids, and electrowinning sludges will also require more characterization based on pilot plant operations before further conclusions can be drawn.

COMPARISON TO OTHER WASTES

Knowledge of the chemical characteristics of manganese nodule processing waste, as explained above, is indirect. The predicted chemical composition of the waste is based upon inferences drawn from knowledge of the probable processing methods. The one available analyses of the CUPRION process waste produced from pilot plant tests cannot be assumed as representative of waste from full-scale plants.

In view of the lack of detailed information on the chemical composition of nodule processing waste, comparison to other wastes can be important. The characteristics of mining wastes, dredged material, and drilling muds and cuttings are described in this section. The important characteristics of these materials are the chemical composition of the solid phase of the waste and, of particular importance, the concentration of dissolved pollutants associated with the discharge or that can be leached from the solids after discharge.

Heavy metals are the pollutants of concern. Manganese nodule processing wastes are expected to be essentially free of organic compounds. Because of this lack of organic material, mining waste is most directly comparable to manganese nodule processing rejects. Silt- and clay-sized dredged material is similar to nodule processing wastes with regard to metals concentrations and chemical behavior. However, they can also contain up to 10 percent or more organic material which can serve as a food source to organisms in the marine environment. This is also true of drilling muds and cuttings. For this reason the primary emphasis is placed upon the characteristics of mining wastes. Discussion of the observed biological impacts of mining waste, dredged material, and drilling muds and cuttings is presented in Chapter 7.

A direct comparison is made in Tables 24 and 25 of the chemical characteristics of the wastes based upon data presented in Appendix C. It should be noted that the concentration ranges presented for mining waste, dredged material, and drilling muds and cuttings are based upon many measurements of actual wastes. The values for manganese nodule processing waste are based upon a single analysis of effluent from a CUPRION process pilot plant. Metal recovery of the plant was not at levels as high as expected from a full scale, operational plant. Accordingly, the concentrations of copper, molybdenum, and nickel in the solid phase of the rejects as shown in Table 24 are considered to be higher than would be expected from a full-scale plant. Improved value metal recovery may also reduce the concentration of other associated metals in the rejects. Also, the manganese concentration in rejects from a four-metal process would be substantially lower.

Table 25 presents a comparison of the chemical composition of the dissolved components in the four waste materials. Before discussing the values presented, the reader should carefully note the meaning of the symbol "<" which indicates "less than". The value of < 50 ug/l means, for example, that the analytical method employed could not detect concentrations below 50 ug/l. The true concentration could be 49 or 0 ug/l. It is known only that the concentration is not greater than 50 ug/l.

The dissolved phase chemical analysis was performed on the same CUPRION process sample from which the solid phase was done. As such, the results are similarly unrepresentative. This is particularly evident in the molybdenum concentration (63,000 ug/l). It is anticipated that molybdenum will be recovered in a full-scale plant.

TABLE 24. SUMMARY COMPARISON OF SOLID PHASE CHEMICAL COMPOSITION, mg/kg

	Manganese Nodule Processing Waste[a]	Mining Waste	Dredged Material	Drilling Muds and Cuttings
As	55	2.2 to 6	0.03 to 23	<1.0 to 3
Cd	49	0.14 to 0.3	0.02 to 7	<1.0 to <2.0
Cr	140	4.9 to 13.9	0.25 to 190	2 to 1,007
Cu	1,119	170 to 370	0.23 to 449	2 to 28
Fe	63,500	15,800 to 17,000	100 to 95,000	N.D.
Hg	0.018	<0.00005 to 0.005	0.01 to 2.7	<1 to 2.2
Mn	321,900	78 to 325	188 to 570	N.D.
Mo	190	5.4 to 15.8	N.D.	N.D.
Ni	2,800	9.3	1.2 to 82	1 to 21
Pb	413	3.9 to 6.7	0.25 to 600	<1 to 24
Zn	1,100	26.9 to 49.9	0.25 to 1,246	12 to 236

N.D. = no data.

[a] Results are from one analysis of wastes from a CUPRION process pilot plant and are considered not to be representative of waste from a full-scale plant. Some values are expected to be lower for full-scale plants.

< = less than. The value of <50 mg/kg means, for example, that the analytical method employed could not detect concentrations below 50 mg/kg. It is known only that the concentrations is not greater than 50 mg/kg.

TABLE 25. SUMMARY COMPARISON OF DISSOLVED PHASE CHEMICAL COMPOSITION, ug/l

	Manganese Nodule Processing Waste[a]	Mining Waste	Dredged Material	Drilling Muds and Cuttings
As	25	14 to 88	1 to 24	N.D.
Cd	<50	<0.1 to <0.5	0.2 to 2.9	60 to 80
Cr	<100	0.6 to <5	0.5 to 30	<100 to 1,080
Cu	<50	3 to 280	1 to 8	N.D.
Fe	<50	8 to 1,200	2.5 to 33	N.D.
Hg	<0.3	<0.1 to 0.24	0.01 to 1.8	N.D.
Mn	<20	1 to 4	30 to 2,300	N.D.
Mo	63,000	100 to 300	N.D.	N.D.
Ni	<200	<1 to <10	2 to 21	N.D.
Pb	<10	<1 to 5	0.9 to 12.5	<500
Zn	<40	0.8 to 170	10 to 70	60 to 230

N.D. = no data.

[a] Results are from one analysis of wastes from a CUPRION process pilot plant and are considered not to be representative of waste from a full-scale plant.

< = less than. The value of <50 ug/l means, for example, that the analytical method employed could not detect concentrations below 50 ug/l. It is known only that the concentrations is not greater than 50 ug/l.

The comparison of dissolved metals concentrations shown in Table 25 indicates, with the exception of molybdenum and nickel, that all metals concentrations are within the range observed for other wastes discharged to the marine environment.

Table 26 presents a comparison of the dissolved metals concentration in the nodule processing waste to EPA water quality criteria. Note that there are two types of receiving water criteria; 24-h average criteria, also known as the chronic value, and the maximum at any time criteria, also referred to as the acute value. The 24-h average or chronic value is designed to apply to continuous discharges such as outfalls. The composition of the effluent can vary during the day and produce receiving water concentrations which at times exceed the criteria value. The average value of several samples taken over the 24-h period must not exceed the criteria, however.

The maximum at any time, or acute, criteria also apply to continuous discharges but are based upon short-term bioassays. Marine organisms are expected to survive short term exposures to concentrations near the upper limits of the criteria values. The acute criteria are, therefore, higher than the chronic criteria. The acute criteria are, therefore, most applicable to ocean dumping which is a periodic and not a continuous process.

A second important point to consider is that the water quality criteria apply to ocean dumping or ocean discharges after initial dilution. In the case of ocean dumping, this is the concentration in the wastefield 4 hours after discharge. Under the 403(c) regulations which regulate continuous discharges from outfalls, initial dilution is the amount of dilution which can be achieved within a mixing zone. The mixing zone is defined as, "the zone extending from the sea's surface to the seabed and extending 100 meters in all directions from the discharge points(s) or to the boundary of the zone of initial dilution as calculated by a plume model...". The later part of the definition has little relevance to negatively buoyant jet discharges because no model presently exists which can be readily applied to describe their behavior.

The required initial dilutions presented in Table 26 are computed by simply dividing the metal concentration by the criteria value. Results less than zero are shown as zero or, in other words, no initial dilution would be necessary in order to meet water quality criteria.

Table 26 lists metals for which water quality criteria have been established. As shown earlier, other potentially toxic metals, for which no criteria has been established, are also expected to be present in manganese nodule processing waste. These metals must be evaluated further. For the metals listed in Table 26, the dilution needed to meet current water quality criteria is small. Also recall that the listed metals concentrations are probably conservatively high. Initial dilutions achieved during ocean dumping are expected to be at least an order of magnitude greater than the 2:1 dilution listed in Table 26. Dilutions achieved through outfall discharge of nodule processing rejects may be less than 28:1 depending upon the definition of the mixing zone used.

TABLE 26. COMPARISON OF DISSOLVED METALS CONCENTRATIONS TO WATER QUALITY CRITERIA FOR MARINE WATERS

	Nodule Processing Waste Dissolved Metals Concentrations[a] ug/l	EPA Water Quality Criteria, 24-h Avg. ug/l	Dilution Required for Outfall[b]	EPA Water Quality Criteria, Maximum ug/l	Dilution Required for Dumping[b]
As	25	no criterion	no criterion	508	0
Cd	<50	4.5	11:1	59	0
Cr	<100	18	6:1	1,260	0
Cu	<50	4	13:1	23	2:1
Hg	<0.3	0.025	12:1	3.7	0
Ni	<200	7.1	28:1	140	2:1
Pb	<10	25	0	668	0
Zn	<40	58	0	170	0

[a] Results are from one analysis of wastes from a CUPRION process pilot plant and are considered not to be representative of waste from a full-scale plant.

[b] Assumes concentration in waste equal to "<" value; e.g., <50 = 50.

Criteria values from Federal Register, November 28, 1980.

In summary, the ocean disposal of manganese nodule processing waste is expected to meet present water quality criteria after initial dilution. More information on the composition of the waste from a full-scale plant is needed to be conclusive. It should be remembered however that substantial changes could be made in the water quality criteria by the time the first discharge dumping application is submitted; late 1980s. The 28:1 dilution needed to meet chronic criteria may be harder to meet for an outfall. The 403(c) mixing zone definition is impractical to apply to negatively buoyant jets. Less is also known about the behavior of such jets and the nature of dilution.

6. REPRESENTATIVE DISPOSAL AREA CHARACTERISTICS

The purpose of this section is to provide a summary description of the physical and biological characteristics of general areas where disposal of manganese nodule processing waste may possibly occur in the future. This is a necessary step so that the potential impacts of ocean disposal can be discussed with reference to known marine resources. A more detailed description of representative area characteristics is presented in Appendix D.

No specific locations have been proposed publicly for nodule processing plants or for waste disposal sites. Nor is this section intended for purposes of site selection. Four regions have been chosen for general discussion on the basis that land-based processing plants could be located within the region due to their proximity to the Pacific Ocean nodule mining area. These regions are classified as

- Western Gulf of Mexico
- Southern California Bight
- Pacific Northwest
- Hawaii.

Within each region more specific areas have been described to illustrate how characteristics vary with depth and distance offshore. In general, nearshore, midshelf, and deepwater (seaward of the shelf) areas are described. A summary of important physiographic and bathymetric features and circulation patterns is provided for each region. Similarly, a brief description of the significant physical oceanographic characteristics (e.g., temperature, salinity, density, dissolved oxygen, and currents) is provided for the specific areas within each region. In addition, biological oceanographic characteristics of each region are summarized for each specific area.

This information represents a synthesis of available literature and is not intended to be a detailed analysis as would be needed for site selection. However, this information is sufficient to form the basis for the preliminary estimates of the fate of discharged wastes. These estimates, which are also presented in this chapter, are based upon the predictive relationships developed in Chapter 3.

WESTERN GULF OF MEXICO

Physical Characteristics

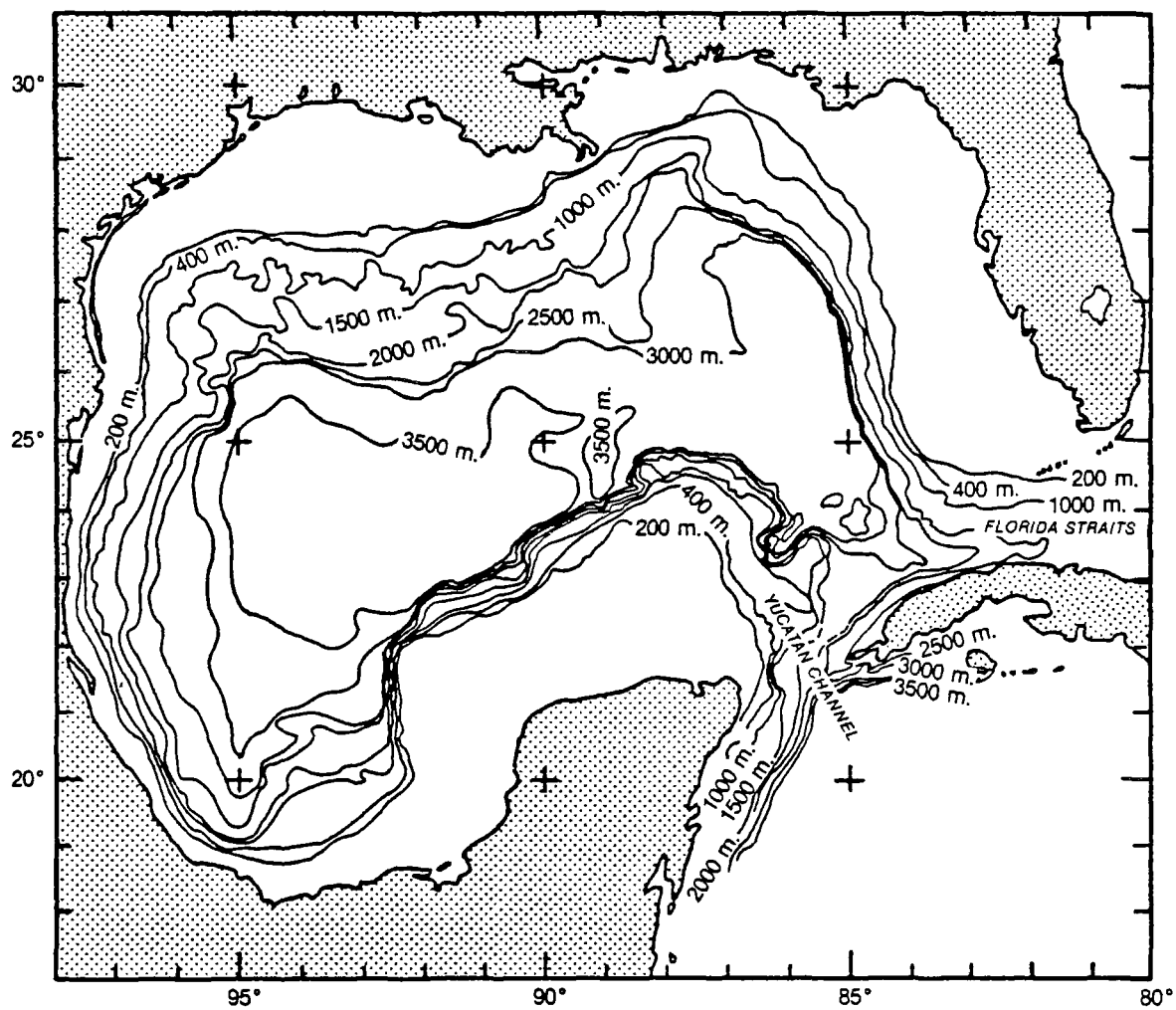
The Gulf of Mexico is a relatively shallow (3,600 m maximum depth) semi-enclosed water body connected to the Atlantic Ocean by the Florida Straits and the Caribbean Sea by the Yucatan Channel (Figure 18). A simplified view of the basin's configuration is obtained by grouping similar bathymetric features and characteristics into distinct physiographic subdivisions as shown in Figure 19. The basin is asymmetrical with its greatest depths occurring west of 90^{o} W longitude, while the two primary channels for water exchange are situated 3 to 6^{o} to the east and trend in a general northwest-southeast orientation. This bathymetric configuration is a primary influence on the Gulf's circulation and oceanographic characteristics.

The large scale circulation pattern in the Gulf of Mexico is dominated by two current systems; the strong, well-defined clockwise Loop Current in the east, and an elongated, less permanent clockwise circulation cell located over the deeper areas of the central and western Gulf. The Loop Current enters the eastern Gulf through the Yucatan Straits, exiting through the Straits of Florida (Leipper 1970; Maul 1977). The Loop Current exhibits a definite growth and decay cycle which begins with the Loop Current increasing its penetration into the Gulf to a stage where a large eddy separates from the loop, and drifts and spreads into the western Gulf (Behringer et al., 1977; Elliot 1979). However, significant seasonal and yearly variation has been noted in this pattern (Molinari 1978, 1980; Maul 1977).

Characteristics of Representative Areas

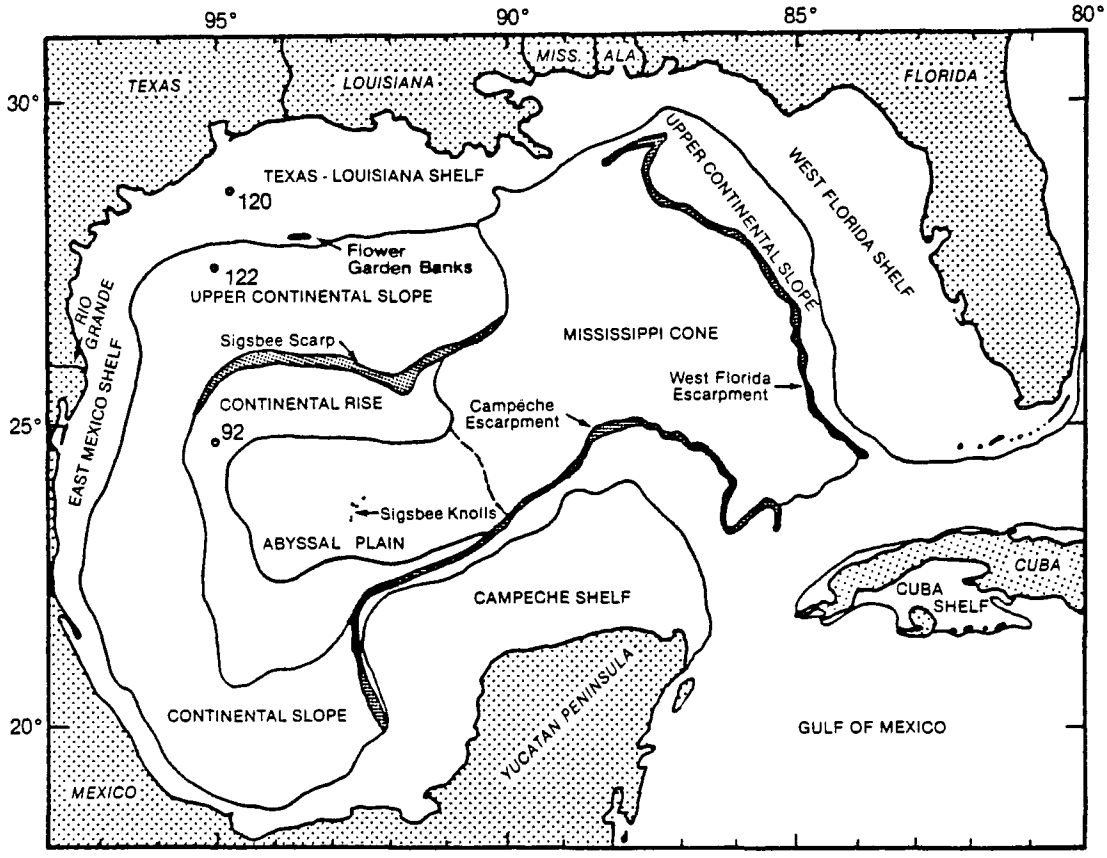
Two general locations are considered as representative of potential nodule processing waste disposal sites; a midshelf site and a deepwater site. In addition, conditions at an upper-slope site are also described because of the site's historical use for chemical waste disposal (Atlas et al., 1980). Shallow nearshore waters and a gentle bottom slope effectively preclude disposal of nodule processing wastes through a nearshore outfall pipe.

Oceanographic data from Texas A & M western Gulf synoptic oceanographic surveys in February and March, 1962, serve to define selected parameters in each area. Stations 120, 122, and 92 shown in Figure 19 are considered representative of mid-shelf, upper-slope, and deep basin areas, respectively. In synthesizing the physical oceanographic nature of each area, many technical documents were reviewed in addition to the Texas A & M transect data. Nevertheless, the data set available for compiling general area characteristics was found to be limited (e.g., seasonally or for a particular parameter).



REFERENCE: Nowlin 1972

Figure 18. Bathymetry of Gulf of Mexico.



REFERENCE: after Ewing et al., 1958.

Figure 19. Physiographic subdivisions of the Gulf of Mexico and selected stations of Hidalgo 62-H-3 cruise of March 22-27, 1962.

Mid-Shelf--

Nearshore surface salinities of the mid-shelf region are typically low due to intrusion of freshwater from continental drainage (Nowlin 1972). Salinity increases with depth and with distance offshore. Due to significant mixing, temperatures are relatively uniform with depth. This temperature-salinity combination results in a typical March density gradient of 1.0 sigma-t units in the upper 30 m (98 ft). Dissolved oxygen levels are relatively uniform with depth, decreasing from 6.5 to 5.8 ml/l.

Current measurements on the shelf indicate that the currents are typically aligned alongshore, are highly seasonal, and exhibit layering of contrasting flow in late spring and during summer (Armstrong 1980). Mean surface currents are downcoast to the southwest throughout the year, with an onshore component in summer. Mid-depth to bottom flows are directed upcoast and offshore (east and southeast, respectively) from May to August, and downcoast the remainder of the year. Deeper eastward currents do occur during some winter periods. Mean current speeds decrease with depth, being approximately 15 cm/sec near the surface and decreasing to 10 cm/sec near the bottom. Seasonally, speeds are lowest in summer and highest in the fall and spring. Flow variability is principally due to wind shifts and tidal currents.

Upper-Slope--

Further offshore, the salinity is relatively constant at 35.9 ppt in the upper 50 m (164 ft), increasing somewhat between 100 and 200 m (328 and 656 ft) to 36.1 ppt, and thereafter decreasing gradually with depth to approximately 35 ppt. In March, temperature measurements indicate a gradual reduction in temperature from approximately 20^{o} C near the surface to 4^{o} C at 1,000 m (3,280 ft). The resultant density profile consists of a small positive density gradient to 50 m (164 ft) depth, a sharp density increase between 50 and 120 m (164 to 492 ft), tapering off to a relatively small increase with depth thereafter. Dissolved oxygen concentrations decrease from surface values of 6.5 to 7.0 mg/l to a minimum of approximately 3.5 mg/l at between 250 and 400 m (820 and 1,312 ft), and increase to 5.0 mg/l at 1,000 m (3,281 ft). Geostrophic flow is predicted to generally be eastward, varying from 25 cm/sec near the surface to less than 5 cm/sec below 350 m (1,148 ft). At the industrial-chemical waste disposal site A (water depths of 900-1,400 m), absolute near-surface currents on the order of 26 cm/sec or less have been measured (Mungall and Horne 1978).

Deep Basin--

Beyond the slope, over the abyssal plain, salinities commence at 36.1 ppt at the surface, increase slightly to a maximum of 36.35 ppt at 125 m (410 ft) and decrease sharply thereafter, reaching a minimum of 34.89 ppt at 580 m (1,902 ft). Below greater depths, salinity approaches 34.97 ppt. Temperature decreases rather slowly from 22.3^{o} C at the surface to 20.5^{o} C at 125 m (410 ft). At this depth however, a pronounced gradient occurs, with temperature decreasing 15^{o} C in the next 800 m (2,624 ft). Beyond this depth the temperature remains relatively constant at 4.2^{o} C. The associated

density profile indicates a uniform surface density of 25 sigma-t units in the upper mixed layer [in this case down to 25 m (82 ft)]. A relatively sharp pycnocline occurs beyond this point, with sigma-t values increasing another 2.75 units by the 1,000 m (3,281 ft) depth. Thereafter, the density remains relatively constant at 27.75 sigma-t units.

Dissolved oxygen concentrations of 6.1-6.9 mg/l in the upper 100 m (328 ft) decrease sharply to a characteristic minimum of 3.83 mg/l at approximately 250 m (820 ft). Beyond this depth, dissolved oxygen concentrations increase, at first relatively slowly to 4.9 mg/l at 775 m (2,542 ft), then quickly to 5.91 at 70 m (3,182 ft), and thereafter again slowly to a maximum value of 4.83 mg/l at 2,920 m (9,579 ft).

Calculated geostrophic flows for a deep-basin area indicate westward surface currents of up to 35 cm/sec, decreasing to no current at approximately 350 m (1,148 ft). Beyond this depth, very low flows are indicated, eastward at up to 1.2 cm/sec down to 550 m (1,804 ft). and thereafter again westward at greater depths, but at less than 1 cm/sec.

Fate of Material

The fate of instantaneously dumped material is considered at Stations 120, 122, and 92 (Figure 19). The 4 hour fate computations using the methods described in Chapter 3 are summarized in Table 27. As can be seen from these results, the cloud impacts the bottom at the shelf site. Due to vertical dispersion, which is anticipated to be high due to the vertical shear in the horizontal currents, the finer particles may be suspended longer than otherwise expected. At the upper continental slope site (No. 122) the cloud impacts the bottom if its initial density equals 2.0 g/cm^3 but not 1.4 g/cm^3. The cloud is trapped for initial densities of at least 1.4 g/cm^3 at the deeper continental rise site (No. 92). In all three of these sites the area of impact after 4 hours is less than 0.5 km^2, and the dilutions are high except at the shelf site. Since the current speeds are less than 5 cm/sec at depths below 350 m, the center of mass is expected to travel no more than 0.7 km in 4 hours time.

Discharge of a negatively buoyant fluid from a marine outfall requires a bottom slope steep enough so that the fluid travels away from the outfall in a flow driven by gravity. While the minimum slope necessary is dependent on the particulars of a given situation, the slope is probably on the order of several degrees. Figure 18 indicates that in the western Gulf of Mexico, the bottom slopes near the shoreline are but a fraction of one degree except at the tip of the Mississippi River delta. Hence, construction of an outfall is impractical unless steep bottom slopes exist locally.

Marine Biological Characteristics

Oceanic environments far beyond the continental shelf in the Gulf of Mexico are characterized as oligotrophic. Nutrient concentrations are typically quite low within the euphotic zone, and phytoplankton standing stocks and primary productivity are therefore low as well. Production at all higher trophic levels, including both pelagic fishes and deep benthic

TABLE 27. INSTANTANEOUS DUMP CHARACTERISTICS FOR SELECTED SITE LOCATIONS WITHIN THE GULF OF MEXICO

Site				Variable Values Calculated for Four Hours after Dump			
Description[a]	Distance Offshore[b] (km)	Depth (m)	Initial Cloud Density (g/cm^c)	Trapping Level[c] (m)	Area (km^b)	Dilution	Thickness[d] (mm)
Shelf #120	100	44	1.4	bottom	0.01	37	64
			2.0	bottom	0.01	37	160
Upper Continental	220	1,100	1.4	600	0.15	4,800	
Slope #122			2.0	bottom	0.44	31,000	3
Continental Rise	540	2,900	1.4	1,300	0.54	13,000	
#92			2.0	1,400	0.62	53,000	

[a] Site locations shown in Figure 6-2.

[b] Distance south of Galveston, Texas.

[c] Instantaneous dump volume = 3000 m^3.

[d] Thickness defined as volume of solid mass/area, assuming all of the material settles to the bottom within the 4-h area.

communities, is correspondingly low. Nearshore and over the continental shelves, phytoplankton production is higher, supporting important commercial fisheries for both pelagic and demersal species.

Soft-bottom benthic habitats over the continental shelf of the western Gulf of Mexico are divided into white-shrimp grounds nearshore (to depths of 22 m) and brown-shrimp grounds further offshore (depths of 22 m to at least 90 m, and perhaps to the edge of the continental shelf at about 182 m). Each has its own characteristic fauna of both invertebrates and fishes. Both the white shrimp (Penaeus setiferus) and the brown shrimp (P. aztecus) are of prime commercial importance, and both are estuarine-dependent, utilizing shallow, brackish waters nearshore as nursery areas for their young. A number of the demersal and pelagic fish species, especially those of the white shrimp grounds, are similarly estuarine-dependent.

There is a series of hard-bottom banks or reefs on the outer continental shelves of Texas and Louisiana which provide substrate for typical reef-dwelling organisms (e.g., corals, coralline algae, gorgonians, and the associated fish fauna). In some cases, notably for those banks in the northern Gulf of Mexico such as the East and West Flower Garden Banks (Figure 19), the location of the banks is such that many of the resident species are climatologically near the limits of their existence, and for certain species, at least partially separated from the gene pool of those species. It has been suggested that these two facts make these communities susceptible to collapse should the existing organisms be destroyed by any anthropogenic factors, such as the disposal of manganese nodule processing wastes. It has also been suggested that the northwestern Gulf of Mexico represents a near marginal environment for many of the resident fish species, but especially those associated with the banks and reefs of the outer continental shelf, many of which are considered to be of tropical faunistic affinity. The vulnerability of these unique environments should certainly be considered in any decision of where to dispose of manganese nodule processing wastes.

Nearshore waters of the Gulf of Mexico support important commercial fisheries. In particular, waters of the north central Gulf in the vicinity of the Mississippi River delta have been described as being among the most productive fishing grounds in the world (Thompson and Arnold 1971). Nearly all of the commercial fish catch in this region comes from the area within a few miles of the coast; the only currently-utilized commercial species of note beyond 12 miles from shore are groupers and red snappers. Another important fact to consider is that 90 percent of the U.S. commercial catch in the Gulf of Mexico is of species spending part or all of their lives in estuarine waters.

The most valuable Gulf of Mexico fishery is for the various shrimp species, especially brown and white shrimp. The largest shrimp catches are made in the northern Gulf of Mexico, between the mouth of the Mississippi River and Freeport, Texas. Brown shrimp, the most valuable species, are occasionally taken in depths to 91 m, but most of the catch of this species is from waters of less than 55 m depth. White shrimp are caught in waters of less than 27 m depth. The distribution of the various shrimp species may

be altered by the deposition of manganese nodule processing wastes on the continental shelf, since the species have been shown to actively select the type of substrate they inhabit. Covering the bottom with a layer of inorganic particulate wastes could make the bottom unsuitable for brown and white shrimp, which are known to prefer substrates of soft mud or peat with large amounts of decaying organic matter or vegetation.

Approximately 75 percent of the Gulf of Mexico fish catch is used for fishmeal, oil, or other processed products. The principal catches in this fishery are from the area east of the Mississippi River delta, however. The largest domestic fishery in the Gulf of Mexico in terms of quantity of landings is for menhaden, a pelagic species which is used for fishmeal, oil, and other processed products. These fish are caught primarily within 24 km of shore between Empire and Intracoastal City, Louisiana.

Although there are important fisheries in the Gulf of Mexico for fish species inhabiting hard banks and reefs (e.g., snappers, groupers, seabasses), over 87 percent of the reef fish landings are from the eastern gulf.

There is potential for expanding and/or developing other fisheries in the Gulf of Mexico for species currently underutilized. Commercially exploitable stocks of tuna occur over the continental slope between the 183-m and 1,830-m depth contours and a fishery could develop for these fishes in the future. Other species (e.g., tilefish and yellowedge grouper) inhabit waters overlying the upper continental slope in this region, and are believed to be present in stocks of commercially important size. There is also potential for diversifying the shelf fisheries, now directed primarily at shrimp, so that abundant bottomfishes (e.g., sciaenids, demersal sharks) and shellfish (e.g., lobster, crabs, clams) could also be harvested.

SOUTHERN CALIFORNIA BIGHT

Physical Characteristics

The southern California Bight, which extends from the California-Mexico boundary northward to Point Conception is morphologically classed as a continental borderland (Figure 20). The southern California continental margin consists of a very narrow shelf down to approximately the 100 m (328 ft) depth, a limited basin slope, a relatively wide borderland having a series of basins and interbasin ridges, and a true continental slope which extends to the deep-sea floor. Within the borderland there are more than 20 basins extending as deep as 3,000 m (9,842 ft) separated by submarine ridges, banks, and islands which reach elevations of 500 m (1,640 ft) above sea level (Uchupi and Emery 1963). The basins contain thick sediment fills, whereas the higher areas consist of sedimentary, igneous, and metamorphic rocks. Shelves around the islands and along the mainland coast resemble typical continental shelves except for being much narrower. A number of submarine canyons cut across the shelf, providing pathways for offshore transport of coastal sediments. The seaward boundary of the borderland province is distinguishable by a continental slope followed by an 8 to 20 km (4.3 to 10.8 nmi) wide ridge at depths of 400 to 1,600 m (1,312 to 5,249

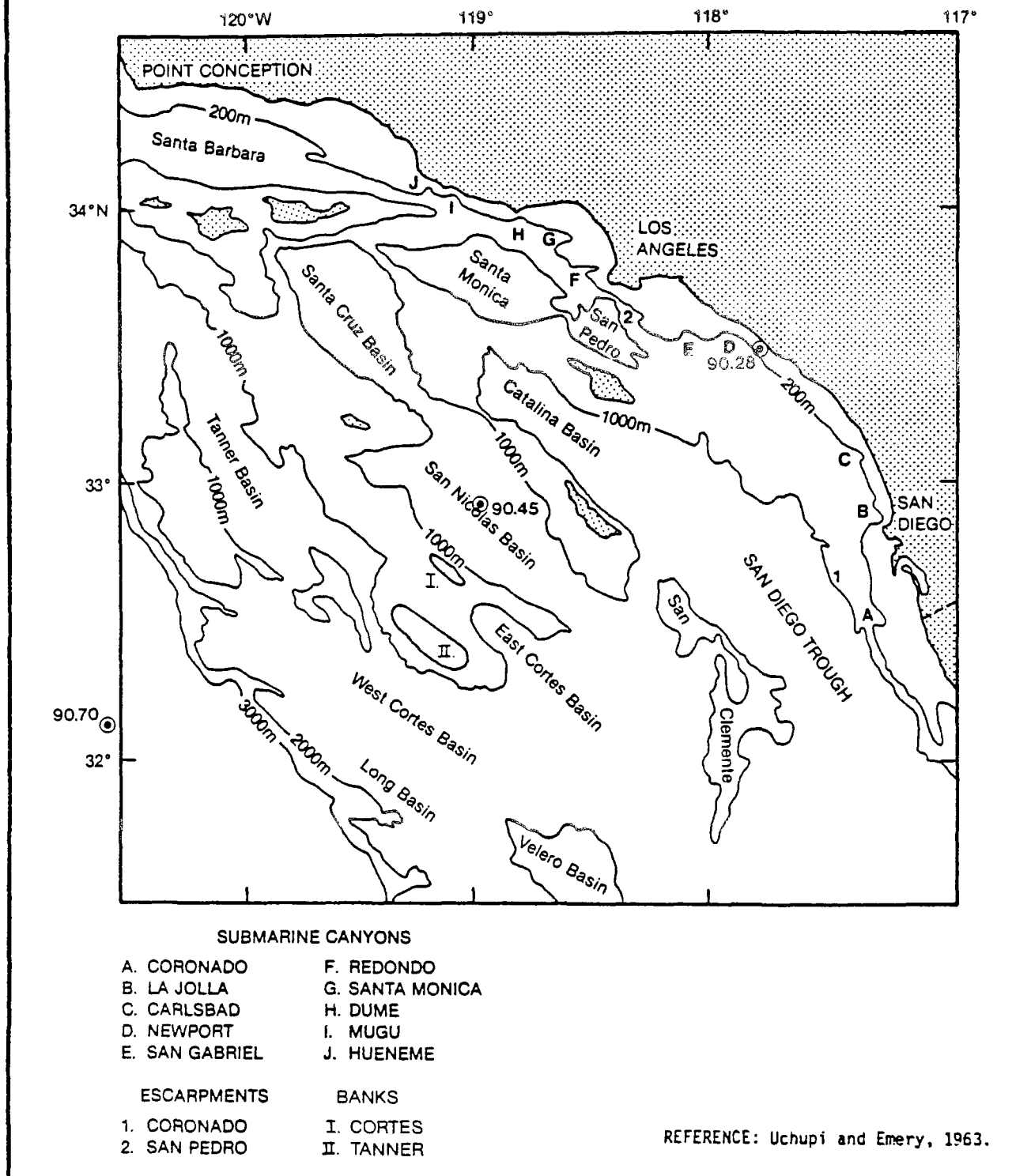


Figure 20. Continental borderlands off southern California showing basins, canyons, and escarpments.

ft). Beyond the ridge the topography deepens abruptly, dropping to the ocean basin at 3,400 to 3,800 m (1.8 to 2.1 nmi).

Along northern and central California, the coastline exhibits a general northwest-southeast orientation. At Point Conception the coastline has an abrupt change in orientation to an east-west alignment (gradually the coast returns to a northwest-southeast orientation). This abrupt change in orientation has a significant effect on the circulation pattern of the Bight.

The general circulation pattern within the Southern California Bight is strongly influenced by the California Current system. The California Current is a broad [500 to 1,000 km (270 to 540 nmi)], weak (5 to 10 cm/sec), southward-flowing eastern boundary current extending from Washington to Baja California. The water carried south by the California Current is cooler than the waters farther offshore and is also characterized by its low salinity, high oxygen, and high phosphate.

Below the California Current is the northward flowing California Undercurrent. This current occurs at intermediate depths beneath the pycnocline and seaward of the continental shelf. It is narrower [approximately 50 km (27 nmi) in width] than the overlying southward-flowing California Current. The Undercurrent, which is believed to have the Equatorial Pacific water mass as its source, is characterized by high temperature, salinity, and phosphate concentrations, but is low in dissolved oxygen.

At Point Conception, the southward-flowing California Current no longer flows along the coast. A northward flowing counter current or eddy forms between the California Current and the coast, and extends from Point Conception to San Diego. This northward flow is termed either the Southern California Countercurrent or Eddy depending on its strength and pattern. The northward flow is sometimes continuous around Point Conception, particularly during winter months, when the term countercurrent rather than eddy is commonly used to describe it. However, the relative infrequency with which drift bottles released in the Bight are retrieved north of Point Conception suggests that the northward flow usually contributes the majority of its volume to recirculation in the California Current.

Representative Areas

The physical oceanographic characteristics of three southern California Bight disposal areas are presented in the following section; a shelf/canyon area, a borderland basin area, and finally a deep ocean basin area. The information presented represents a synthesis of data obtained by review of a large number of references.

Shelf/Canyon--

Shelf temperature profiles determine the local density structure much more than salinity, and change markedly from season to season. In summer there is a shallow warm layer which rarely exceeds 5 m (16 ft) in thickness,

followed by a 20 m (66 ft) thermocline having a gradient of 0.25°C per meter, and an isothermal (10°C) bottom layer. In the winter, the difference between the mean surface and bottom temperatures is significantly reduced to 2.3°C, being only slightly colder at the bottom. Below 20 m (66 ft), the normal winter cooling is reversed, a common feature on the west coast shelf (Huyer 1977). The average shelf temperature is 15°C during the summer and 13.6°C during the winter.

Horizontal currents on the Southern California continental shelf are variable, having root mean square changes in a few hours to 10 days which typically exceed the seasonally averaged mean values. Typical speeds observed on the nearshore shelf are from 7 to 10 cm/sec, but can vary between 0-50 cm/sec (Hendricks 1975). During spring and summer, when the water column is thermally stratified, surface and bottom currents may be opposed, whereas during fall and winter, the water column is less stratified and the flow structure is more unidirectional. Mean surface currents in all seasons sweep to the south. At their weakest during the fall they still exceed 2 cm/sec. Although the current structure has been found to be similar in 60, 30, and 15 m (197, 98, and 49 ft) of water, the amplitude of mean currents is substantially reduced at shallower stations.

Canyon flows are expected to differ from those of the nearby shelf due to the channeling effect of the canyon walls. Higher axial current speeds occur near the heads of submarine canyons at more frequent intervals than at other bottom sites. It should be noted that upcanyon movement can occur as well as downcanyon movement. Periodic turbidity currents are known to flush accumulated bottom material down canyon axes and into basin or outer shelf areas.

Background dissolved oxygen levels at a shelf disposal site will be similar to those at the shoreward CalCOFI line 9 station (90.28) located in approximately 200 m (656 ft) of water. Surface values remain fairly constant near 8.6 mg/l during the spring months, decreasing to 7.9 mg/l in the winter. At 100 m (328 ft), however, the dissolved oxygen values are much lower, ranging from an April minimum of 2.5-3.0 ml/l to a high in December of 4.0 ml/l. At 200 m (656 ft), dissolved oxygen concentrations below 2.0 ml/l have been recorded between February and August.

Borderland Basin--

Surface temperatures typically range from 19°C in August to as low as 14.5°C in January. A pronounced spring thermocline forms at 10 to 20 m (33 to 66 ft) as at shelf stations, and tends to persist through October. Salinity, in contrast, is relatively uniform in the upper 50 m (164 ft), increasing somewhat beyond 100 m (328 ft) depth. The characteristic density profile exhibits a strong density gradient associated with ambient temperature, following the same pattern as temperature but in reverse magnitude. A very strong density gradient forms in the spring, becomes maximum [sigma-t difference is 1.0 from 10 to 30 m (33 to 98 ft) depths] in the summer and dissipates in the fall. Dissolved oxygen values are at a maximum near the surface (7.8 mg/l), decrease with depth, and are relatively constant in the upper 50 m (164 ft) throughout the year. At 100 m (328 ft)

and greater depths, a relatively pronounced DO minimum occurs during June, gradually returning to maximum values in December and January. Concentrations below 2.1 mg/l have been recorded at depths beyond 300 m (984 ft).

Dynamic topography contours for surface geostrophic flows relative to flows at 500 m (1,640 ft) (Wyllie 1966) for a mid-Bight location indicate south to southeast flows for February through June, with northerly flows from July to January. Flows at a 200 m (656 ft) depth relative to those at 500 m (1,640 ft) appear to be northward throughout the year except during March and April, when calculated flows become very low. Although monthly mean charts serve only as a guideline, the trend of the southward-flowing California Current moving inshore during April-May and eliminating the Southern California Countercurrent at the surface is evident, and may happen briefly even at the 200 m (656 ft) level. Outside of this period, however, flows can be expected to be northward. Dynamic topography charts indicate approximate current speeds of 0-10 cm/sec at the surface, and less than 5 cm/sec at 200 m (656 ft).

Deep Ocean--

Surface temperatures vary from 17°C during August through October to a low of 14.5°C between January and June. At 100 m (328 ft) the temperature variation is slight, remaining at approximately 10.5°C. Although a thermocline is present, it is far less pronounced than at nearshore stations. Surface salinity varies little, remaining at 33.4 ppt. An increase of 0.1 ppt is apparent at depths of 100 to 200 m (328 to 656 ft) in October and November. The density profiles appear to follow the water temperature pattern in the upper 50 m (164 ft), and seem to be dependent primarily on salinity variations in waters below this depth. The maximum density gradient occurs in September and October. Seasonal density variation at depths below 50 m (164 ft) is small, amounting to approximately 0.2 sigma-t units or less. Dissolved oxygen in the surface waters remains seasonally constant at 7.8 mg/l and decreases approximately 2.9 mg/l per 100 m (328 ft) of depth from 50 to 200 m (164 to 656 ft). There is evidence of slight maxima in May and minima in November. However, the annual range at a given depth is approximately only 1.4 mg/l below 75 m (246 ft) deep. At 200 m (656 ft), a value of 3.6 mg/l has been reported. Values as low as 2.1 mg/l occur at depths below 300 m (984 ft). Calculated geostrophic flows at the surface relative to a 500 m (1,640 ft) depth appear to be between 2 and 15 cm/year to the southwest throughout the year. Maximum currents probably occur in the June/July and November/December periods (Wyllie 1966). Currents at 200 m (656 ft) relative to 500 m (1,640 ft) appear to be much weaker, being between 0 and 3 to 4 cm/sec. For much of the year (e.g., August to December) the flow pattern appears to be poorly defined.

Fate of Material

The fate of instantaneously dumped material is considered at CalCOFI Stations 90.28, 90.45, and 90.70 (Figure 20). The 4 hour fate computations using the methods described in Chapter 3 are summarized in Table 28. None of the CalCOFI density profiles are sufficiently strong to trap the cloud at

TABLE 28. INSTANTANEOUS DUMP CHARACTERISTICS FOR SELECTED SITE LOCATIONS IN THE SOUTHERN CALIFORNIA BIGHT

Site				Variable Values Calculated for Four Hours after Dump			
Description[a]	Distance Offshore[b] (km)	Depth (m)	Initial Cloud Density (g/cm^c)	Trapping Level[c] (m)	Area (km^b)	Dilution	Thickness[d] (mm)
Cal COFI 90.82	5	200	1.4	bottom	0.03	400	15
			2.0	bottom	0.03	400	38
Cal COFI 90.45	126	900	1.4	200[e]	0.03	400	
			2.0	200[e]	0.03	400	
			1.4	900[f]	0.3	1,400	
			2.0	900[f]	0.3	1,400	
Cal COFI 90.70	300	>3,000	1.4	200[e]	0.03	400	
			2.0	200[e]	0.03	400	
			1.4	3,000[f]	2	320,000	
			2.0	3,000[f]	2	320,000	

[a]Site locations shown on Figure 6-13.

[b]Distances measured on line to SW from Dana Pt.

[c]Initial dump volume = 3,000 m^3.

[d]Thickness defined as volume of solid mass/area, assuming all of the material settles to the bottom within the 4-h area.

[e]Trapping level is greater than this value.

[f]Trapping level is less than or equal to this value.

depths less than 200 m, yet none of the profiles report densities at depths greater than 200 m making it impossible to determine whether the cloud impacts the bottom. Hence in Table 28 the trapping level for sites 90.45 and 90.70 are chosen equal to 200 m and the water depth. These two depths bracket the possible area and dilution values.

The maximum slope from the shoreline to the 200 m contour shown in Figure 20 is roughly 3 degrees. This slope may be sufficiently steep to allow discharging of material heavier than seawater from an outfall. However, careful experiments would be necessary to establish the adequacy of a nearshore site. In the southern California Bight, the ideal location for an outfall site is at the head of a submarine canyon. Very steep canyon slopes insure predominantly downward transport of discharged material. Even though upcanyon transport occasionally exists, no significant upward transport of material above the depth of the outfall is expected based on the behavior of sludge discharged from the Hyperion sludge outfall.

Marine Biological Characteristics

Although phytoplankton production is generally not nutrient limited waters of the California Current beyond the continental shelf off southern California, annual primary production is nevertheless low relative to areas over the shelf and nearshore. Consequently, production at all higher trophic levels, including both pelagic fishes and deep benthic communities, is also low. An additional factor which reduces the amount of organic matter reaching deep benthic communities in this area is that terrigenous sediments from southern California are currently being deposited in the deep basins of the continental borderland, and hence are not transported into the deep sea by turbidity currents, as is the case in other areas (e.g., offshore of the Pacific Northwest coast).

There is typically an onshore-offshore gradient in both phytoplankton standing stocks and primary productivity off southern California, such that the highest stocks and highest production occur nearshore. Production nearshore is enhanced seasonally by coastal upwelling, since the phytoplankton nearshore are at other times limited by the availability of fixed nitrogen.

The complex topography of the California continental borderland represents a variety of habitats for benthic organisms. Some of the deep basins of the continental borderland have a depauperate benthic fauna due to their low dissolved oxygen concentrations, which are caused by reduced water exchange and the decay of organic matter within the basins. Various shallow benthic habitats also exist on the continental borderland of southern California. Several hard-bottom banks (e.g., Cortes and Tanner Banks; cf. Figure 20) are unique in that they provide shallow water habitats at great distance from shore (approximately 180 km). Also present on the continental borderland are a number of offshore islands which are surrounded by both hard and soft bottom substrates for benthic community development. These islands also represent important habitat for various pinnipeds, including California sea lions, Stellar sea lions, and northern elephant seals.

Important nearshore habitats which could be particularly vulnerable to impacts of the disposal of manganese nodule processing wastes include rocky intertidal and subtidal habitats, kelp beds, and submarine canyons.

Major fisheries in the Southern California Bight are focused on pelagic species, such as northern anchovies, jack mackerel, and tunas, rather than demersal species. Trawl fisheries, which are of greatest importance in other coastal areas, are not extensive in southern California, due both to the small area of the continental shelf and to certain regulatory limitations. The small southern California trawl fishery, which catches primarily rockfishes and flatfishes, is largely limited to the Santa Barbara Channel.

Tuna fisheries account for a substantial portion of the landings in southern California. While yellowfin and skipjack tunas are caught primarily off the coasts of Central and South America, both bluefin tuna and albacore are seasonal migrants into southern California waters, and an offshore fishery there is directed at these species.

A significant oil and fish meal reduction fishery is centered in the channel region extending between Santa Barbara-Santa Cruz Island and Santa Catalina-Dana Point. This fishery, directed primarily at northern anchovy, also takes jack mackerel, Pacific mackerel, bonito, bluefin tuna, and squid. Both northern anchovy and jack mackerel are schooling species which are particularly abundant near the surface in waters overlying the deep basins of the continental borderland. Adult jack mackerel are abundant over rocky banks at depths of 9-55 m, around the rocky perimeters of offshore islands, and in rocky coastal areas associated with kelp beds. Over 90 percent of the catch of jack mackerel is from the vicinity of Santa Catalina and San Clemente Islands and on Cortes Bank.

Other lesser fisheries in southern California include: a developing fishery for squid within 4.8 km of shore, both on the mainland coast and in the vicinity of the channel islands; a spiny lobster fishery in rocky coastal areas; an abalone fishery centered in the vicinity of kelp beds around the channel islands and near Santa Barbara; and a developing pot fishery for sablefish. Fisheries with considerable potential for future expansion include: the squid fishery; the oil and fish meal reduction fishery for northern anchovies and jack mackerel (especially if other markets could be developed); and fisheries for currently underutilized groundfish species such as sharks, skates, and rays.

Certain species of commercial importance have demersal eggs and hence are potentially vulnerable to burial under manganese nodule processing wastes. Squid, for instance, attach their eggs to sandy substrates in semi-protected bays. California halibut also spawn demersal eggs. Selection of a disposal site for these wastes should consider avoidance of spawning areas utilized by such species.

While there is currently a developing fishery for Pacific hake in the Pacific Northwest, this species is not fished commercially in southern

California. Pacific hake undertake extensive seasonal migrations, however, and it is known that the hake caught off the Pacific Northwest were spawned at depths of 183-503 m over the California continental slope. During the spring and summer, adult hake move northward and inshore, where they become subject to the fishery over the Pacific Northwest continental shelf.

PACIFIC NORTHWEST REGION

Physical Characteristics

The northwest offshore region discussed in this section extends from Cape Mendocino in northern California to Cape Flattery in Washington. The continental shelf in this region is generally narrower, steeper, and has greater depths than average values for other continental shelves of the world. Significant features of the shelf are the submarine canyons which traverse the seaward edge of the shelf, and the banks which rise abruptly 60-73 m (197-239 ft) near the shelf edge (Figure 21).

The prominent feature of Pacific Northwest shelf circulation is a southward coastal jet during the upwelling season (Hickey 1979b). In spring, the center of the southward flow moves from a summer position of 15 km (8 nmi) offshore to within 10 km (5.4 nmi) of the coast. The width of the flow increases at this time, extending out over the continental slope (Huyer et al., 1978). Over the inner shelf, the currents are apparently much weaker than at mid-shelf. Surface currents over the outer shelf are generally believed to be southward. Beyond the shelf, geostrophic calculations indicate a mean southward flow which is weaker than at mid-shelf.

At depths of 200 to 300 m (656 to 984 ft) there is a northward undercurrent (Favorite et al., 1976), whose presence has been verified off Oregon in spring and early summer (Huyer and Smith 1976) and off Washington in late summer and early fall (Cannon et al., 1975; Reed and Halpern 1976). Between July and September, the northward flowing jet over the Washington continental slope has been observed to be 20 km (10.8 nmi) wide and 200 m (656 ft) thick, (excluding flow components below 5 cm/sec). A maximum core speed of 16 cm/sec has been measured at a depth of 192 m (630 ft) in 600 m (1,968 ft) of water (Hickey 1979b). Below 60 m (197 ft), slower northward flow was observed, on the average, over a 6-week period (July-September) as far as 80 km (43.1 nmi) offshore, across the slope, and over the entire shelf.

Representative Disposal Site Characteristics

Typical physical oceanographic conditions at shelf, slope, and basin sites off the Oregon coast are presented in this section. Although the salinity, temperature, and density data are isolated measurements, they do represent conditions expected during the winter and summer periods. The current profiles are mean currents over the winter and summer periods. Further offshore, over the lower slope and deep-ocean basin where current measurements are not available, calculated geostrophic flows are presented.

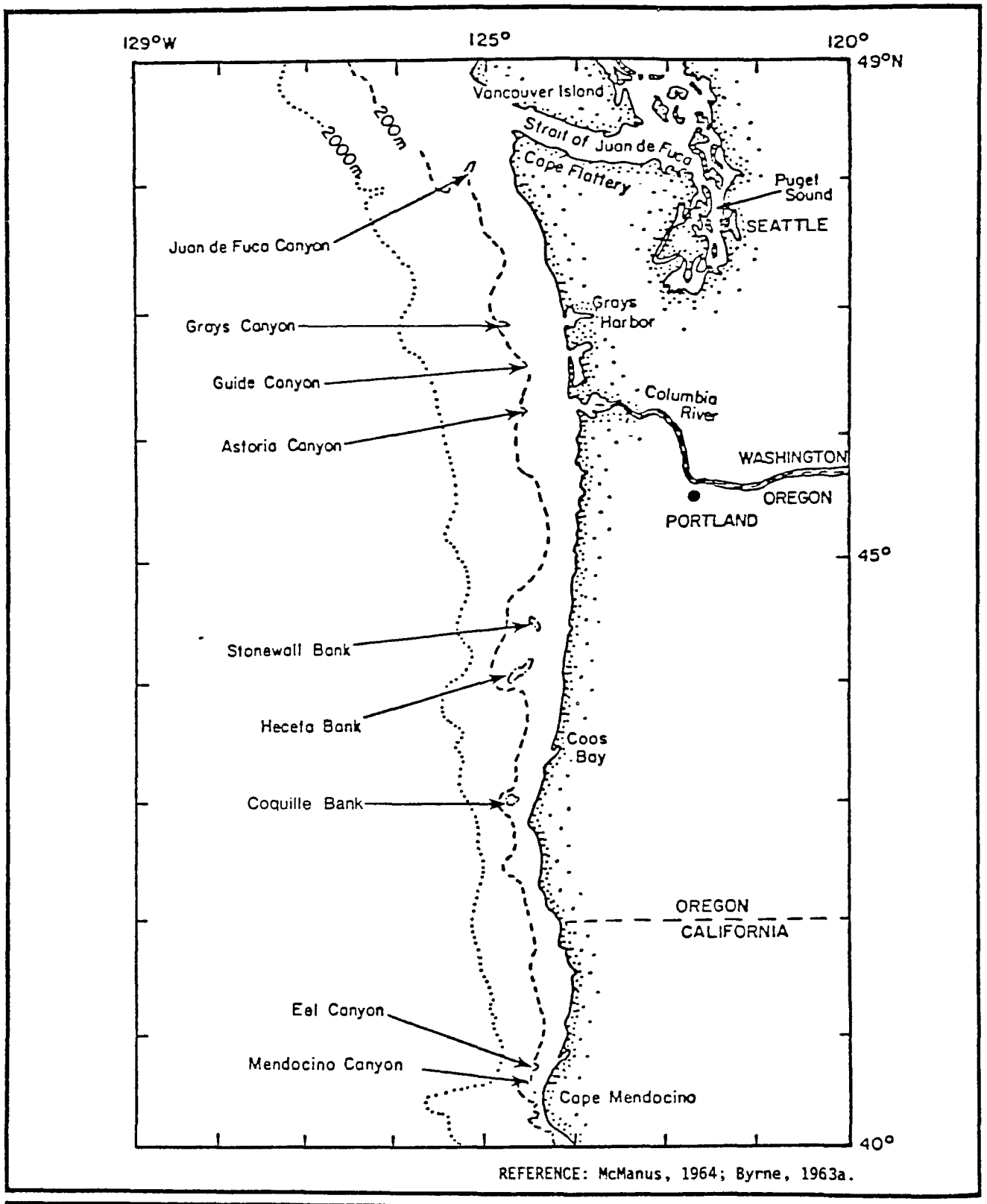


Figure 21. Relative positions of major submarine banks and canyons off Northwest coast.

Shelf--

The pronounced temperature gradient which is apparent in the upper 20 m (66 ft) in summer becomes less intense in winter extending down to 40 m (131 ft) depth. Beyond this depth, temperature variations are slight, decreasing to 6^{o} C in deeper waters. Density data indicate a significant dependence on salinity in both the winter when the temperature gradient is small, and during the summer when a strong thermocline is present. Longshore velocity components are much greater than onshore components, and near surface flows are predominantly southward in both summer and winter periods. Movement below 75 m (246 ft) is northward during both seasons.

The distribution of dissolved oxygen (DO) in northwest coastal waters is complicated due to upwelling, freshwater discharges, entrainment of deep water, and wave action (Stephansson and Richards, 1964). Biological activity nearshore is also more intense and more variable than farther offshore. Maximum surface DO values of 10.0 to 10.7 mg/l occur nearshore between June and July. The generally high surface values exceed levels expected for colder upwelled waters in atmospheric equilibrium, and are attributable to high photosynthetic production rates.

Upper Slope--

A strong thermocline and halocline can persist during the summer in the upper 10 m (33 ft). In winter, smaller gradients can occur and two stratification levels appear at approximately 10 and 60 m (33 and 179 ft), the upper one being due to cool low-salinity water very near the surface. Upper slope currents are strongly southward in summer down to 100 m (328 ft), beyond which a slow northward current occurs. Average currents down to 150 m (492 ft) persisted in an onshore direction during a 30-day measurement period. In winter (January-April), the mean longshore current magnitudes are very low, with some southward movement down to 100 m (328 ft) and northward flow beyond to the sea floor. Mid-slope temperature and salinity profiles appear similar to those on the upper-slope during both the summer and winter periods. Southward currents persist from 50-200 m (164-656 ft), while movement in the onshore direction is very slight.

Lower-Slope and Upper-Basin--

In lieu of measured currents in the offshore area, calculated geostrophic flow profiles are used. Summer surface currents at 65 km (35 nmi) offshore are southward in summer, decreasing from approximately 6 cm/sec to no current at a depth of 150 m (492 ft). In an adjacent area 10 km (5.4 nmi) further offshore, near-surface southward currents of 5 cm/sec decrease to negligible speed at 50 m (164 ft).

Beyond the continental shelf, DO values remain relatively constant in the upper mixed layer at near 9.0 mg/l. DO concentrations increase to maxima of 9.3 to 9.6 mg/l between March and May. As the temperature further increases in summer, lower DO solubility results in decreased surface concentrations of approximately 8.2 mg/l in the upper 10-20 m. A subsurface maximum at depths of 20 to 50 m persists at the previously established winter concentration of 9.6 mg/l, however.

Fate of Materials

The fate of instantaneously dumped material is considered at four offshore regimes characterized by water depth. Each region has two stations, one having winter density profiles, the other summer density profiles. Each station is shown in Figure 22. The 4-hour fate computations using the methods described in Chapter 3 are summarized in Table 29. As can be seen from these results, the density stratification is not sufficiently strong to trap the 3,000-m^3 dump except at the continental slope station during the summer. The area of impact after 4 hours does not exceed 0.11 km^2 except at the slope station. The dilutions are modest at the nearshore stations and much larger in deeper water. In this region the surface currents are to the south and below 100 m the currents are on the order of 1 cm/sec to the north. Hence, all of the instantaneous dump clouds are advected slowly to the north, while continuous surface discharges are carried to the south until the particles fall below 100 m depth.

The maximum slope from the shoreline to the 50 m contour shown in Figure 22 is roughly 1 degree. The slope from the 50 to 100 m contour is even less. Location of an outfall a reasonable distance from shore is unlikely to allow adequate dispersion of negatively buoyant waste material. However, a detailed examination of the nearshore bathymetry may reveal acceptable sites.

Marine Biological Characteristics

Oceanic primary production far beyond the continental shelf of the Pacific Northwest is relatively low due to low light levels in winter and nutrient limitation in summer. Production at higher trophic levels, including both pelagic fishes and deep benthic communities, is correspondingly low. Nearshore and over the continental shelf, phytoplankton production is higher, due in large part to seasonal coastal upwelling, which typically occurs duing spring and summer. The higher primary production over the shelf supports important commercial fisheries for both pelagic and demersal species.

In deep benthic habitats at the base of the continental slope, the abundance of benthic organisms is apparently correlated with the magnitude of the input of organic detritus via turbidity currents. Consequently, much larger benthic populations may exist in areas receiving frequent turbidity current deposits (e.g., Cascadia Channel) than in other nearby areas where turbidity currents are of minor significance (e.g., Cascadia Abyssal Plain).

On the continental shelf of the Pacific Northwest, the abundance of macroepibenthic organisms is largely determined by the type of substrate. Within 20 km of the Oregon coast, for instance, the bottom is essentially 100 percent sand, reflecting the high wave energy in this environment during winter storms. This sand has a very low organic carbon content, and as a consequence, both the numerical abundance and biomass of macroepibenthic organisms is low there. With increasing distance offshore, however, the sediment grain size decreases and the organic carbon content increases (as a

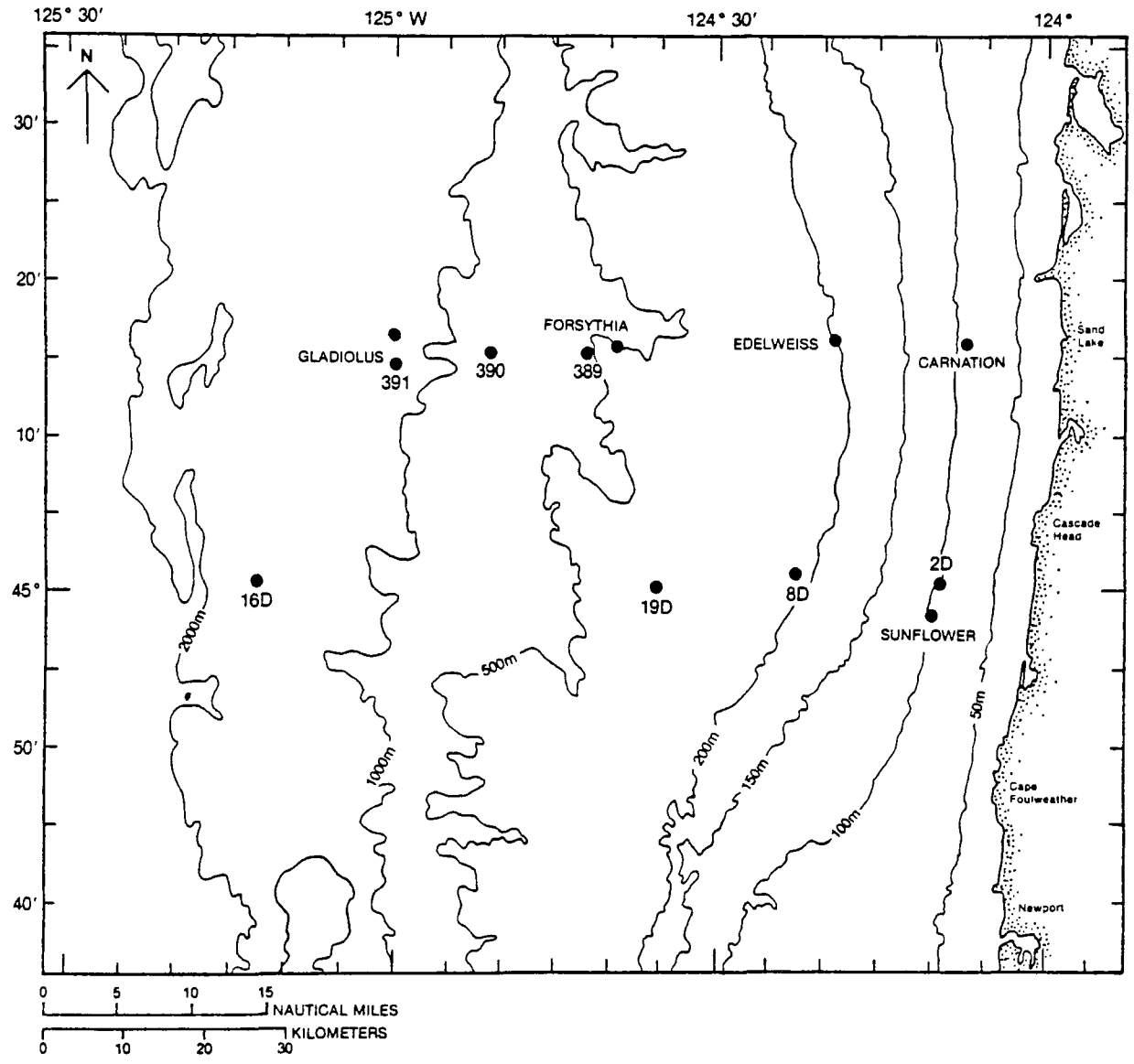


Figure 22. Stations used for the estimation of instantaneous dump characteristics in the Pacific Northwest.

TABLE 29. INSTANTANEOUS DUMP CHARACTERISTICS FOR PACIFIC NORTHWEST SELECTED SITE LOCATIONS OFFSHORE OF THE COAST

Site				Variable Values Calculated for Four Hours after Dump			
Description[a] (S = Summer W = Winter)	Distance Offshore[b] (km)	Depth (m)	Initial Cloud Density (g/cm^c)	Trapping Level[c] (m)	Area (km^b)	Dilution	Thickness[d] (mm)
Shelf:							
Carnation (S)	11	99	1.4	bottom	0.02	120	2
			2.0	bottom	0.02	120	81
Sunflower (W)	12	97	1.4	bottom	0.02	110	33
			2.0	bottom	0.02	110	82
Upper Slope:							
Edelweis (S)	28	196	1.4	bottom	0.03	400	15
			2.0	bottom	0.03	400	38
8D (W)	29	218	1.4	bottom	0.04	500	13
			2.0	bottom	0.04	500	33
Mid Slope:							
Forsythia (S)	47	492	1.4	bottom	0.11	3,100	4
			2.0	bottom	0.11	3,100	11
19D (W)	57	435	1.4	bottom	0.10	2,400	5
			2.0	bottom	0.10	2,400	13
Slope:							
Gladiolus (S)	83	1,412	1.4	611	0.16	5,300	
			2.0	1,124	0.43	29,000	
16D (W)	96	1,356	1.4	bottom	0.59	50,000	1
			2.0	bottom	0.59	50,000	2

[a] Site locations shown on Figure 6-34.

[b] Distance measured from site due east to coastline.

[c] Initial dump volume = 3,000 m^3.

[d] Thickness defined as volume of solid mass/area,assuming all of the material settles to the bottom within the 4-h area

result of the smaller particle size and of the higher primary production in the waters overlying the outer continental shelf). As a consequence, both the numerical density and the biomass of macroepibenthic organisms increase with distance offshore to depths of 200 m. The biomass of these organisms at 200 m depth has been estimated to be 73 times higher than the biomass at 50 m depth. The numerical abundance of benthic infauna exhibits a bimodal distribution, with high abundances nearshore and near the shelf break. Filter feeders dominate nearshore, while deposit feeders are more abundant near the shelf break. One result of the higher production in the overlying waters and of the higher abundance of macroepibenthic organisms near the shelf break is that demersal fishes are most abundant on the outer continental shelf and upper continental slope (depths of 91-411 m).

Rocky intertidal and subtidal environments nearshore support diverse benthic communities. These areas also provide important habitat for both Stellar sea lions and sea otters.

Commercial fisheries are of great economic importance in Washington and Oregon. Both pelagic and demersal species are heavily utilized. Although the continental shelf is relatively narrow, demersal trawling is not limited to the shelf but extends offshore to depths of at least 1,280 m. Demersal trawls are utilized to capture a wide variety of fishes including flatfishes, rockfishes, and lingcod. Midwater trawls are utilized to harvest Pacific hake, widow rockfish, and shortbelly rockfish. Wide-ranging epipelagic fishes, such as albacore and several species of salmon (notably chinook and coho), are caught by trolling.

Certain Pacific Northwest fisheries are dependent on seasonal migrations of the fish. Albacore, for instance, only enter the offshore waters of the Pacific Northwest (typically 80-241 km from shore, and occasionally to 482 km from shore) when the surface waters have warmed appreciably (e.g., late summer and early fall). Albacore are then subject to a brief, but intensive fishery. Pacific hake migrate to the shelf waters of the Pacific Northwest for feeding during spring and summer. During fall and winter, they are found over the continental slope off California. The only commercial fishery for this species occurs in the Pacific Northwest. The salmon troll fishery, conducted primarily within 19 km of the shore, is also subject to seasonal variations in abundance because the salmon undertake spawning migrations to the freshwater rivers and streams of the Pacific Northwest.

Two invertebrate species support important commercial fisheries in the Pacific Northwest. Dungeness crabs are caught in pots at depths less than 91 m, primarily in sand or mud bottom areas. Pink shrimp are caught in trawls, primarily in depths of 91-183 m, over bottoms of green mud or a mixture of mud and sand. They are occasionally caught at depths as shallow as 64 m or as deep as 302 m.

Currently-underutilized fish species could support expanded fisheries in the future in the Pacific Northwest. Demersal species which could be caught in greater numbers than at present include certain sharks, skates, and flatfishes. Pacific hake catches could also support expanded fisheries

in coming years. Among the pelagic fishes, there is potential for increasing the catch of Pacific herring (especially if they could be fished in the open ocean), northern anchovies, Pacific mackerel, and pomfret. Squid could also be caught in commercial quantities in this area.

Commercial species of the Pacific Northwest exhibit such a great diversity of life cycles and reproductive strategies that it is difficult to make generalizations. Fishes which reproduce in the area may be either oviparous (egg laying; e.g., Pacific cod) or ovoviviparous (bearing live young; e.g., certain rockfishes). Fish eggs may be pelagic (e.g., sablefish), semipelagic (initially demersal, subsequently pelagic; e.g., Pacific halibut), demersal without parental care (e.g., Pacific cod), or demersal with parental care (e.g., lingcod). Eggs of commercially-important invertebrates may also be pelagic (e.g., crabs, shrimp) or demersal (e.g., squid). While a number of commercially-important species leave the marine waters of the Pacific Northwest to spawn (e.g., albacore spawn in the warmer waters of the central Pacific, Pacific hake spawn off California, Pacific herring spawn in protected bays and estuaries, salmon migrate to freshwater rivers and streams) others spawn in the marine waters of the region (e.g., Pacific cod, Pacific halibut, lingcod).

HAWAII

Physical Characteristics

Previous studies by Jenkins et al. (1981) have identified the island of Hawaii as a potential location for a manganese nodule processing plant and noted that one ocean mining group has publicly expressed interest in this site. For this reason, the physical and biological characterization of this region is focused specifically on the waters around the island of Hawaii and especially the eastern or windward site.

Bathymetry--

Figure 23 presents the bathymetric contours in the vicinity of Puna Canyon. The morphology of the adjacent Puna Ridge was surveyed using a submersible by Fornari et al. (1979). The ridge is a submarine continuation of the East Rift Zone of Kilauea volcano, and represents a principal locus of submarine volcanic activity and a major outbuilding site for Kilauea. The micromorphology consists of fresh lava pillows and cylinders with a lack of interstitial sediments and benthic fauna.

Circulation Patterns--

The primary factors which influence current patterns in Hawaiian waters are the West Wind Drift, tidal motions, and an anticyclonic gyre northeast of the islands. Currents generally show strong tidal variations, frequently including direction reversals over a tidal cycle, but are modified locally by winds, internal wave motions, and other factors.

In examining data available near proposed dredge spoil disposal sites off of Hilo (Figure 24), it became apparent that previous oceanographic

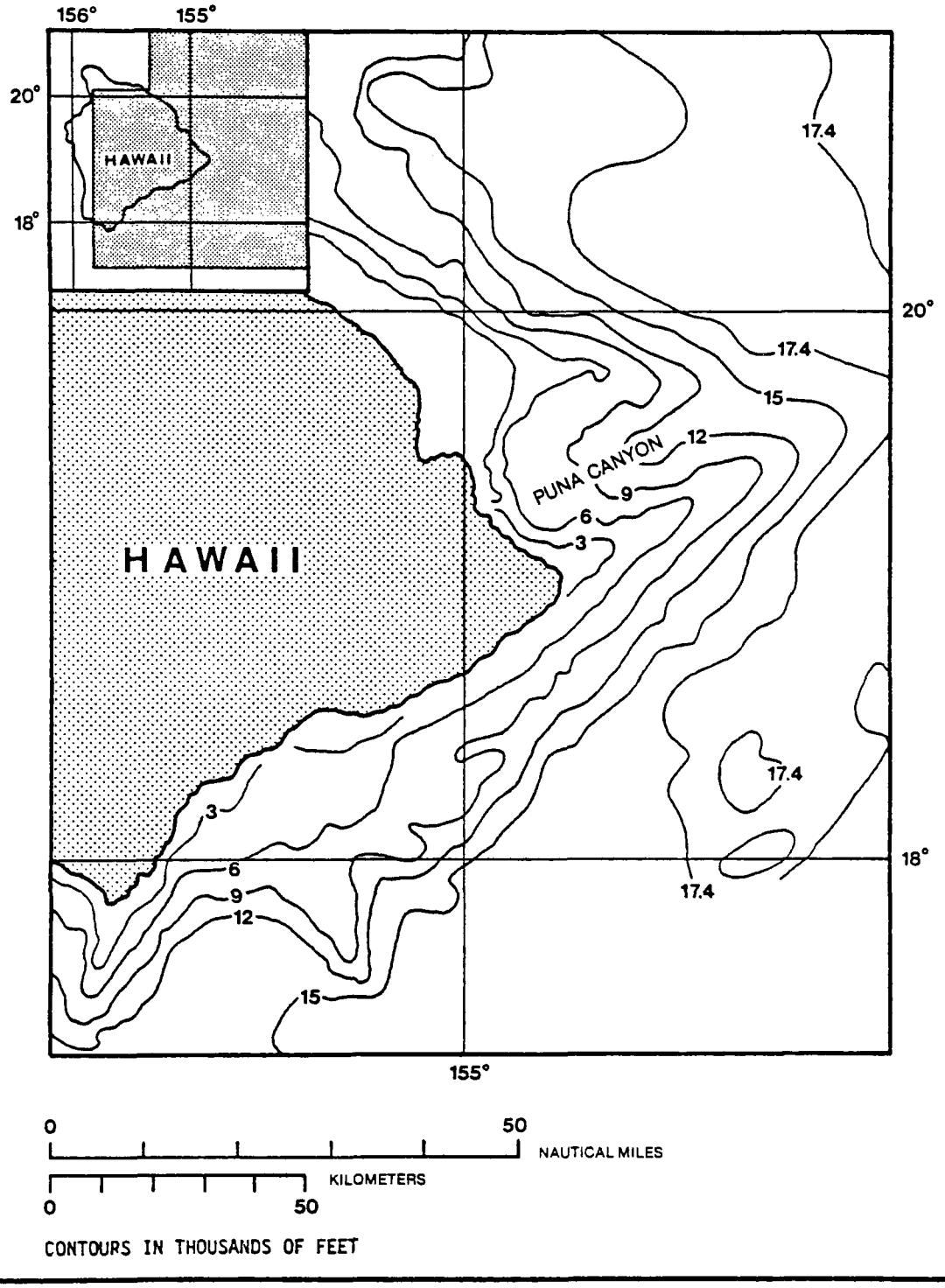


Figure 23. Bathymetry of the Puna Canyon.

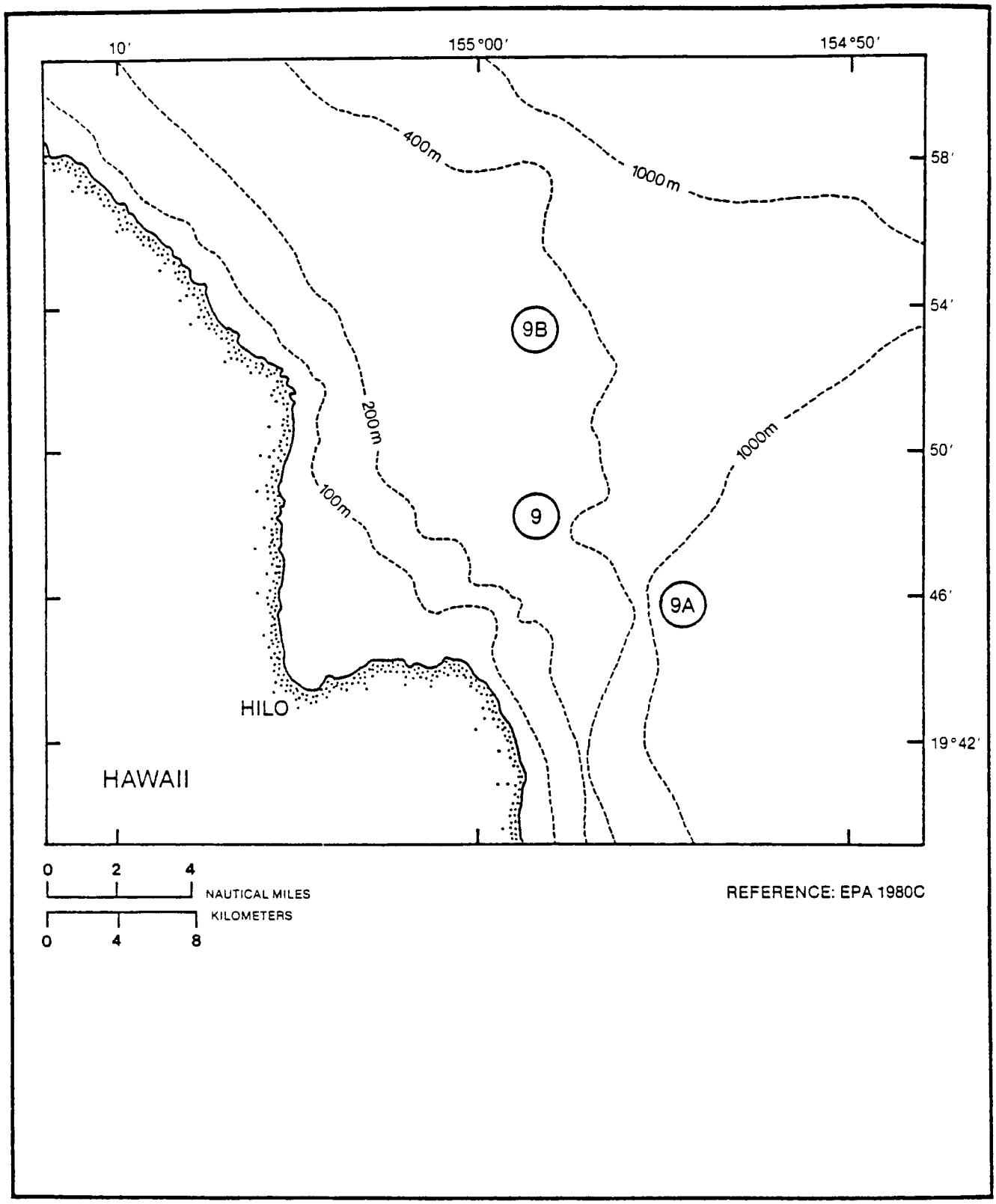


Figure 24. Proposed and alternative dredged material disposal sites.

measurements were made either within Hilo Bay or much farther offshore in waters exceeding 3,000 m (10,000 ft) (Neighbor Island Consultants 1977). A very limited amount of current data is available for dredge spoil disposal sites 9 and 9B near Hilo Bay. At the Inner Hilo site 9 which is in 340 m (1,115 ft) of water, two days of surface current measurements (drogue movements) indicated northwesterly flows at between 15 and 36 cm/sec. Upper subsurface currents were highly variable with some tidal correlation. Deeper currents decreased in magnitude but became more uniform in direction, remaining between 338^{0} and 20^{0} of magnetic north. Surface currents had 180^{0} reversals in direction. At 15 m (50 ft), currents ranged from 15 to 57 cm/sec, decreasing toward the bottom to between 0 and 15 cm/sec. At site 9B (Outer Hilo) which is in 329 m (1,080 ft) of water, surface drogue measurements indicated a moderate west-southwesterly flow. Subsurface currents of less than 26 cm/sec were generally oriented toward the northwest. A tidal influence was evident on all records. The EIS for Dredged Material Disposal Sites Designation (U.S. Environmental Protection Agency 1980c) indicates that current depths of these sites were 29, 19, 16, and 11 cm/sec for meters at 15, 45, 183, and 340 m, respectively, with deeper flows being towards the north.

Current measurements have also been made at nearby University of Hawaii Station 212 off Alia Point to the north of Hilo in 210 m of water (Wyrtki et al., 1969). August 3 through 15 recordings for a meter at 30 m (98 ft) depth indicated strong easterly (107^{0} true) average current speeds of 32.7 cm/sec, with weak tidal currents superimposed.

In January, the surface water temperatures were 25^{0} C, decreasing to 22^{0} C at 152 m (500 ft). At this point, a relatively sharp thermocline occurred down to 243 m (800 ft). Beyond this depth, temperatures continued to decrease, reaching 9^{0} C at 426 m (1,400 ft).

Currents nearshore appear to be southward and can reportedly be as high as 100 cm/sec. Deeper than 30 m (100 ft), currents decrease significantly, becoming negligible. Offshore, from 15 to 35 km, northward surface currents are weaker, being 25.7 cm/sec or less. Subsurface currents decrease quickly as a function of depth, and tend to flow to the south.

Currents along the canyon axis at 426 m (1,400 ft) depth range from 0 to 13 cm/sec, and directionally are a function of tides, being upcanyon on a rising tide and downcanyon on a falling tide. Bottom visibility is very high due to the lack of any sediment sources nearby, the closest drainage being 50 km (28 mi) away.

Representative Area

For the purpose of this project, the Puna Canyon area is discussed in view of its proximity to an existing dredged material disposal site (9B). It should be noted that site 9A in 2,103 m (6,900 ft) of water (Figure 24) was relocated to site 9B due to intense commercial fishing at 9A (Neighbor Island Consultants 1977).

Fate of Material

The fate of instantaneously dumped material is considered at Site 9 which is shown in Figure 24. The 4-hour fate computations using the methods described in Chapter 3 are summarized in Table 30. These results show that the cloud impacts the bottom. Due to the steep bottom slope, the cloud is likely to travel down Puna Canyon into much deeper water, and the 4-hour trapping level may be much greater than that shown in the table. Similarly, if an outfall discharging material more dense than seawater were located near the head of Puna Canyon, a turbidity plume would carry most, if not all, of the material down the canyon into very deep water.

Marine Biological Characteristics

Due to the strong vertical stratification of the water column in open ocean environments of the tropical Pacific, the supply of nutrients to the epipelagic zone is limited, and phytoplankton primary production there is very low. As a consequence, production at all higher trophic levels, including both pelagic fishes and deep benthic communities, is also very low. Deep benthic organisms are in particularly low abundance in open ocean areas of the tropical Pacific because they are far removed from terrigenous sediment sources with their associated organic detritus, the productivity of the overlying waters is very low, and the benthic communities are separated from the epipelagic communities by a deep water column. Ambient sedimentation rates are very slow, and hence it is likely that benthic organisms in these habitats are ill-adapted to significant increases in these rates, which could accompany disposal of manganese nodule processing wastes in the open ocean.

Phytoplankton primary productivity near the Hawaiian islands is enhanced due to an "island mass effect" which appears to be associated with increased turbulence and vertical mixing in the channels between the islands. Primary production is also elevated near the islands due to the contribution of benthic algae, especially the coralline algae which are the primary reef-building organisms in this area.

Coral reefs are well developed along the leeward or Kona (western) coast of the island of Hawaii, but there is little coral growth on the windward (eastern) side of the island, due to the exposure of this coast to waves driven by the trade winds. The only fringing reef on the island of Hawaii is located on the northwestern side of the island. Coral growth is less vigorous north of Keahole Point on the Kona coast of Hawaii, perhaps due to the finer sediments and higher turbidity found in this area. This may be a natural phenonemon related to the protected nature of this coast with respect to the prevailing wind and waves.

The amount of wave exposure has a direct relationship with both the amount and type of coral growth in nearshore environments on the island of Hawaii. The Kona coast has a rich and varied benthic fauna, both intertidally and subtidally, while there are fewer benthic organisms on the windward coast. Consequently, even the type of fishes inhabiting a nearshore area can be a function of the amount of wave exposure.

TABLE 30. INSTANTANEOUS DUMP CHARACTERISTICS FOR SITE LOCATIONS OFFSHORE OF THE ISLAND OF HAWAII

Site				Variable Values Calculated for Four Hours after Dump			
Description[a]	Distance Offshore[b] (km)	Depth (m)	Initial Cloud Density (g/cm^c)	Trapping Level[c] (m)	Area (km^b)	Dilution	Thickness[d] (mm)
Site 9	9	329	1.4	bottom	0.06	1,250	8
			2.0	bottom	0.06	1,250	19

[a]Site location shown on Figure 6-53.

[b]Distance measured from nearest point of land.

[c]Instantaneous dump volume = 3000 m^3.

[d]Thickness defined as volume of solid mass/area, assuming all of the material settles to the bottom within the 4-h area.

Coral reef communities are particularly susceptible to environmental perturbations associated with the introduction of sediments to the nearshore environment. High turbidity may limit algal growth or interfere with filter-feeding organisms. Deposited sediment may bury the hard substrate needed for attachment or cause abrasion of soft benthic organisms. For these reasons, it is less desirable to dispose of fine particulate wastes (such as manganese nodule processing wastes) in areas where coral reefs are present than in areas where they are absent.

Due to the narrowness of the insular shelf around Hawaii, there is not an extensive shelf community beyond the reefs, but rather the sea floor increases in depth rapidly with increasing distance from shore.

One seasonal inhabitant of Hawaiian nearshore environments deserves special attention. Humpback whales range over much of the North Pacific Ocean but overwinter near the Hawaiian islands, especially along the northwestern and southern coasts of the island of Hawaii. The overwintering grounds of this endangered species are receiving consideration as a national marine sanctuary.

Hawaiian fisheries are primarily conducted within 32 km of the coast. On the island of Hawaii, both Hilo and Kona are important commercial fishing centers. Kona is an important sport fishing port as well. Because Kona is located on the leeward side of the island, its fisheries are more diversified and its landings are greater than at Hilo, where rough waters limit fishing activity. Tuna fisheries are the most important fisheries around the island of Hawaii, followed by the fisheries for limpets, wahoo, scads, and blue marlin. Due to the narrow insular shelf, trawls are little used in Hawaiian fisheries; handlines and trolling are the major fishing methods.

Yellowfin tuna are caught in a night handline fishery between 24-80 km from shore off both Hilo and Kona. Other species caught in this fishery include albacore, bigeye tuna, several billfish species, and dolphin (mahimahi). All of these species, as well as wahoo, are taken in the daytime handline, surface troll, and longline fisheries within 32 km of the coast.

In areas having rocky bottoms with dropoffs, pinnacles, and depressions, bottomfish species such as snappers, amberjack, and jack crevalle are caught on deep-sea handlines. There is also a midwater handline and net fishery for scads within 3.2 km of the coast in depths of 27-107 m.

In sandy bottom areas at depths of 27-91 m off the Kona coast of Hawaii, there is a small commercial fishery for crabs. Precious corals, which grow only at depths of 100-400 m, also support a minor commercial industry on the island of Hawaii. An important bed of precious corals occurs off Keahole Point on the Kona coast; other areas likely have such beds but have yet to be explored.

Within 32 km of shore around the island of Hawaii, most of the pelagic fish stocks are already heavily exploited and there is probably little room for expansion of existing fisheries. The tuna fisheries and fisheries for billfishes could conceivably be extended into waters farther from shore in the future. Presently underutilized species in these waters include sharks and shrimp. The development of a fishery for sharks is subject to market acceptance, but could be substantial. Shrimp are believed to be abundant at depths of 274-640 m over a variety of substrates, and it is possible that a fishery could develop in the future.

It is worth noting that the most important commercial species in the Hawaiian fisheries are wide-ranging pelagic fishes (e.g., tunas, marlins, dolphin, etc.) which are not limited to the waters around the islands. Thus, they would be less susceptible to adverse effects of waste disposal than would local demersal species which support important fisheries in other geographic areas (e.g., the Pacific Northwest).

SUMMARY - MARINE BIOLOGICAL CHARACTERISTICS

The marine biological environments of the four representative disposal areas (Hawaii, Pacific Northwest, Southern California, and Gulf of Mexico) all have several features in common and a number of important differences. In all four areas, the lowest primary production, and hence the lowest production at higher trophic levels, occurs in open ocean environments far beyond the shelf. In all of the areas, the benthic biomass in the deep sea is low as a result of the physical isolation of these environments and the low productivity of the overlying waters. The only fisheries of note in the open ocean portions of these four areas are for wide-ranging pelagic species, and hence the open-ocean fisheries are not limited to restricted geographical areas.

In each representative disposal area, primary productivity is enhanced nearshore, although by different mechanisms. In Hawaii, phytoplankton primary productivity is enhanced near the islands by the so-called "island mass effect," and there is also an important contribution to overall community productivity by benthic algae. In the Pacific Northwest and off southern California, nearshore productivity is increased by seasonal coastal upwelling. Primary productivity over the shelf in the northwestern Gulf of Mexico is apparently higher due to the river discharge along the coasts of Louisiana and Texas.

Coral reef communities, which are particularly susceptible to adverse impacts of the marine disposal of fine particulate wastes, are found near shore in the Hawaiian islands and near the shelf break on several banks in the northwestern Gulf of Mexico. On the island of Hawaii, extensive coral growth is only found on the leeward, or Kona coast. High wave energy restricts the growth of coral on the windward coast. Coral reef communities of the northwestern Gulf of Mexico are limited to hard banks far from shore (e.g., the East and West Flower Garden Banks; cf. Figure 19). These isolated habitats are believed to be climatologically near the limits of existence for many of the resident species, and therefore especially vulnerable to anthropogenic sources of stress.

Hard bottom banks are also found far offshore (180 km) from the Southern California Coast (e.g., Cortes and Tanner Banks; cf. Figure 20). While they do not support coral reef communities, these banks do provide substrate for the development of unique, shallow water benthic habitats. Their communities are also susceptible to impacts from anthropogenic stresses.

Due to the narrowness of the insular shelf off the island of Hawaii and the precipitous increase in depth with distance offshore, benthic organisms are most abundant nearshore, especially in the vicinity of coral reefs along the Kona coast. Macrobenthic organisms are also found in abundance over the inner continental shelf of the northwestern Gulf of Mexico, especially on the white and brown shrimp grounds at depths less than 91 m. In contrast, however, macroepibenthic organisms are relatively rare on the inner continental shelf of the Pacific Northwest. Due to strong winter storms in this region, the sediments out to approximately 20 km from shore are 100 percent sand size particles, with a low organic content which apparently does not support high organism abundance. Beyond 20 km from shore, benthic biomass increases with increasing distance from shore, reaching a maximum near the shelf break, but remaining high even over the upper continental slope. The complex topography of the California borderland does not lend itself to generalizations about across-shelf gradients in benthic biomass. Benthic biomass is high on shallow banks and around the channel islands, but may be depauperate in the deep basins of the borderland due to low dissolved oxygen concentrations.

Important commercial fisheries are conducted in each of the representative disposal areas. In open ocean waters of the tropical Pacific Ocean, the only fishery of note is for wide-ranging tuna species. The primary Hawaiian fisheries are conducted nearshore, and are directed at pelagic species such as tuna, marlin, and other billfishes. Some demersal species are caught on handlines, especially in areas with rocky bottoms, but trawls are not regularly utilized. Important pelagic fisheries in the Pacific Northwest are directed at salmon within 19 km of shore year-round, and at albacore in the open ocean during some summers. Demersal species are caught in large quantities by trawls, especially over the outer continental shelf and upper slope. Developing fisheries in the Pacific Northwest include those for Pacific hake, widow rockfish, and pink shrimp over the outer continental shelf. In southern California, the primary fisheries are for pelagic species, such as tuna, northern anchovies, and jack mackerel. Demersal fisheries are very limited in southern California due to the narrow area of the continental shelf and to some regulatory limitations. Abalone, spiny lobster, and kelp are harvested in rocky subtidal habitats near shore which could be adversely affected if they received significant inputs of fine particulate wates. In the Gulf of Mexico, fisheries of importance include those for white and brown shrimp, primarily conducted over the inner continental shelf to depths of 55 m, and the fish meal and oil reduction fishery for menhaden, conducted within 24 km of shore near the Mississippi River delta. Many of the commercial fish species in this region, as well as the white and brown shrimp, are estuarine dependent (i.e., they utilize estuaries as spawning and/or nursery areas during part of their life cycle).

7. ENVIRONMENTAL CONSIDERATIONS RELATED TO MANGANESE NODULE PROCESSING WASTE DISPOSAL

Since no empirical data are available on the effects of marine disposal of manganese nodule processing wastes, an environmental assessment must utilize information on the physical/chemical characteristics of the wastes (Chapter 5), the available ocean disposal technologies (Chapter 3), and the individual characteristics of representative disposal areas (Chapter 6) to arrive at an evaluation of significant environmental considerations. This evaluation will include a discussion of how each factor affects the magnitude, duration, or spatial extent of potential effects. In addition, available information on the effects of marine disposal of other wastes will be examined to determine its relevance to predicting effects of manganese nodule processing waste disposal.

The discussion which follows will be divided into three sections. First, environmental effects of the marine disposal of other wastes will be described in some detail. Wastes considered include mine tailings, drilling muds, dredged material, and sewage solids. Next, generic effects of the marine disposal of manganese nodule processing wastes will be discussed for each of three possible receiving environments: open ocean, outer continental shelf, and nearshore. Factors considered will include the characteristics of the wastes, the various methods of disposal, and the characteristics of each environment which will influence the type of effect on the biota. An attempt will then be made to estimate the relative significance of the identified potential environmental effects. Finally, this information will be combined with the characteristics of each representative disposal area to arrive at significant environmental considerations for each area. These are expected to be the primary environmental considerations to be taken into account in determining the acceptability of manganese nodule processing waste for ocean disposal and for selecting a possible site for the disposal of these wastes.

MARINE DISPOSAL OF OTHER WASTES

An initial review of the marine disposal of other wastes has been conducted to provide examples of the kinds, duration, and extent of impacts attributable to characteristics of the wastes or of the receiving water environment. Emphasis has been placed on metalliferous wastes or wastes containing a substantial degree of metallic contaminants. Mine tailings are perhaps most similar to manganese nodule processing wastes, due to their largely inorganic nature and their content of various metals. Hence, the discussion which follows will emphasize environmental investigations of the effects of these wastes. While not as comparable to manganese nodule processing wastes, the disposal of other wastes (e.g., drilling muds, dredged material, sewage solids) will also be discussed with regard to their environmental effects.

Mine Tailings

The physical/chemical characteristics of mine tailings are highly variable, even among mines extracting the same minerals (see Appendix C). Sources of this variation include differences in the grain size and crystalline structure of the tailings, and differences in the chemical composition of the tailings and associated effluent. This variation among mine wastes complicates assessment of the environmental consequences of tailings and effluent disposal. Accurate assessment of the environmental consequences of mine waste disposal is further complicated by between-site differences in the physical, chemical, and biological characteristics of the receiving environments.

Despite the high degree of variation among mine wastes and receiving environments, general statements about the environmental impacts of mine waste disposal are possible. For the marine environment, Ellis and Littlepage (1972) provide a review of such impacts. They divide the general effects of mine waste disposal in the marine environment into primary and secondary effects. Primary effects include:

1. Acute poisoning. Acute poisoning may result from the "inadequate removal of poisons from discharged effluent."

2. Chronic poisoning. Chronic poisoning may result from the introduction of sub-lethal levels of toxic substances into the receiving environment. Organism response may include reduced growth, reduced fecundity, reduced longevity, and other evidences of ill health.

3. Enrichment. Enrichment and eutrophication may occur through the addition of nutrients into the ecosystem.

4. Suffocation. Suffocation of the biota may result from direct smothering by particulates or from anoxia due to the decomposition of organic matter in the water column.

5. Temperature and salinity effects. Alterations of temperature and/or salinity in the receiving environment may alter metabolic rates, osmotic regulation, and behavioral patterns of the biota. Responses of the biota may be diverse and may occur at the individual, species, or ecosystem level.

Secondary effects include:

1. Bioaccumulation of toxic substances. Plants and animals in the receiving environment may accumulate toxic substances in their tissues.

2. Changed standing stocks and production rates. The introduction of "abnormal chemicals", including toxic

substances and nutrients, may alter biological production and cause changes in the structure and function of the ecosystem.

3. Species losses and population explosions. Alterations of the receiving environment by pollutants may cause the elimination of some species and the enhancement of others. Ecosystem structure may be greatly altered.

Of the many possible primary and secondary effects discussed by Ellis and Littlepage (1972), bioaccumulation of toxic substances has been the subject of increasing research efforts in recent years. Much of the impetus for this research comes from the realization that bioaccumulation is a route by which toxic substances may be introduced into the human population by ingestion of seafood organisms. Mine wastes pose a potential for bioaccumulation since residual metals are present in the tailings and effluent, and these metals may be assimilated or concentrated by the biota in the receiving environment. The toxicity of many metals is well known (cf. Eisler 1979).

Metals may be assimilated by marine organisms from water or food. To be incorporated into an organisms tissues, metals must be available to the biota in a dissolved form. The rate at which metals dissolved in mine effluent are discharged into the receiving environment, and the rate at which metals are released from mine tailings into seawater, or within the organisms' digestive tracts, are, therefore, critical. Laboratory experiments by McGreer et al. (1980) demonstrated that the uptake of metals from mine tailings is "generally proportional to the concentration of metals in seawater" for the deposit feeding bivalve Macoma balthica.

Whereas metals dissolved in the liquid effluent from a mining operation will be discharged into the marine environment only when the mill is operating, metals from disposed tailings may continue to be released into the marine environment in dissolved form, or be ingested by biota, long after the mining operation ceases. Submerged tailings may therefore have long-term effects on the indigenous biota.

Recent studies indicate that characteristics of both the tailings and the receiving environment will influence levels at which metals contaminate the resident biota. From their comparison of the bio-uptake of metals from three mines, McGreer et al. (1980) concluded that "the metal-binding associations within the mine tailings were responsible for controlling metal release." Thus, the geochemistry of the tailings directly influences the concentrations of dissolved metals, which in turn influence the levels of contamination in at least some indigenous organisms. Sediment diagenesis of metals in the disposed mine tailings may also contribute to high concentrations of dissolved metals in the pore waters of estuarine sediments. Subsequent diffusion of these dissolved metals to the sediment-water interface may result in high concentrations of metals in the overlying waters, and may prevent metals in the underlying sediments from being retained in the deeper parts of the sediment deposit (Elderfield and Hepworth 1975). Bioturbation of sediments may also act to increase the

availability of sediment metals to overlying waters. The upper reaches of estuaries may be particularly sensitive to the disposal of mine tailings since circulation and sedimentation patterns may tend to retain metals in their upper reaches (Merefield 1976; Yim 1976).

Copper Mines--

Impacts of tailings on Rupert Inlet and adjacent waters have been studied extensively since the Island Copper Mine began operation in 1971. Most of the mine tailings are deposited on the bottom of Rupert Inlet soon after discharge, but some small particles (< 5 um) become suspended in the water column (Goyette and Nelson 1977). Additional quantities of small particulates are subject to resuspension by tidal currents (Goyette and Nelson 1977). Increased concentrations of copper and zinc in the sediments are associated with the tailings.

The tailings have gradually moved along the bottoms of Rupert and Holberg Inlets. Movement of the tailings away from the deposition point is thought to be caused primarily by tidal currents (Goyette and Nelson 1977), although slumping of tailings from one wall of the fjord to the opposite wall may also occur (Evans and Poling 1975). Goyette and Nelson (1977) note that the deposition of tailings was initially predicted by Utah Mines Ltd. to occur only in Rupert and Holberg Inlets at depths greater than 100 m. This prediction was based on limited current data collected at two stations, the first between Quatsino Narrows and Hankan Point and the second near the mine site. Utah Mines Ltd. interpreted these data to indicate that current velocity would be highest above a depth of 60 m, and that a zone of vertical stability would exist from 60-m depth to the bottom of the inlet (Goyette and Nelson 1977). Contrary to prediction, tailings deposition in the nearshore area was increasing during the summer of 1975, and geochemical data suggested that tailings were also spreading into Quatsino Sound (Goyette and Nelson 1977).

Turbidity has increased markedly in Rupert and Holberg Inlets, primarily through the resuspension of the fine particulates by currents (Goyette and Nelson 1977). Whereas most of the suspended particles were predicted to occur at depths in excess of 60 m, high turbidity levels are usually encountered below 30 m (Goyette and Nelson 1977). Furthermore, "extreme turbidity can exist throughout the entire water column" (Goyette and Nelson 1977). Disposal of tailings into Rupert Inlet has not appreciably altered levels of "dissolved" (e.g., passing through a 0.45 um filter) heavy metals, total cyanide, total mercury, pH, salinity, alkalinity, or dissolved oxygen in the water column (Evans et al., 1972).

The major biological impact of tailings disposal into Rupert Inlet has been the obliteration of the benthic community. After three and one-half years and the disposal of 35 million tons[a] of tailings, mine-derived

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[a] The comparable volume of nodule processing rejects from a single plant over a 3 1/2-year period would be approximately 10.5 million tons.

tailings in excess of 30 cm thickness had spread throughout the trough of Rupert Inlet and about 3 km into the trough of Holberg Inlet (Evans and Poling 1975). The area covered by such tailings was about 1.6 km^2 at the time of the report by Evans and Poling (1975). The area so affected may now be substantially larger, since tailings were continuing to spread throughout Rupert and Holberg Inlets in 1973-74 (see Goyette and Nelson 1977). Smothering does not occur in shallow water or in the more distant portions of Holberg Inlet, but the deposition of sub-lethal accumulations of tailings appears to reduce biological productivity (Jones and Ellis 1976; Goyette and Nelson 1977; Ellis 1978). The diversity of the benthic community is reduced on tailings deposits up to 26 cm thick, but on tailings deposits of 9 cm thickness or less, species assemblages are indistinguishable using multivariate analysis techniques (Ellis 1978).

In contrast to the benthos, other biological communities in Rupert Inlet appear to be little influenced by the disposal of tailings. After three and one-half years of tailings disposal, Evans and Poling (1975) concluded that there had been "no discernible influence" on phytoplankton, zooplankton, intertidal macroinvertebrates, intertidal fishes, intertidal and sublittoral algae, Dungeness crabs, and pelagic and demersal fishes. The authors failed to find statistically significant correlations between variations in these biological communities and the distribution of tailings.

The bioaccumulation of metals is evident only in the tissues of some species of shellfish. Other organisms are apparently unaffected (Evans et al., 1972; Ellis 1978). Ellis (1978) credits effluent controls and the use of the deep outfall for "controlling traditional metal accumulation problems" which have characterized tailings disposal into shallow water environments. Elevated levels of copper have been found in two species of bivalves, however. Whereas control levels of copper are 5 to 87 ug/g in the mussel Mytilus edulis, levels at Hankin Point (at the junction of Rupert and Holberg Inlets) are 82 to 150 ug/g (Goyette and Nelson 1977). Temporal data on the accumulation of copper in the tissues of M. edulis suggest that levels do not increase consistently through time (Ellis 1978). Levels of copper in the tissues of the deposit-feeding bivalve Macoma iris appear to be inversely correlated with distance from the tailings disposal area. Tissue levels at Red Island, east of the disposal site, averaged 30 ug/g, tissue levels at a location just west of the disposal site averaged 66 ug/g, and tissue levels in Holberg Inlet averaged 30 ug/g (Goyette and Nelson 1977). In summary, Ellis (1978) concluded that while no short-term problems were evident for metals accumulation in the biota of Rupert and Holberg Inlets, insufficent time had elapsed for the evaluation of long-term problems.

Impacts of the disposal of copper tailings from the Britannia mine on the ecology of Howe Sound, British Columbia (Figure 40) have been studied less extensively than impacts in Rupert and Holberg Inlets; nevertheless, a considerable body of information exists. As in Rupert and Holberg Inlets, the most obvious impact of the tailings is the complete burial of the natural sediments in a portion of Howe Sound, and the "substantial disruption" of solid substrate habitats by tailings (Goyette 1975). The benthic biota is completely absent in the area adjacent to the Britannia

town docks to a depth of 33 m (McDaniel 1973). Tailings completely cover this part of Howe Sound, blanketing the natural substrate and precluding the development of a benthic community. Areas immediately north and south of the tailings disposal site also exhibited depauperate benthic communities (McDaniel 1973).

In nearshore areas, effluent and tailings from the Britannia mine "visibly discolored the shoreline" for 1 km on either side of the mine, and caused biological diversity to be reduced for up to 2 km distant (Levings and McDaniel 1973; Ellis 1978).

Biological observations by submersible indicate that the benthic fauna in the area consists of a "sparse fauna of very large animals" (Levings and McDaniel 1973). Levings and McDaniel (1973) reported that benthic organisms are particularly sparse in those deeper parts of Howe Sound where a turbidity cloud resulting from effluent and tailings disposal exists within 20 m of the bottom. They speculated that the obliterative effects of the tailings would probably be long-term, since larvae would not find the areas of constant tailings deposition and reworking to be suitable for settlement. Levings and McDaniel (1973) observed "normal" benthic communities in areas north and south of the tailings deposits.

Concentrations of copper and zinc in the sediments of Howe Sound are greatly enhanced when compared with four "control" areas within Howe Sound (Thompson and McComas 1974). In a subsequent study, Thompson and Paton (1978) found the interstitial waters of the surface sediments to be enriched in dissolved copper when compared with the underlying, deeper sediments. Thompson and Paton (1978) speculated that "diagenetic and/or complexation processes" were responsible for the release of dissolved copper from the sediments in the near-bottom waters, which exhibited higher concentrations of dissolved copper than did surface and mid-depth waters.

Concentrations of copper and zinc in the tissues of the mussel Mytilus edulis and the oyster Crassostrea gigas in Howe Sound and adjacent waters indicate widespread contamination of these filter-feeding shellfish in Howe Sound, where tissues of specimens were green. The sources of the copper and zinc are speculated to be the acid mine wastes disposed of in Britannia Creek (Goyette 1975) and the submerged tailings in Howe Sound (Thompson and McComas 1974). Thompson and Paton (1978) caution, however, that the bioavailability of copper from the several possible sources in Howe Sound is unknown, since the chemical speciation associated with each source is unknown.

Limited environmental data from the Jordan River Copper Mine (B.C.) document some of the same types of impacts which were observed at the Island Copper Mine and the Britannia Copper Mine, but on a smaller scale because of the smaller discharge volume (Table 40). Tailings disposed of at 3 m depth smothered the benthic fauna over a few tens of square meters in the immediate discharge area (Ellis 1978). Suspended solids concentrations were occasionally elevated near the outfall, but levels of dissolved and particulate heavy metals in the water column did not increase (Ellis 1978). Beach sediments near the outfall exhibited significantly higher (probability

level not given) concentrations of copper than did control sites, but the data did not indicate that copper levels in the sediments near the outfall were increasing during the last 2.5-year period of operation (Ellis 1975). Six months after disposal ceased, copper levels in the sediments near the outfall and downstream of the outfall (by longshore drift) remained high, while levels upstream of the outfall dropped. Ellis (1975, 1978) found copper levels in the tissues of littleneck clams (Protothaca staminea) to be elevated near the discharge, but concluded that these higher levels were caused by uncontrolled beach discharges prior to the last operational period (1972-1974), and that the regulated discharge of 1972-1974 did not contribute to the contamination of littleneck clams.

Although the Atlas Consolidated Copper Mine (Cebu, Philippines) disposes of over 68,000 tons of tailings per day, little information on the environmental impacts of those tailings is available. At the time of disposal, tailings flow down a trench into Tanon Strait. By 1972, the tailings stabilized at a minimum depth of 12 m below sea level on the floor of Tanon Strait, and reached an equilibrium slope of 20 percent (Salazar and Gonzales 1973). Deposition of tailings did not occur beyond 244 m from the discharge at that time. Salazar and Gonzales (1973) report "no adverse effects on the marine life in the area," and state that the discharge point has become a favorite fishing area. The basis for these conclusions are not given.

Data collected by Castilla and Nealler (1978) indicate that the nearshore disposal of copper tailings from the El Salvador Copper Mine has caused substantial ecological damage. Tailings have accumulated in Chañaral Bay (Figure 42), the first disposal area, to a depth of 2 m. Turbidity is high, as indicated by Secchi disk readings of 2 to 3 m in Chañaral Bay and only 0.6 m in the present disposal area at Caleta Palito.

Castilla and Nealler (1978) found Chañaral Beach to be totally devoid of sandy beach macrofauna. Adjacent hard substrates were also devoid of biota. Although no data on plankton were presented, the authors stated that they believed plankton communities in Chañaral Bay to be adversely affected by the resuspension of tailings caused by waves and currents.

Prior to the discharge of tailings at Caleta Palito, "rich" intertidal and subtidal benthic communities were present (Castilla and Nealler 1978). Initiation of the discharge saw "massive fish and molluscs mortalities" within a few days, and the "substantial" alteration of the remaining biota by chemical and physical processes. The mass mortalities of sea stars, limpets, crabs, urchins, fishes, and littoral algae which occurred in July, 1975, the first year of the discharge, recurred again in July, 1976 (Castilla and Nealler 1978). The discharge at Caleta Palito also causes greenish pyrite slicks on the water surface, and shoaling of the nearshore receiving environment.

The copper mine at Repparfjord, Norway, has been in operation since 1972, but no data on the environmental impacts of the tailings are presently available. Doughty (1975) states only that the tailings have not contaminated the fjord, and that the fishing season has never been disrupted.

Iron Mines--

Tailings from the Ma On Shan Iron Mine in Hong Kong have spilled over the nearshore retaining dams (Figure 45) and into the littoral and sublittoral environment (Wong et al., 1978). Consequently, substrate characteristics in that area have been altered. Compared with sediment at Long Harbour and Railway Beach, sediments near the Ma On Shan mine are of finer texture (Table 46) and more alkaline (Table 47), and contain lower amounts of organic carbon, total nitrogen, and available phosphate (Table 47). Wong et al. (1978) reported that sediments in the tailings disposal area exhibited higher levels of copper, iron, manganese, lead, and zinc than sediments at Long Harbour and Railway Beach. Only levels of cadmium and chromium were not enhanced at the disposal site.

Biological effects of tailings disposed at Ma On Shan were ascertained through comparisons of macrofauna at the disposal site with macrofauna at Long Harbour and Railway Beach. Effects of tailings disposal included: 1) the development of a fauna dominated by burrowing forms, especially molluscs and crustaceans, 2) a reduction in the number of species present, 3) enhanced abundances of the dominant mollusc and crustacean species, and 4) expanded depth ranges of two dominant brachyuran crabs (Wong et al., 1978). Bioassays of tissues from crabs and tissues and shell from edible bivalves revealed enhanced body burdens of copper, iron, manganese, lead, and zinc, compared with body burdens of those metals in specimens from Long Harbour and Railway Beach (Wong et al., 1978). Body burdens of cadmium and chromium were not elevated at the tailings disposal site.

Seven years after the abandonment of the Kennedy Lake Iron Mine on Toquart Bay, British Columbia (Figure 46), Levings (1975) conducted a series of biological observations along transects perpendicular to the shoreline. He found the distribution of tailings on the beach and in the bay to be "patchy". Patches of black magnetite sand lost during the loading process exhibited the greatest variety of benthic infauna, including littleneck clams (Venerupis japonica). Tailings deposits were found to support only populations of the soft-shelled clam Mya arenaria. "Natural" substrates in adjacent areas ranged from coarse sands to cobbles. Few organisms were observed in the coarse sand, but the hard substrates were colonized by numerous epifaunal forms.

Lead-Zinc Mines--

No data on present environmental conditions in the receiving environment near the Greenex Lead-Zinc Mine (Figure 47) are available at the time of this writing. However, after 1 year of operation (1974), toxic and burial effects of tailings from the mine had obliterated 90 percent of the benthos in Agfardlikavsa Fjord (Anon. 1975). Concentrations of zinc, cadmium, and lead were high in the waters of Agfardlikavsa Fjord and in the proximal portion of Qaumarujuk Fjord. Metals concentrations in the biota were also elevated: concentrations of lead and zinc in the tissues of mussels and seaweeds were as much as an order of magnitude higher than background levels at distances up to 5 km from the discharge point (Anon. 1975).

Bauxite Mines--

Red mud is not discharged into the marine environment at the bauxite refinery in Gove, Australia (Figure 49). However, incomplete neutralization of supernatant waters prior to their discharge into the estuary temporarily caused problems (Baseden 1976). Final neutralization of supernatant liquid by seawater in the estuary caused the deposition of white deposits of hydrated alumina and magnesium hydroxide in the estuary and on the mangroves. Some dead fish were observed, probably the victims of gill agglutination. The neutralization problem has since been eliminated, and after 18 months of operation, the mean numbers of benthic taxa at sites near the discharge point did not differ significantly (probability level not given) from pre-operational levels. It should be noted, however, that mangroves in areas adjacent to the disposal channels are being stressed by the discharge (Baseden 1976).

Although red muds are not discharged into the marine environment at Gove, they have been discharged elsewhere. Red muds owe their color to the presence of iron oxide (Fe_2O_3) which may constitute 2 to 25 percent of the mud. Blackman and Wilson (1973) review the effects of red muds on marine fauna, and stress that the toxicity of red mud varies due to differences in the chemical compositions of bauxite ores and differences in treatment processes. In general, red muds in suspension are more toxic than red muds deposited on the bottom. The toxicity of red muds also varies with the organism. Toxicity tests with the fish Agonus sp. suggest that red muds in suspension are especially toxic to fish. After comparing the environmental impacts of red mud disposal in two different marine receiving environments, Blackman and Wilson (1973) concluded that hydrographic characteristics of the receiving environment are the key factors which determine the extent and severity of impacts associated with red mud disposal. Impacts may be minimal or absent where circulation is good and turbulence within the water column is high. Alternatively, severe impacts may occur in receiving environments with poor circulation.

Potash Mines--

Although the Cleveland Potash Mine in Boulby, Yorkshire is operational, no environmental data are presently available. Design predictions indicate that the effluent will be jetted through nozzles on the sea bed. Dissolved solids are expected to be reduced to 36 ppt within 30 m of the discharge, and currents are expected to disperse much of the insoluble material (Cleasby et al., 1975).

Drilling Muds

Drilling muds are complex mixtures of barite, clay minerals, and several additives which are discharged to the sea near drilling operations. Drilling muds may contain relatively high levels of potentially toxic trace elements such as barium, chromium, zinc, copper, and lead. The metals in drilling mud discharges may occur as components of the mineral additives, as organic complexes (e.g., chrome lignosulfonate), or as part of the formation

drill solids. Numerous laboratory and field studies have been conducted on the effects of drilling mud discharges to the marine environment.

Near a drilling site in the area of the shelf break (120 m depth) along the mid-Atlantic coast, Menzie et al. (1980) observed lower abundances of macrobenthic organisms, although the trophic relationships among the dominant infauna, as represented by polychaete feeding guilds, were apparently not affected by the discharge (Maurer et al., 1981). The density decreases were attributed to an increase in the clay content of the sediments and increased predation by demersal fishes and megainvertebrates, which were attracted to the area by increased microrelief of the substrate. Sessile benthic organisms were also smothered by the discharge. Several organism groups had elevated tissue concentrations of barium and mercury following drilling discharges; however, no simple correlation existed between the metal concentrations in the sediments and in organism tissues (Mariani et al., 1980). Chromium concentrations were elevated in post-discharge polychaete samples, but were unchanged in sediments, molluscs, and brittle stars. This relationship emphasizes the need to study metal availability according to species groups and discharge characteristics, since the drilling mud discharged at that site contained over 1,100 mg/kg (dry weight) of chromium (Ayers et al., 1980).

Smothering of benthos and elevated sediment metal concentrations were also observed at a drilling mud discharge site in the Beaufort Sea (Crippen et al., 1980). There was no correlation between sediment metal concentrations and organism tissue levels, however, and the only evidence for bioaccumulation was for mercury, which was elevated 185 times above background levels in surficial sediments.

Hydrodynamic characteristics near drilling mud discharge sites have been shown to have a pronounced effect on solids depositional patterns and benthic effects. At a well site in lower Cook Inlet, Alaska, ($\sim$60 m depth) strong currents prevented any detectable localized accumulation of drilling solids (Houghton et al., 1980). There were also no measurable effects on benthic macroinvertebrate communities near the discharge site (Lees and Houghton 1980). Meek and Ray (1980) detected measurable settling of drilling solids within 150 m of a site on Tanner Bank, California ($\sim$60 m depth). Following discharge, however, wave and current induced resuspension of deposited particles resulted in 70-90 percent of the discharged material being transported away from the site and dispersed to undetectable levels.

Dredged Material Disposal

Dredged material removed during harbor and channel maintenance operations is disposed into the nearshore marine environment in many coastal areas of the U.S. Although the biological effects of dredged material disposal are relatively well documented by laboratory bioassays and field surveys, the potential impacts are not directly comparable to the case of manganese nodule reject disposal. The potential acute effects of burial of benthic organisms are probably similar for the two wastes, although the potential recovery of normal benthic communities may be quite different.

The immediate effects of dredged material disposal on the benthos are associated with smothering of organisms unable to burrow to the surface of the newly-deposited sediments. Examples of such organisms include tubiculous polychaetes and some amphipods. Even for some relatively active forms, the change in natural sediment grain size or compaction may result in the new substrate being unacceptable. Thus, the immediate effects of sediment deposition are usually declines in species richness and biomass of infaunal and epifaunal organisms (see, for example, Boone et al., 1978; Oliver et al., 1977).

The first recovery stage following deposition of dredged material is usually evidenced by an immigration of large megafaunal organisms, such as peracarid crustaceans, demersal fishes, and echinoderms. This early recolonization phase is obviously affected by the availability of potential recruits from surrounding habitats. The second successional phase is usually characterized by high abundances of opportunistic polychaetes. Such species are usually subsurface deposit feeders, which utilize organic matter contained in the deposited material.

Many infaunal and epifaunal organisms from coastal areas are adapted to relatively high sedimentation rates or other sediment disturbances (e.g., longshore transport or wave-induced resuspension). These organisms display considerable ability to tolerate single-event covering by natural sediments. Swartz et al. (1979) reported that test organisms (bivalve molluscs, polychaetes, amphipods, and cumaceans) did not have increased mortalities at 10 days following burial by up to 30 mm of clean sandy sediment (209 um mean grain size). With the exception of cumacean mortalities in very coarse sediments, the test assemblage was not adversely affected by alterations in sediment grain size (26 to 1,395 um mean grain size) after a 15 mm burial. In a series of laboratory exposures simulating dredged material disposal, Maurer et al. (1978) found that many of the test species (e.g., polychaetes, amphipods, and gastropod molluscs) were able to successfully migrate through 10-20 cm deep layers of deposited sediment. The authors emphasized, however, that survival following burial was highly dependent upon sediment type, species, and temperature. Thus, extrapolations of the data to field situations should be done with caution.

Although motile benthic fauna may tolerate considerable sedimentation, sessile epifauna (e.g., corals, oysters, mussels) are sensitive to smothering by a relatively thin layer of sediments. For these organism groups, the impacts of sediment smothering may be long-lasting, since repopulation would require recruitment by larval settling and the modified substrate may be unacceptable for larval attachment.

Dredged material may contain from < 1 to 18 percent organic matter and therefore has nutritional characteristics considerably different from the primarily inorganic nodule rejects and wastes. The inorganic nature of the rejects will probably restrict the initial recolonization by opportunistic species. Colonization by megafauna may also be altered because of lack of infaunal prey items.

Sewage Solids

Sewage solids are discharged to the marine environment through outfalls and by dumping. These wastes have a relatively high organic component and, as such, are considerably different from the entirely inorganic nodule rejects. Sewage solids have been shown to cause severe modifications in the structure of benthic communities in localized areas near sewage outfalls (Bascom et al., 1978; Mearns 1981). However, many of the effects may result from sediment oxygen depletion in areas of high solids deposition and from modifications in normal trophic relationships due to increased organic content of the sediments. The sewage wastes from large municipal areas generally have high levels of metals such as silver, cadmium, zinc, copper, nickel, chromium, and lead. Thus, although the metals are primarily adsorbed onto organic particulates in sewage wastes, examination of the degree and extent of contamination provides some indication of the potential effects of manganese nodule reject disposal if differences in bioavailability are disregarded.

Extensive studies near highly-contaminated areas of the southern California Bight (Los Angeles County sewage outfall) have demonstrated significantly higher tissue burdens of several metals in filter-feeding bivalve molluscs such as mussels (Mytilus californianus) and rock scallops (Hinnites giganteus) (Young et al., 1978). A lesser degree of elevated tissue metal concentrations has also been detected in other invertebrates such as abalone, rock crab, and spiny lobster. An important finding of the southern California studies is that demersal fishes (Dover sole; Microstomus pacificus) living in direct contact with the highly-contaminated sediments near a major outfall displayed no evidence of overall tissue contamination by seven metals (McDermott et al., 1976).

A similar pattern has been observed at ocean disposal sites receiving sewage sludge and dredged materials in the New York Bight and Long Island Sound. Grieg et al. (1977) reported that windowpane flounder (Scophthalmus aquosus) collected near the dump sites did not accumulate metals to a greater degree than at a control site. The only metal showing increased concentrations in rock crabs from the disposal sites was silver (approximately 3x elevation). Grieg and Wenzloff (1977) also found no evidence of bioaccumulation of metals in winter flounder (Pseudopleuronectes americanus) collected from the New York Bight sewage sludge dumpsite. The ability of fishes in contaminated areas to regulate toxic metals is also indicated by studies from the Derwent Estuary, Tasmania (Eustace 1974), the Firth of Clyde, U.K. (Halcrow et al., 1973), and deepwater disposal site No. 106 (Grieg et al., 1976).

Summary

A review of the impacts of other wastes in the marine environment indicates the general kinds of potential impacts that may occur following manganese nodule processing waste disposal. Although no currently produced wastes could be expected to accurately simulate manganese nodule rejects, mine tailings and, to a lesser extent, drilling muds probably provide the most applicable information on generic impact types. This is because these

wastes are both inorganic and fine grained. Other substances disposed of in the marine environment have significant organic components (e.g., sewage solids and dredge spoils), resulting in quite different potential impacts on marine organisms.

The available ecological data on the marine disposal of mine tailings, most of which deals with impacts of the disposal of copper mine tailings, indicate that the primary effects are the smothering of benthic communities and the bioaccumulation of certain metals in some animal species. The effects of the burial of natural benthic substrates by a layer of inorganic particulate mine tailings vary with the depth of burial. Whereas deep burial may result in a total obliteration of the pre-existing benthic communities, sublethal accumulations may only result in a reduction in biological productivity. In the vicinity of the Island Copper Mine, for instance, benthic diversity was reduced on tailings deposits up to 26 cm thick, but on deposits of less than 9 cm, species assemblages were unchanged.

Although mass mortalities of fishes, molluscs, limpets, crabs, urchins, sea stars, and littoral algae were reported upon initiation of the tailings discharge from the El Salvador Copper Mine, extensive studies near the Island Copper Mine have failed to detect any influence on phytoplankton, zooplankton, intertidal macroinvertebrates, intertidal fishes, intertidal and sublittoral algae, Dungeness crabs, and pelagic and demersal fishes. Hence, it is not clear that mine tailings discharges consistently impact communities other than the subtidal benthos.

With regard to bioaccumulation of metals, the only organisms which demonstrate a consistent pattern of metal uptake in the presence of mine tailings are the bivalve molluscs (e.g., mussels, clams, oysters). Even so, bioaccumulation is apparently dependent upon organism species and the physical/chemical form of the metal. The potential for bioaccumulation of metals contained in the waste depends on the concentration of the dissolved metal in the effluent, the release of dissolved metals from the disposed tailings into seawater, and the release of dissolved metals from ingested particulates in the digestive tracts of the organisms in question. It seems apparent that metal release from the disposed tailings is a function of the metal-binding capacity of the tailings, which in turn is a function of the geochemistry of the tailings. In this sense, these results are not directly applicable to an estimation of the potential for bioaccumulation of metals from manganese nodule processing wastes, since the metal-binding capacity of these wastes is unknown at this time.

The deposition of drilling muds on the ocean floor has been shown to result in a reduction in the abundance of macrobenthic organisms, although the trophic relationships among the dominant infauna were not affected. The reductions in abundance appeared to be related both to a change in the grain size of the sediments and to increased predation by fishes and megainvertebrates. Sessile benthic organisms were also smothered by the drilling mud deposits. Although drilling muds may contain relatively high levels of metal ions such as chromium, zinc, copper, and lead, and although the deposition of drilling muds on the seafloor may result in higher

sediment concentrations of such metals, evidence for the uptake of these metals by organisms found in the presence of such deposits is inconsistent.

In most respects, sewage solids and dredge spoils are sufficiently different from manganese nodule processing wastes that an examination of their ecological impact on marine communities is of little value for predicting the effects of the marine disposal of manganese nodule processing rejects. While sewage solids often have high levels of metals such as silver, cadmium, zinc, copper, nickel, chromium, and lead, and bioaccumulation of several of these metals has been demonstrated for marine organisms inhabiting the area around large sewage outfalls, the metal-binding capacity of the largely organic sewage solids is likely quite different from the metal-binding capacity of manganese nodule processing rejects, and therefore extrapolation of these results is unwarranted.

GENERIC EFFECTS OF MANGANESE NODULE PROCESSING REJECTS DISPOSAL ON MARINE COMMUNITIES

Possible Biological Impacts of the Deep Ocean Disposal of Manganese Nodule Processing Rejects

Wastes resulting from the smelting of manganese nodules would likely consist of two fractions: a fine particulate fraction having a particle size similar to that of clay and a coarse fraction having a particle size similar to that of coarse sand. Disposal of the fine particulate matter would be subject to many of the same considerations to be discussed later with regard to the disposal of the fine particulate wastes from the various hydrometallurgical processes. In particular, the settling velocities of the particles in these wastes would likely be of similar magnitude, and hence, those factors affecting where, when, and how these materials were deposited, and how long they might be expected to remain in the water column, would be similar. They may, of course, have different chemical characteristics. Nevertheless, for the purposes of this discussion, the effects of the disposal of this fraction on open ocean communities will be considered to be similar to those discussed below for the hydrometallurgical process wastes.

Due to the large particle size of the coarse fraction (> 1.7 mm), settling velocities would be much more rapid than those of the fine particulates. In fact, even in water of several thousand meters depth, the coarse fraction would likely settle to the bottom on a time scale of hours. Hence, this waste fraction will not likely have any appreciable impact on biotic communities within the water column. Depending upon the dispersal of this slag, it may cover and kill the benthic communities in a given locale, although the area involved would likely be small. Since natural sedimentation rates in the deep ocean are quite slow (on the order of millimeters per thousand years), slag deposited on the ocean floor may not be covered for a very long time, and hence, the soft-substrate benthic communities at that locale, which are adapted to living on a substrate of clay-size particles, would not be expected to recover until burial was complete. If, as expected, the slag is relatively inert, leaching of heavy metals or other potentially toxic constituents would not be expected to occur, and hence, biological uptake of these materials is unlikely.

Wastes resulting from the various hydrometallurgical processes would consist of a slurry of fine particulate matter and various dissolved substances. The communities impacted by the deep ocean disposal of such wastes and the nature of those impacts would be influenced by the method of introducing the wastes into the ocean. The waste slurry could be dumped en masse in a manner analogous to the barge dumping of dredge spoils, or the slurry could be pumped overboard in various ways. The ship carrying the wastes could be stationary or under way, and the wastes could be discharged at the surface or by pipe to some subsurface depth. The rate of pumping could also be varied.

The effects of inorganic particulate suspensions on marine fauna have been reviewed in detail by Moore (1977). Responses of organisms to particulate exposures are highly dependent upon species, life history stage, particle characteristics, and water quality. Effects may be lethal, sublethal, direct, or indirect. For example, sponges and corals are generally highly susceptible to damage from sedimentation, while many adult fishes can tolerate relatively high levels of suspended solids. In fishes, juveniles are generally more susceptible to damage from particulates than are adults. Adverse effects of suspended particulates on fishes are usually associated with gill clogging, and highly angular particles have been shown to cause more severe effects than spherical particles (Moore 1977). Major potential impacts of suspended particulates on several organism groups are summarized in Table 31.

If processing wastes are introduced into the euphotic zone, either by dumping or by pumped discharge at the surface, phytoplankton could be impacted in several ways. The fine particulate fraction of the slurry would cause some increase in turbidity. The exact magnitude of this increase will depend on the method of release of the wastes (e.g., a pumped discharge into the surface layer would probably result in greater turbidity than would a barge dump, which would leave a smaller residual amount of particulate matter in the upper layers of the ocean). An increase in turbidity will cause a decrease in the penetration of sunlight, and hence, decrease phytoplankton photosynthesis.

There is also a possibility that the discharge of wastes could stimulate phytoplankton production if appreciable quantities of limiting nutrients were dissolved in the liquid fraction of the slurry. For instance, phytoplankton production in much of the ocean is known to be limited by the availability of fixed nitrogen, so appreciable quantities of dissolved ammonium and/or nitrate could stimulate production. Other possible stimulatory nutrients include silicate (necessary for the growth of diatoms) and trace metals (like iron, which has been shown to be limiting in some cases). Alterations in the availability of nutrients can also bring about changes in the species composition of the phytoplankton community.

There is considerable variability in the response of phytoplankton species to the addition of relatively small quantities of trace metals. The most commonly reported response is a reduction in the rate of primary production by the phytoplankton (cf. Knauer and Martin 1972; Patin et al.,

TABLE 31. SUMMARY OF POTENTIAL IMPACTS OF INORGANIC PARTICULATES ON MARINE FAUNA

Organism Groups	Potential Effect
Porifera	Burial, clogging of pores, reduced pumping
Corals	Burial, reduced larval settlement
Polychaeta	Smothering, clogging of mucus nets, reduced larval settlement
Copepoda	Clogging of filtering mechanism, reduced food intake
Bivalve molluscs	Reduced feeding efficiency, gill clogging, larval mortality, reduced settling, shell deformities
Fishes	Gill clogging and erosion, respiratory stress, modified swimming behavior, smothering of eggs

Reference: Moore (1977).

1974; Ibragim and Patin 1976). Toxic effects of metals such as copper and zinc are apparently related to the free metal ion activity in the water, rather than the total metal concentration (Sunda and Guillard 1976; Canterford and Canterford 1980; Huntsman and Sunda 1981). The activities of the free metal ions are difficult to predict, however, because they are only partially determined by the total metal concentration in the water. For most of the heavy metals (e.g., mercury, cadmium, silver, nickel, selenium, lead, copper, chromium, arsenic, and zinc) the free metal ion activities are a function of the pH and alkalinity of the water, the concentration of natural organic or inorganic ligands (e.g., Cl^-, $SO_4^=$, or humic substances), the concentration of competing metals, and the presence of adsorptive surfaces (Sunda et al., 1978). At any given time, it is likely that the bulk of a given metal is bound up in organic or inorganic complexes, or adsorbed onto the surface of suspended particulates. Iron/manganese oxides are one of the most important sinks for metals in the marine environment, and since manganese oxides are a major component of the manganese nodule rejects, it is likely that most of the metals contained within the rejects would be either adsorbed onto the particulate wastes, precipitated as hydrous oxides, or bound in the original nodule matrix.

Even very low free metal ion activities may have adverse effects. Toxic effects of copper on phytoplankton have been observed at cupric ion activity levels ($\sim 10^{-9.6}$ moles/l) similar to those calculated for natural ocean waters with no organic ligands present (Anderson and Morel 1978; Reuter et al., 1979). Thus, relatively small increases in natural cupric ion concentrations in open ocean waters could potentially result in toxic effects on sensitive species. While it is generally true that the free ionic species of the metal is the most bioavailable, this is not always the case. Certain organomercurial compounds are more toxic than mercury as $HgCl_2$, for instance (Huntsman and Sunda 1981).

The free metal ion activities in the immediate vicinity of the disposal of manganese nodule processing rejects in the open ocean will depend on factors such as the total concentration of the metals, the pH of the solution, the sorptive capacity of the particulate wastes, and the natural organic or inorganic ligands present in the water. Generalizations concerning the behavior of trace metals in the marine environment are difficult to make since individual metals have different affinities for naturally occurring ligands (Engel et al., 1981). For example, copper has a very high affinity for organic matter and could be expected to exist primarily in association with organic ligands in nearshore areas of high organic content. In contrast, cadmium has a low affinity for organic ligands and could be expected to occur primarily as $CdCl_2$ in seawater.

For laboratory cultures, it is sometimes possible to estimate the metal speciation, but for natural oceanic waters, the theoretical calculation of the metal speciation is of little value because the nature, concentration, and metal binding capacity of naturally-occurring organic ligands is unknown (Canterford and Canterford 1980). Consequently, it would be difficult to predict the effect on phytoplankton of the addition of a given quantity of any of these metals to the euphotic zone of the open ocean.

Whereas the initial effect of the addition of trace metals to unpolluted waters may be a reduction in the rate of photosynthesis, the primary effect will be to alter the species composition and succession of a phytoplankton community (Huntsman and Sunda 1981). Phytoplankton species are known to vary in their sensitivity to the toxicity of free metal ions (Erickson et al., 1970). The result of their varying sensitivities may be that the more resistant species replace the more sensitive species (Thomas and Seibert 1977).

The residence time of these ions within the euphotic zone will depend on the disposal method, the currents, the density stratification, and the various processes affecting the residence time of the particulate fraction. The multiplicity of factors affecting these processes makes it impossible to predict the effects on phytoplankton. In all likelihood, such effects would be relatively small in spatial extent, but their temporal persistence is entirely unpredictable with information currently available.

Changes in either the level of primary production or the phytoplankton species composition could cause changes at higher trophic levels, since, as discussed earlier, nearly all life in the deep ocean is ultimately dependent on phytoplankton for the fixation of carbon. Since impacts of waste discharge on phytoplankton are likely to be extremely localized, however, it is unlikely that higher trophic level effects would be significant. Fine particulate matter will slowly sink out of the euphotic zone, and the dissolved components of the discharge may be diluted beyond levels having any impact on phytoplankton production. The presence of a strong pycnocline, however, could cause a retention of particulate matter deep within the euphotic zone, and this could have important consequences for phytoplankton, especially in those areas where phytoplankton are aggregated at such depths (Chan and Anderson 1981).

Zooplankton throughout the water column are also potentially affected by the deep-sea disposal of nodule processing wastes, but since the biomass of zooplankton is much greater in the first several hundred meters, the method of disposal will have a pronounced effect on the magnitude of any such adverse impact. A pumped discharge of wastes into the surface layer would likely have the greatest effect on zooplankton. Pumping the wastes to intermediate depths (several hundred meters) could lessen potential impacts on zooplankton. The effect of a barge dump would likely depend upon the amount of the particulate matter remaining behind in the water column.

Adverse effects on zooplankton could occur in several ways. Some dissolved components of the wastes may be directly toxic to zooplankton. It has been demonstrated, for instance, that the free cupric ion may be toxic to a freshwater crustacean, Daphnia magna (Andrew et al., 1977), while the free cadmium ion may be toxic to a shrimp, Palaemonetes pugio (Sunda et al., 1978). Since many zooplankton are filter feeders, the introduction of inorganic particulate matter may interfere with zooplankton grazing. The fine size of the particulate matter is similar to the size range of phytoplankton ingested by zooplankton. This material could clog zooplankton filtering apparatuses, abrade their mouth parts, and/or actually be ingested by the animals. Such effects could cause zooplankton mortality or simply

reduce the efficiency of their grazing on phytoplankton. Similar effects have been demonstrated for marine planktonic copepods (Calanus helgolandicus) which ingested large amounts of "red mud," the residual substance after the extraction of aluminum from bauxite (Paffenhofer 1972). If the particulate matter is inert, the zooplankton may simply pass it through their guts and incorporate it into fecal pellets. This is, in fact, a beneficial result of zooplankton grazing (i.e., the removal of fine particulates from sea water and the incorporation of this material into much larger pellets which consequently sink much faster out of the water column; cf. Hirota 1981). If, however, heavy metals or other potentially toxic constituents of the particulate matter leach out in the zooplankton guts, they may be taken up by the zooplankton and incorporated into their tissue. This may provide an avenue for this material to begin bioaccumulating.

Just as for phytoplankton, adverse effects on zooplankton may have important ramifications for higher trophic levels, since nearly all are dependent on the transfer of organic matter, produced by phytoplankton, through the zooplankton, before it can become available to other animals. Adverse impacts on zooplankton within the euphotic zone would likely be extremely localized, however, for the same reasons as for phytoplankton. Adverse impacts on zooplankton below the euphotic zone may be more widespread and long lasting, depending upon the amount of particulate matter retained within the water column. This in turn is dependent not only upon the disposal method, but also upon the density profile of the water column and ambient currents in the area. Zooplankton below the euphotic zone are less likely to be adversely impacted by fine particulates, however, since most species there are carnivores, rather than filter feeders.

Among the pelagic fishes of the open ocean, perhaps the most susceptible stages to adverse effects of nodule processing wastes are the eggs and larvae, together referred to as ichthyoplankton. Direct toxic effects of dissolved substances on ichthyoplankton are a distinct possibility. Engel and Sunda (1979) have demonstrated, for instance, that the free cupric ion is capable of inhibiting hatching by the eggs of two marine fish species, spot (Leiostomus xanthurus) and Atlantic silverside (Menidia menidia). Other fishes may also be susceptible to the effects of free metal ions. Larval fish generally feed on phytoplankton and/or small zooplankton. Their ability to do so may be impaired by the presence of large quantities of fine particulate matter, which could decrease the visibility of the food to these larvae. Ingestion of fine inorganic particulate matter may also block food intake, as demonstrated for herring larvae which ingested "red mud," the waste generated by aluminum production from bauxite (Rosenthal 1971). Larval fish may also be indirectly affected by adverse impacts on phytoplankton and/or zooplankton. Ichthyoplankton would be particularly susceptible to adverse effects if the processing wastes were discharged at the surface, since most ichthyoplankton are found near the surface. Discharging at depths below the epipelagic zone (0-100 m) or dumping the wastes en masse would likely minimize the potential impacts on epipelagic ichthyoplankton. It should be emphasized, however, that available information on zooplankton and ichthyoplankton inhabiting the mesopelagic zone (100 to 1,000 m) is limited.

Adult pelagic fishes are less likely to be adversely affected by any form of disposal of nodule processing wastes. Because of their strong swimming abilities, pelagic fishes should generally be able to avoid turbid water areas created by the disposal of such wastes. Experiments conducted with tunas in captivity have demonstrated that they are able to detect and avoid areas of high turbidity (Barry 1978). At the highest turbidities tested, tunas sometimes stopped feeding and occasionally engaged in a behavior described as "coughing" if they entered the turbid water (Barry 1978). It seems likely that the avoidance of turbid waters by tunas is a response to the visual properties of the water, and that their cessation of feeding upon entering turbid water is due to their inability to locate prey (Barry 1978). Such turbidity-related effects would of course be extremely localized and short-lived since the residence time of the particulate matter in the euphotic zone would be relatively short, and it is doubtful that these far-ranging fishes would spend an appreciable amount of time within such areas. Barry (1978) reported no ill effects on the captive tunas during short-term exposure to turbid waters. Similar arguments could be advanced for the lack of expected turbidity-related effects on other nektonic species, including the marine mammals (i.e., whales, porpoises, seals, etc.).

Although marine fishes have been shown to have considerable ability to regulate most metals in their muscle tissues (Eustace 1974; Halcrow et al., 1973; Grieg et al., 1976), laboratory investigations indicate that the uptake of metals in marine fishes is complex, and dependent on fish species and tissue in addition to the form of the metal. Westerhagen et al. (1980) found that the liver was the main organ of cadmium accumulation in juvenile dab (Limanda limanda) and plaice (Pleuronectes platessa). Cadmium accumulated at relatively low levels in muscle tissue (2-3 x controls) after a 96-day exposure to a soluble cadmium concentration of between 5 and 50 ug/l. Although such laboratory experiments may provide information on potential metal uptake rates, depuration rates, and the fate of cellular metals, the relationship to potential bioaccumulation in the sea is questionable. In laboratory exposures, organisms are generally exposed to filtered seawater and a metal in the form of a soluble salt. In such cases, the metal would exist in solution primarily in ionic form or with a soluble inorganic ligand. Thus, the potential for direct uptake is considerably greater than under natural conditions where a metal may occur in a form much less available for direct uptake (e.g., adsorbed onto particulates). In addition, most pelagic fish species would spend such a short time in the presence of these wastes that bioaccumulation would be extremely unlikely.

Adverse impacts of the nodule processing wastes on deep benthic communities will likely vary depending upon the amount of material deposited on the sea floor, the dispersal of this material, and the amount and duration of increased turbidity just above the bottom. These factors will vary considerably with the disposal method chosen. Empirical relationships between solids deposition rates and changes in benthic community parameters are not available, although rough, qualitative impact estimates may be obtained by comparing predicted deposition rates due to ocean discharges or dumping with natural sedimentation rates. If the predicted rates are small relative to natural rates, it may be inferred that the potential for impacts

on the benthic communities will also be small. Alternatively, a high deposition rate of discharged solids relative to background values is indicative of a substantial impact potential, especially in communities adapted to naturally low sedimentation rates. It seems probable that the large, mobile scavengers would be able to avoid burial under a fine "rain" of particulate matter and that they would be able to evacuate areas of increased turbidity, if these areas were not too widespread. The area affected will of course depend on a number of factors, including the disposal method, the density profile of the water column, ocean currents, etc., and therefore the affected area is difficult to predict at this time.

Subsurface deposit-feeding animals would probably be affected the least of any benthic organisms because they are only dependent on the growth of bacteria beneath the surface of the sediments. Bacterial growth could be affected if the processing wastes buried the bottom with a sufficiently deep cover of sediments, but the depth of deposition required for such an effect is unknown (Jumars 1981).

Suspension feeders and surface deposit feeders would probably be similarly affected by the deposition of nodule processing rejects on the ocean floor and by the associated increased turbidity near the bottom. The former organisms feed on suspended particulate organic matter, while the latter ingest similar particles after they have settled on the bottom. If the fine particulate matter in the processing wastes "scavenges" organic matter from the water (i.e., if organic matter is adsorbed onto its surface), the particles could be ingested by these animals and provide them an increased food supply. The suspension feeders are likely adapted to very low ambient levels of suspensate, however, and their filtering apparatuses may be clogged if particulate levels are too great. In addition, since these animals live in an environment where natural sedimentation rates are on the order of millimeters per thousand years, they may possess only very limited burrowing abilities and they may be buried if the rate of sedimentation is too high. Burial under a layer of sediments, even if it is only a very thin layer, may result in mortality of these organisms (Jumars 1981).

If an area of the deep ocean floor was covered with sediments and the resident fauna irretrievably buried, it may be a very long time before the community returns to a "normal" state, since the majority of the meso- and macrofauna are slow-moving deposit feeders with low dispersal abilities. As in any environment where the natural community is removed, the first colonists will probably be those with the highest dispersal ability. It is impossible to predict recovery times, however, since the generation times of deep ocean benthic invertebrates are unknown. In addition, there is no way to predict the direction in which community succession will proceed, since such perturbations have never been studied in the deep oceans.

Considering that many of the deep ocean benthic organisms feed on particulate matter, there is a very real possiblity that they will ingest particulate-bound heavy metals or other potentially toxic substances and incorporate them into their tissues. While this would provide a starting point for bioaccumulation in benthic organisms, this is of less consequence

to humans than in other areas of the ocean (especially closer to shore) where the top carnivores may be ingested by humans and bioaccumulation may represent a health hazard. Hence, bioaccumulation will be discussed in detail only with regard to continental shelf organisms.

Possible Biological Impacts of the Disposal of Manganese Nodule Processing Rejects on the Continental Shelves

As in the deep oceans, the possible biological impacts of the dumping of wastes resulting from the smelting of manganese nodules would vary depending upon the size fraction of the wastes. For the purposes of this discussion, the effects of the disposal of the fine particulate fraction (clay-size particles) on continental shelf communities will be considered to be similar to those discussed below for the hydrometallurgical process wastes. Dumping of the coarse particulate fraction (sand-size particles) may cover and kill the resident benthic organisms, although the area involved would likely be small. Depending upon the conditions in the local area, slag dumped on the shelves may be buried by natural sedimentation (which would of course occur much more rapidly than in the deep oceans, since sedimentation rates on the shelves are much higher), or it may be swept clear by ambient currents, if they are sufficiently strong. If the slag is buried by natural sediments, the indigenous soft-substrate benthic fauna may return to the area. If, however, the slag remains free of sediments (which would likely occur where the natural substrate had also been sand-size particles) the slag may or may not be recolonized by the natural sand-dwelling fauna, depending upon its suitability (particle size, organic content, etc.) to these organisms. If, as expected, the slag is relatively inert, leaching of heavy metals or other potentially toxic constituents would not be expected to occur, and biological uptake of these materials would be unlikely.

The continental shelf communities impacted by the disposal of hydrometallurgical process waste slurries and the nature of those impacts would again be influenced by the method of introducing the wastes into the ocean. All dumping methods applicable to deep ocean disposal would also be possible on the outer continental shelves.

In the case of processing wastes introduced directly to the euphotic zone, the types of impacts on phytoplankton would likely be much the same whether the disposal was over the continental shelf or in the deep ocean. Increases in turbidity would cause decreases in the penetration of sunlight, and hence decrease phytoplankton photosynthesis. The magnitude of such an effect would again depend on the method of release of the wastes (e.g., a pumped discharge into the surface layer would probably result in greater turbidity than would a large-scale dump of the wastes, which would leave a smaller residual amount of particulate matter in the upper layers of the water column). Due to stronger currents, tidal mixing, and possible coastal upwelling over the shelves, there is a greater potential for these wastes to remain in suspension in the upper layers of the water column over the shelves than in the open ocean.

In areas where the low availability of nutrients naturally limits phytoplankton production, or at certain seasons when nutrients may be limiting, stimulation of phytoplankton production is also a possible effect of the disposal of manganese nodule processing wastes if the liquid fraction of these wastes contains either appreciable quantities of dissolved ammonium, nitrate, silicate, or trace metals. Alterations in the availability of nutrients can also bring about changes in the species composition of the phytoplankton community.

As in the open ocean, the disposal of manganese nodule processing wastes over the continental shelves could have adverse effects on phytoplankton if such disposal results in increased concentrations of metals in seawater. As noted above, adverse effects associated with elevated metal concentrations include reduction in the rate of primary production by phytoplankton (cf. Knauer and Martin 1972; Patin et al., 1974; Ibragim and Patin 1976) and alteration in the species composition and succession of phytoplankton communities (Thomas and Seibert 1977; Huntsman and Sunda 1981). Effects such as these appear to be related to the free metal ion activity in the water rather than the total metal concentration (Sunda and Guillard 1976; Canterford and Canterford 1980; Huntsman and Sunda 1981).

For reasons discussed above, a number of factors [e.g., the pH and alkalinity of the water, the concentration of natural chelators, the concentration of competing metals, and the presence of adsorptive surfaces (Sunda et al., 1978)] affect the activities of free metal ions, and therefore it is difficult to predict the effect on phytoplankton of the addition of a given quantity of any of the heavy metals to the euphotic zone above the continental shelves. Nevertheless, several factors act in concert to reduce the likelihood of adverse effects on phytoplankton over the continental shelves.

The first factor is that, in general, waters over the continental shelves have higher concentrations of particulate matter than waters of the open ocean. Consequently, there is a greater likelihood that free metal ions will be adsorbed onto particulate matter in the waters over the continental shelves. In addition, compared to open ocean waters, waters nearer the continents may have a relatively high content of natural chelators due to the higher concentrations of organic matter. Metal ions there would have a greater chance of being bound by naturally-occurring organic ligands, which would render them unavailable to the phytoplankton (Sunda and Guillard 1976). Lastly, there is some evidence that phytoplankton species which have evolved in and are adapted to physically-variable environments would, because of their adaptations, be better able to tolerate any toxic compound than would morphologically-similar species adapted to more stable environments (Fisher 1977). Such differences may even occur at the intraspecific level, since Murphy and Belastock (1980) have demonstrated that clones of a single diatom species which occurred in polluted estuarine environments were less sensitive to certain organic chemical wastes than were clones of the same species from neritic and oceanic environments. Such differences in resistance to chemical stress may be associated with changes in membrane structure and permeability (Fisher 1977). Even though the aforementioned

factors act in concert to minimize the potential adverse effects on phytoplankton in shelf environments, there is still cause for concern because the shelf environments are not only more productive, but also because they are more closely linked with food chains leading directly to man, with numerous species of importance in commercial and recreational fisheries.

In areas of the continental shelves shallow enough to support benthic algal growth, the dumping of processing wastes could have similar effects on the growth of these algae (i.e., reduced photosynthesis, stimulation or inhibition of growth, alteration of community species composition and succession, and burial of both substrate and algae).

Changes in either the level of primary production or the phytoplankton species composition could cause changes at higher trophic levels, since much of the secondary production on the continental shelves is ultimately dependent on phytoplankton for the fixation of carbon. Whereas impacts of waste discharge on phytoplankton in the deep ocean are likely to be both extremely localized and short-lived, the greater potential for slower settling and/or resuspension of the fine particulate matter over the continental shelves suggests that impacts on phytoplankton associated with the physical properties of the particulate wastes may not only cover a wider area, but may persist for a longer time in the waters over the shelves. The potential for adverse impacts on economically important organisms at higher trophic levels is also enhanced due to shorter food chains which tend to prevail in shelf waters. This is in part due to the larger size of phytoplankton cells in shelf waters relative to open ocean waters (Parsons and LeBrasseur 1970). It should be noted, however, that nearshore and shelf phytoplankton assemblages are naturally adapted to higher levels of suspended solids. Thus, they may be less sensitive to a given turbidity increase than open ocean assemblages.

Adverse effects on zooplankton of the disposal of manganese nodule processing wastes over the continental shelves are similar to those expected in the open ocean. Zooplankton are generally abundant at all depths above the continental shelves, however, so there is less potential for minimizing impacts on these animals by discharging the wastes deep below the euphotic zone. Once again, dissolved components of the wastes may be directly toxic to zooplankton, or the fine particulate matter may clog zooplankton filtering apparatuses, abrade their mouthparts, and/or actually be ingested by the animals. Zooplankton mortality or reduction in grazing efficiency may result. As in the case of open ocean disposal of these wastes, the incorporation of this fine particulate matter into fecal pellets may be a beneficial effect of zooplankton grazing resulting in increased sedimentation of particulate matter. Moreover, binding of metals to organic substances in fecal pellets may reduce the availability to other organisms.

Just as for phytoplankton, adverse effects on zooplankton may have important ramifications for higher trophic levels, since many are dependent on the transfer of organic matter, produced by phytoplankton, through the zooplankton, before it can become available to other animals. Notable exceptions include those fishes able to feed directly on phytoplankton

(e.g., anchovies in areas of coastal upwelling) and certain filter-feeding benthic organisms (e.g., clams in shallow regions of the shelves). Adverse effects on zooplankton over the continental shelves may be more widespread and persistent than in the deep ocean, since there is a greater potential for slower settling and/or resuspension of the fine particulate matter, due to stronger currents, tidal mixing, and possible coastal upwelling over the shelves.

The possibility of adverse effects of the disposal of manganese nodule processing wastes on ichthyoplankton is especially important in the continental shelf environment, because most commercial fish species inhabit shelf areas. In addition to the potential adverse effects on planktonic fish eggs and larvae mentioned earlier (direct toxic effects, interference with feeding, indirect food-chain effects), an additional consideration is the potential impact on those fish species which lay their eggs on the bottom. Demersal eggs could be buried and killed by the dumping of fine particulate matter on the sea floor over the continental shelves. Rosenthal (1971) demonstrated, for instance, that suspensions of "red mud," the waste product from the production of aluminum from bauxite, retarded the rate of development of herring embryos and increased their frequency of embryonic malformations. Herring eggs are demersal, and Rosenthal (1971) reported that red mud particles adhered to the chorion of these eggs, possibly interfering with gaseous and other material exchanges between the eggs and the surrounding medium. It is conceivable that manganese nodule processing wastes might have similar effects on demersal fish eggs.

Although pelagic fish species inhabiting the continental shelves are also strong swimmers capable of avoiding turbid water areas created by the disposal of manganese nodule processing wastes, they are generally not as wide-ranging as the oceanic pelagic fishes. They may be more closely associated with certain topographic features (e.g., the shelf break, rocky outcrops, favored feeding and/or spawning areas) and therefore more susceptible to adverse impacts (e.g., interference with feeding behavior, bioaccumulation of heavy metals and/or other potentially toxic constituents of the wastes) attributable to disposal of these wastes in a specific area.

As in the deep sea, the adverse impacts of the nodule processing wastes on continental shelf benthic communities will likely vary depending upon the amount of material deposited on the sea floor, the dispersal of this material, and the amount and duration of increased turbidity just above the bottom. These factors will vary considerably with the disposal method chosen. Regardless of the disposal method, however, the fact that the water column is so much shallower over the shelves than in the deep sea (a factor of 10 to 100 times shallower) means that the particulate wastes are likely to settle out of the water more quickly and not be as dispersed laterally as in the deep sea. An additional factor that must be considered, however, is that the ambient currents in some areas of the continental shelves may be of sufficient magnitude to keep these particulate wastes in suspension and transport them great distances before deposition occurs. In certain areas of the continental shelves, sediments may be transported across the shelf, deposited in the vicinity of the shelf break, and periodically sloughed off as turbidity currents into the deep sea. Hence, particulate matter deposited on the shelves may eventually end up on the deep ocean floor.

Large, mobile organisms, such as demersal fishes and crabs, would likely be able to avoid burial under settling particulate matter and evacuate areas of increased turbidity, provided that these areas were not too widespread.

The types of potential impacts on shelf benthic communities are similar to those discussed above for the deep-sea benthos, but the significance of a given impact is likely to be greater. The greater concern over potential adverse impacts of the dumping of manganese nodule processing rejects on benthic communities on the continental shelves is because many of the affected organisms are either currently or potentially in food chains leading directly to humans.

The consequences of blanketing the sea floor over the continental shelves with a layer of fine particulate matter will depend upon the rate of deposition and the thickness of the deposit. While it is difficult to make accurate predictions, it is probably safe to predict that shelf-dwelling organisms would likely be less affected by a given thickness of sediment cover than would deep-sea organisms. The shelf organisms live in an environment with much higher ambient sedimentation rates, and consequently they should have better burrowing abilities and should be less likely to be irretrievably buried. The ability to stay at the sediment-water interface may not guarantee survival, however, especially for surface deposit feeders. These organisms are dependent on ingestion of organic matter in the sediments, and a layer of primarily inorganic, waste-derived sediments may not contain adequate organic matter for their nourishment.

There is a very real possibility that suspension feeders and surface deposit feeders inhabiting the continental shelves would ingest particulate processing wastes if such wastes were discharged in their environment. It is also possible that particulate-bound heavy metals or other potentially toxic substances ingested by these organisms could be incorporated into their tissues, and thus provide a starting point for bioaccumulation through benthic food chains. Considering that many of the larger organisms on the continental shelves (e.g., demersal fishes and crabs, including commercially valuable species) ingest benthic suspension feeders and deposit feeders, there is concern that bioaccumulation in these organisms may represent a health hazard for humans.

If an area of the continental shelf was covered with rejects and the resident fauna irretrievably buried, recovery of the community to a "normal" state would likely proceed much more quickly than in the deep sea. Benthic invertebrates on the continental shelf, in particular, have excellent dispersal abilities, since many have planktonic larvae. While the first colonists are likely to be those with the highest dispersal ability, the direction of succession is difficult to predict, especially because the suitability of sediments for colonization by benthic invertebrates is a function of the grain size of the sediments, which in this case remains unknown.

Recovery potential of marine communities has been evaluated following both natural and anthropogenic stresses. The available evidence indicates that even in cases of drastically disturbed nearshore sediments there is generally a relatively rapid recolonization (Rosenberg 1972; Dauer and Simon 1976). In a comprehensive study in Monterey Bay, Oliver et al. (1977) found that successional patterns following disturbance were dependent upon the nature of adjacent undisturbed communities. In situations where large motile organisms (e.g., peracarid crustaceans) were abundant, these groups generally constituted the initial colonizers in addition to opportunistic polychaetes (i.e., those with short generation times and ability to change from larval dispersal to brooding). If large motile organisms were not abundant, opportunistic polychaetes provided the primary initial colonization. The second phase was characterized by a return of the normal, pre-disturbance community. In general, early colonizers do not reach a stable community dominance that prevents a return of the normal indigenous species. Continued dominance has been observed, however, in cases of repeated (annual) defaunation of benthic communities (Santos and Simon 1980).

Documented cases of faunal recovery have usually been associated with disturbances such as oil spills, dredge spoil deposition, deoxygenation, and natural turbidity flows. As such, the recovery processes have occurred in natural sediments, usually containing from 1 to 10 percent organic matter. Many of the initial opportunistic colonizers of disturbed sediments are deposit feeders (e.g., the polychaete Capitella capitata). These organisms ingest deposited sediment, either at or below the sediment surface, and utilize organic matter contained therein as food. If a substantial layer of reject material were deposited on the bottom, colonization processes may be different than those observed in natural sediments because of the inorganic nature of reject material. The lack of organic matter would limit initial colonization to suspension feeders or surface detritus feeders. These organisms could utilize naturally occurring near-bottom organic matter, either as newly deposited material or as a suspension.

As noted above, the possibility of bioaccumulation of potentially toxic metals is of concern for continental shelf organisms, since many are in food chains leading to humans. Accumulation of the metals may occur through direct uptake of the dissolved metals, ingestion of contaminated particulates, or through ingestion of other contaminated organisms. The biological importance of a trace metal is not only dependent upon its physical/chemical state upon discharge, but also upon the ultimate solute concentration in seawater, which is a function of sorption-desorption, dissolution-precipitation, and metal-ligand associations following discharge.

It was indicated above that iron/manganese oxides are an important sink for metals in the marine environment, and that the metals were also often bound to organic or inorganic particulate matter. Luoma and Jenne (1977) demonstrated that the bioavailability of several metals to deposit-feeding clams is inversely proportional to the sediment-water distribution coefficient. Thus, sinks with a high rate of sediment-to-water desorption resulted in a high bioaccumulation of metals. It is interesting to note

that the rank ordering of sinks relative to bioaccumulation potential varied according to the metal tested. For silver, the concentration factor in clam tissue was about an order of magnitude higher from manganese oxide than from organic particulates. The opposite situation was found for zinc. Luoma and Jenne (1977) also found that the rate of bioaccumulation resulting from ingestion of solids with adsorbed metals was considerably slower than the uptake of soluble forms. The authors concluded that short-term exposures (less than several days) to certain sediment-bound metals (e.g., hydrous oxide bound Zn and Co) would result in negligible bioaccumulation in the clam.

Neff et al. (1978) indicated that bulk metal analyses of solids are not useful in predicting bioavailability of sediment-adsorbed metals. In a series of 136 metal-species-sediment exposures of marine organisms to natural sediments, significant accumulation of metals occurred in only 36 cases (26.5 percent). The observed cases of bioaccumulation, many of which were quantitatively marginal, could not be correlated with the form of the metal present in the sediments.

The physiological state of an organism can also strongly affect the degree of tissue contamination by metals. Although metal concentrations have been demonstrated to be related to body size, the relationships vary among species and metals (Cross et al., 1973; Bryan and Uysal 1978; Boyden 1977). Moreover, Strong and Luoma (1981) have demonstrated that the relationship of body size to metal concentration may differ among populations of a single species and also with season. Other environmental variables affecting metal uptake and accumulation include salinity, water temperature, and the presence of other metals (Phillips 1976).

A wide variety of marine organisms has been shown to accumulate metals in body tissues when exposed to contaminated water or sediments. It is also apparent that accumulated metals may be transferred upward among trophic levels (e.g., from phytoplankton to zooplankton). It is important to note, however, that the occurrence of bioaccumulation of a potentially toxic substance does not necessarily mean that biomagnification will occur. The potential for biomagnification is an important concern since its occurrence can result in high concentrations of potentially toxic substances in higher trophic level organisms (e.g., fishes) which are used as food by man.

Biomagnification has been documented for some high molecular weight organic compounds (e.g., DDT) and for methylmercury; however, there is currently little evidence for biomagnification of inorganic forms of metals (Bryan 1979). Substances displaying evidence of biomagnification are lipophilic and are stored in the fat deposits of an organism. Such tissues are relatively inert and enable only limited active metabolism and/or excretion of the substance. Inorganic substances such as non-methylated metals do not have lipophilic tendencies and are much more available for active regulation by marine organisms. In general, the ability of organisms to regulate metals increases in more taxonomically advanced species (e.g., higher in fishes than in crustaceans; Bryan 1979). In addition, marine organisms generally have more ability to regulate metals important as micronutrients (e.g., copper and zinc) than for non-essential metals (e.g.,

cadmium and lead). The processes of metal regulation not only vary according to the metal and species, but also according to the organism tissues. Based on the low tissue metal levels in many contaminated environments, marine fishes and some invertebrates apparently have a high capacity to regulate metal concentrations in their muscle tissue. The ability of more advanced predatory forms to regulate tissue metal concentrations is an important factor in explaining the apparent absence of biomagnification of inorganic metals.

A wide variety of invertebrate and vertebrate marine organisms have been shown to detoxify and sequester assimilated metals (Roesijadi 1981). The role of metallothionein-type proteins in the detoxification mechanism has been widely studied. It appears that these low molecular weight proteins play an important role in sequestering potentially toxic metals (e.g., Cd, Hg, and Ag) in addition to regulating the metabolism of essential trace metals such as zinc and copper. Metallothionein production in an organism can be induced by exposure to non-essential metals such as cadmium, and thus forms an important role in the development of tolerances to potentially toxic metals. Marine organisms may also be able to genetically adapt to increased environmental metal concentrations. In a study of the polychaete Nereis diversicolor, Bryan and Hummerstone (1973) found that worms living in contaminated sediments were more resistant to zinc than control worms. The tolerance was apparently genetically determined and was probably associated with reduced permeability and more efficient excretion.

Possible Biological Impacts of the Disposal of Manganese Nodule Processing Rejects in Nearshore Areas

Impacts of the dumping in nearshore areas of wastes resulting from the smelting of manganese nodules would likely be much the same as those already described for the dumping of such wastes on the continental shelves. Hence, for the purposes of this discussion, the effects of the disposal of the fine particulate fraction (clay-size particles) on nearshore communities will be considered to be similar to those discussed below for the hydrometallurgical process wastes. Recolonization of areas covered by the coarse particulate fraction (sand-size particles) will depend on burial of these wastes by natural sediments, the suitability (particle size, organic content, etc.) of these waste sediments to natural sand-dwelling organisms, and/or the potential toxicity of heavy metals or other constituents of the wastes which may leach into the water.

The disposal of hydrometallurgical process waste slurries in the nearshore environment would likely involve the use of submarine outfalls. The impact of this disposal method on nearshore ecosystems would depend on the depth of discharge, the local wave and current regime, the physical and chemical nature of the wastes, and on the nature of the biological habitats in the area. One of the most important considerations with regard to predicting the effect of this disposal method on biological communities is the depth of the outfall. Solids discharged from outfalls in waters less than approximately 30 m can be subjected to wave induced resuspension and reintroduction into the euphotic zone. Whether or not this method would be successful at keeping the resultant turbid water at depth is dependent on

the other aforementioned factors (i.e., hydrography, density structure, currents, physical nature of the wastes).

If the processing wastes were discharged directly into the euphotic zone, or, conversely, if they were discharged below this zone and advected into it by other processes (e.g., tides, currents, etc.), impacts on phytoplankton would likely be much the same as those described above for phytoplankton in the open ocean or over the continental shelves. Increases in turbidity within the euphotic zone would cause decreases in the penetration of sunlight, and hence decrease phytoplankton photosynthesis.

Stimulation of phytoplankton production is also a possible effect of the disposal of manganese nodule processing wastes if the liquid fraction of these wastes contains either appreciable quantities of dissolved ammonium, nitrate, silicate, or trace metals. Alterations in the availability of nutrients can also bring about changes in the species composition of the phytoplankton community.

Phytoplankton production may be inhibited and/or phytoplankton species composition may be altered if free metal ions are present in high enough concentrations. As discussed above in regard to potential effects on continental shelf communities, the higher concentrations of particulate matter and of organic substances in the water nearshore may render any introduced free metal ions unavailable to phytoplankton. These ions may be expected to be adsorbed onto particulates or bound to naturally-occurring organic ligands much more frequently nearshore than in the open ocean, and perhaps even more frequently than over the continental shelves. In addition, nearshore algal species may be less sensitive to chemical stress than those algal species inhabiting more stable, less stressed environments offshore. As for the shelf environments, there is still cause for concern, even in the presence of these mitigating factors, because the nearshore environments are not only more productive, but also because they are more closely linked with food chains leading directly to humans, with numerous species of commercial and recreational importance. Any impact on phytoplankton related to the presence of dissolved substances in the waste slurry would probably be minimized by disposal below the euphotic zone (i.e., below 100 m), since appreciable dilution would likely occur before these substances could enter the euphotic zone by such processes as diffusion or upwelling.

Similar effects (i.e., reduced photosynthesis, stimulation or inhibition of growth, burial of both substrate and benthic plants) may occur if the wastes enter the euphotic zone in nearshore areas where benthic plants (i.e., kelps, sea grasses, etc.) are found. Such impacts could have important ramifications because certain benthic plants, notably kelps, are important in structuring the environment and making it suitable for habitation by a large number of associated organisms, while other plants represent food resources for certain animals (e.g., turtle grass is an important food for marine turtles).

Changes in either the level of primary production or the species composition of the various nearshore plant communities could cause changes

at higher trophic levels. Whereas impacts of waste discharge on primary production in the open ocean and over the continental shelves are likely to be temporary because the wastes will eventually settle out of the water column and remain below the euphotic zone, impacts on primary production nearshore are likely to be more long-lasting, since even if the wastes settle onto the bottom, there will be a much greater likelihood of resuspension and reentry into the euphotic zone. In addition, burial of hard substrates will likely make the bottom unsuitable for the growth of most macroalgae, which must be able to attach to a hard substrate to establish themselves in an area. Just as on the continental shelves, the potential for adverse impacts on economically-important organisms at higher trophic levels is also enhanced nearshore due to the shorter food chains which tend to prevail there (Parsons and LeBrasseur 1970).

Adverse effects on zooplankton due to the disposal of manganese nodule processing rejects in nearshore waters are similar to those expected in the open ocean and over the continental shelves. Just as for phytoplankton, adverse effects on zooplankton may have important ramifications for higher trophic levels, since many are dependent on the transfer of organic matter, produced by phytoplankton, through the zooplankton, before it can become available to other animals. This is not as important in nearshore environments as it is in open ocean or outer continental shelf environments, however, since a significant fraction of the nearshore primary production is often performed by benthic plants. Adverse effects on zooplankton in nearshore environments may be more persistent because of the greater potential for retention and resuspension of these wastes in nearshore environments.

The possibility of adverse effects on ichthyoplankton attributable to the disposal of processing wastes is especially important in the nearshore environment, because many fish species utilize these areas as spawning and nursery grounds. In addition to the potential adverse effects on planktonic fish eggs and larvae mentioned earlier (direct toxic effects, interference with feeding, indirect food-chain effects), an additional consideration is the potential impact on those fish species which lay their eggs on the bottom, as discussed above with regard to continental shelf environments. Demersal eggs could be buried and killed by the dumping of fine particulate matter on the bottom in nearshore areas.

Although pelagic fish species inhabiting the nearshore areas are also strong swimmers capable of avoiding turbid water areas created by the disposal of manganese nodule processing wastes, they are generally not as wide-ranging as the oceanic pelagic fishes, and they may be even more closely associated with certain topographic features (e.g., coral reefs, rocky outcrops, favored feeding and/or spawning areas) than are the shelf species, and therefore more susceptible to adverse impacts (e.g., interference with feeding behavior, bioaccumulation of heavy metals and/or other potentially toxic constituents of the wastes) attributable to disposal of these wastes in a specific area.

As in the deep sea and on the continental shelves, the adverse impacts of the nodule processing wastes on nearshore benthic communities will likely

vary depending upon the amount of material deposited on the bottom, the dispersal of this material, and the amount and duration of increased turbidity just above the bottom. These factors will vary with the depth of the waste discharge. Other important factors include the local hydrography, the density structure of the water column, currents, and the physical nature of the wastes.

Ambient currents in some nearshore areas may be of sufficient magnitude to keep these particulate wastes in suspension and transport them great distances before deposition occurs, even in cases where the outfall discharge is well below the surface (cf. Waldichuk and Buchanan 1980). This high waste dispersion potential in the nearshore environment has several important implications related to environmental considerations. In some areas there may be a potential for shoreward transport of discharged wastes, resulting in potential impacts on sensitive or important nearshore habitats (e.g., kelp beds). Thus, the potential for transport of the waste either before or after initial deposition must be considered. It should also be noted, however, that relatively shallow nearshore waters enable much more reliable post-discharge monitoring of waste dispersal and any environmental effects. The basic environmental consideration related to effects on benthos and fishes would be similar to those identified for shelf areas. However, the potential for bioaccumulation of metals is an especially important consideration in nearshore areas because of the occurrence of many important recreational fisheries in addition to commercial fisheries.

Certain benthic habitats unique to the nearshore area (i.e., kelp beds, sea grass beds, coral reefs, intertidal areas) are particularly susceptible to impacts either from increased turbidity or from burial of the substrate by processing wastes. Possible effects on kelp beds, sea grass beds, and other benthic plant communities were mentioned previously in the discussion of impacts on primary productivity. Coral reefs and intertidal habitats (especially on rocky substrates) are of concern because many of the animals in each are suspension feeders, and because alterations in the substrate in each area may cause irreparable destruction of these habitats.

SIGNIFICANT ENVIRONMENTAL CONSIDERATIONS

Environmental considerations identified for the various marine disposal alternatives are listed in Table 32. The diversity of potential impacts involves organisms of essentially every trophic level in every marine habitat. For the sake of discussion, however, and to facilitate estimation of the relative significance of the various impacts for each of the disposal options, the 26 specific potential impacts listed in Table 32 were grouped into the following general categories:

1. Effects on primary production
2. Direct toxic effects
3. Effects on behavior and feeding of marine organisms
4. Bioaccumulation effects

TABLE 32. A LIST OF ENVIRONMENTAL CONSIDERATIONS RELATED TO MARINE DISPOSAL OF MANGANESE NODULE PROCESSING WASTES AND REJECTS

I. Effects on primary production

1. Decrease in photosynthesis by phytoplankton due to increased turbidity
2. Decrease in photosynthesis by benthic flora due to increased turbidity
3. Stimulation of production by phytoplankton due to increased nutrients
4. Stimulation of production by benthic flora due to increased nutrients

II. Direct toxic effects

5. Direct toxicity to phytoplankton
6. Direct toxicity to benthic flora
7. Direct toxicity to zooplankton
8. Direct toxicity to ichthyoplankton
9. Direct toxicity to pelagic fishes
10. Direct toxicity to demersal fishes
11. Direct toxicity to benthic fauna

III. Effects on behavior and feeding of marine organisms

12. Interference with grazing by zooplankton
13. Interference with feeding by ichthyoplankton
14. Interference with pelagic fish feeding behavior
15. Interference with feeding behavior of benthos and demersal fishes
16. Interference with migration patterns
17. Interference with reproductive behavior

IV. Bioaccumulation effects

18. Bioaccumulation of potentially toxic substances in phytoplankton
19. Bioaccumulation of potentially toxic substances in zooplankton
20. Bioaccumulation of potentially toxic substances in fishes
21. Bioaccumulation of potentially toxic substances in benthic fauna

V. Effects of alteration in benthic substrate

22. Effects on benthos due to alteration in substrate or smothering
23. Effects of substrate modification on demersal fish distribution

VI. Inter-trophic effects

24. Higher trophic level effects of impacts on phytoplankton
25. Higher trophic level effects of impacts on zooplankton
26. Higher trophic level effects of impacts on benthic fauna

5. Effects of alteration in benthic substrate

6. Higher trophic level effects.

To evaluate the potential disposal options from an environmental perspective, it is important to consider how these options, in conjunction with environmental factors, influence the relative significance of the environmental considerations identified in Table 32. The various disposal options are summarized in Table 33. The magnitude of each potential impact may be expected to vary with the method of disposal. Effects on primary productivity, for instance, may be considerably reduced by those disposal methods which introduce the processing wastes into the ocean at depths below the euphotic zone (i.e., subsurface dispersal), or which minimize the residence time of the wastes within the euphotic zone (i.e., surface dump). Direct toxic effects, which are normally associated with elevated concentrations of dissolved chemical substances, may be mitigated by disposal methods which result in greater dispersion of the wastes. Interference with the feeding of pelagic organisms (e.g., zooplankton, ichthyoplankton, pelagic fishes) would be lessened by the introduction of wastes below the euphotic zone or by minimizing the residence time of the wastes within the upper layers of the ocean. Interference with the feeding of benthic organisms may be minimized by disposal methods resulting in the greatest dispersion of the wastes, which would reduce both the thickness of waste sediment deposits and the turbidity above the bottom.

The possibility of bioaccumulation is of concern in all of the disposal scenarios, but it is certainly of less significance when the subject organisms are deep-sea benthos, rather than continental shelf or nearshore species potentially in food chains leading to humans. Biological impacts associated with changes in the benthic substrate would be minimized by disposal methods which result in the greatest dispersal of the wastes (i.e., open-ocean dispersal vs. a nearshore dump), the least change in the prior substrate (i.e., disposing of the wastes in areas already having a fine particulate substrate), or the lack of appreciable deposition due to ambient currents. Effects on higher trophic levels due to impacts on lower trophic levels are potentially of importance in all environments, but as in the case of bioaccumulation, the greatest concern is associated with effects on those higher trophic level organisms utilized by humans. Such effects will be more likely where food chains are short (e.g., coastal areas) rather than in areas where food chains are long (e.g., open ocean areas) (cf. Parsons and LeBrasseur 1970).

The relative significance of each potential environmental effect is dependent upon four basic considerations:

- The severity of the effect (e.g., sublethal or lethal)
- The spatial extent of the effect
- The duration of the effect

TABLE 33. DISPOSAL OPTIONS CONSIDERED FOR EVALUATION OF POTENTIAL EFFECTS OF REJECT DISPOSAL

Disposal Zone	Disposal Method
Inner shelf	outfall
	surface dumping
Mid shelf	surface dumping
	surface dispersal
	subsurface dispersal
Deep ocean	surface dumping
	surface dispersal
	subsurface dispersal

- Potential involvement of commercial or recreational species.

Each of these considerations is in turn dependent upon characteristics of the exposed organisms, the receiving water body, and the disposal method.

The overall severity of an effect may range from short-term physiological responses (e.g., change in respiration rate) to death. It is dependent upon the physical/chemical characteristics of the waste, sensitivity of indigenous organisms to the waste, and exposure conditions (e.g., time and concentration). The greater sensitivity of open ocean communities to impacts on primary production reflects both the greater sensitivity to chemical stress of the phytoplankton species found in such environments, and the lower ambient concentrations of natural organic ligands, which could complex with potentially inhibitory free metal ions. Naturally, disposal options which result in the wastes being introduced below the euphotic zone should minimize the potential impacts on primary production. The potentially greater sensitivity of open-ocean organisms to direct toxic effects also reflects adaptation to an environment with few prior chemical stresses. However, it should be emphasized that the response of open-ocean communities to anthropogenic stresses are not well understood and would require considerable further study before definitive estimates of potential effects could be made.

Effects on feeding of marine organisms are likely to be greater in the open ocean than inshore because open-ocean organisms typically feed in waters with very low levels of suspended particulate matter. Effects on feeding are also expected to be greater for epipelagic organisms than for those lower in the water column because both filter feeders and visually-orienting predators are more prevalent near the surface. Deep-sea benthic organisms are likely more sensitive to alterations in the benthic substrate than benthic organisms nearshore because they have evolved in an environment with extremely slow rates of sedimentation. Disposal options which result in greater dispersion of the wastes will tend to mitigate this effect. Finally, higher trophic level effects are most likely for nearshore and shelf organisms because higher level predators of the open ocean are not only more wide-ranging than those inshore, but they are also, in general, more trophic steps removed from the primary producers. Once again, disposal of the wastes below the euphotic zone may tend to minimize effects on higher trophic levels.

The spatial extent of an effect is dependent upon the disposal method (e.g., dispersal or dump) and the distributional characteristics of affected organisms. Plankton, by their very nature, are transient inhabitants of a particular area and any localized effects would generally be ameliorated by dispersion of the affected organisms. In general, the potential spatial effects are greater for the disposal options involving dispersion when compared with dumping. However, evaluation of the spatial extent of effects should also involve a consideration of the dilution necessary to cause no adverse effects. Hence, it may be appropriate to use a combination of disposal option (e.g., slow dispersion from a barge) and naturally high ambient dispersal mechanisms (i.e., currents) to reduce the potential for effects although the waste would be distributed over a large area. Contrary

to the other environmental considerations, effects of a change in benthic substrate will cover the least area when the wastes descend quickly to the ocean floor (e.g., in shallow water nearshore, or during a surface dump). In cases where the wastes are dispersed upon disposal, the area affected would be greater and the depositional rate per unit area would be less, especially in deep waters of the open ocean. The low depositional rates would probably result in a concomitant decrease in the potential impacts on benthic organisms. Higher trophic level effects are relatively unlikely in the open ocean, and hence would not cover a large area. If such effects were to occur over the shelf or nearshore, they would cover a larger area if the wastes were dispersed at the surface than they would if the wastes were discharged at depth.

The duration of an effect is dependent upon the severity of the effect and the recovery potential of the exposed population. Sublethal responses such as changes in primary production or feeding behavior would most likely be extremely transitory (e.g., hours to days) in plankton populations, and would most likely exist only during the limited exposure period prior to waste settling. Even lethal effects on plankton communities would most likely be of limited duration due to rapid mixing and short generation times. Alternatively, if significant bioaccumulation of metals occurred in benthic organisms, the effect would probably be of long duration (e.g., months to years) because of continued exposure to the contaminated sediments. For effects of substrate alteration or smothering of benthos, the effect duration would depend upon reproductive and dispersal characteristics of the organisms. Motile species or organisms having high larval dispersal mechanisms may be able to rapidly repopulate an affected area, while recovery of sessile organisms with limited dispersal capabilities would be considerably slower.

For all disposal options, the involvement of commercial or recreational species is lowest in cases of open-ocean disposal, since there are very few species of economic importance in such environments. Most oceanic fisheries are directed at large, wide-ranging species (e.g., tunas, billfishes, whales, etc.) and the only significant impact on such species might be temporary interference with feeding behavior, and even this is of far less concern than for commercial or recreational species over the shelf or nearshore, since the pelagic species should be able to avoid turbid water areas. Impacts on primary production are only of commercial or recreational importance nearshore where some benthic macrophytes (e.g., kelps, other seaweeds) are routinely harvested. Direct toxic effects on commercial or recreational species may occur over the shelf, but they would be more likely nearshore where dispersion of the wastes may be less pronounced. The feeding of commercial or recreational species may be affected in both nearshore and shelf environments, but in each case, the effects may be greater if the wastes are dispersed near the surface. Bioaccumulation in commercial or recreational species may also occur both over the shelf and nearshore, but benthic and demersal organisms, the most likely to bioaccumulate potentially toxic substances, would be subjected to greater concentrations in shallow water nearshore or when wastes are dumped from the surface over the shelf. Effects of a change in benthic substrate on commercial or recreational species would also be favored by either

shallow-water discharge or a surface dump over the shelf. Higher trophic level effects would again be more prevalent if the wastes were dispersed in the euphotic zone than below it.

Based on the aforementioned considerations, the generic categories of effects may be grouped according to their relative significance. Effects of benthic substrate alteration and bioaccumulation have the highest relative significance. This is because these potential effects of rejects may be lethal, occur over an extensive area, be relatively long lasting, and involve commercial/recreational species. Within the general category of bioaccumulation, however, the relative significance varies considerably according to biotic group. For several groups the relative order of significance of bioaccumulation from highest to lowest, would be: demersal fishes, benthic invertebrates, pelagic fishes, zooplankton, and phytoplankton.

Direct toxicity and effects on feeding and behavior would have an intermediate level of significance. The potential for toxic effects on most biotic groups would be limited because of short exposure times, high dilution rates (for most disposal options) and the possibility of limited availability of toxic substances in the wastes. Potential toxic effects would probably be lowest for zooplankton and pelagic fishes. Potential toxicity of phytoplankton would be of greater significance because of metals contained in reject material (although their availability as soluble forms is currently unknown) and the sensitivity of phytoplankton to metal toxicity (compared to other groups). Toxicity to benthic organisms is of intermediate significance because of the potential for extended contact with, or ingestion of, waste material.

Effects on primary production and intertrophic effects have the lowest relative significance among the generic environmental considerations. Effects on primary production would be of short duration and spatially limited. Because of the relatively low significance of effects on plankton, higher trophic level effects resulting from plankton impacts would also have a low significance. The transitory nature of impacts on plankton would have a minimal potential for affecting consumers unless such effects were extremely widespread.

ENVIRONMENTAL CONSIDERATIONS FOR REPRESENTATIVE DISPOSAL AREAS

Biological and oceanographic conditions important in the consideration of environmental effects of reject disposal in representative disposal areas are reviewed in Appendix D. The following section provides a summary of the major environmental considerations for each representative area.

Western Gulf of Mexico

The outer continental shelf of the western Gulf of Mexico includes a number of offshore banks and coral reefs which should be considered in the selection of potential manganese nodule processing waste disposal sites. As described previously, corals on these reefs may be near the environmental limits of existence and vulnerable to any anthropogenic stresses. These

reefs and banks also provide important habitat for demersal snappers which support local fisheries. There have also been suggestions that potentially commercial stocks of tilefish and yellowedge grouper exist on the outer continental shelf of the western Gulf of Mexico, and that future fisheries may develop to harvest these stocks. The open waters of the Gulf of Mexico are typical of tropical open ocean waters elsewhere (i.e., low primary productivity, low productivity of higher trophic levels, and low benthic biomass). While there are currently no substantial pelagic fisheries in the open waters of the western Gulf of Mexico, it is possible that a fishery for tuna could develop over the continental slope.

Hawaii

Nearshore habitats on the island of Hawaii vary considerably between the windward and leeward coasts. Along the Kona (leeward) coast, there are extensive coral reefs, while on the windward coast near Hilo, there is very little coral growth. Coral reefs are especially susceptible to environmental impacts associated with high turbidity and/or sediment deposition, and there have been suggestions that the coral reefs north of Keahole Point on the leeward coast are already stressed by turbid water conditions. Although the insular shelf around the island of Hawaii is very narrow, it nevertheless has a number of characteristics which should be considered in selecting a potential site for the disposal of manganese nodule processing wastes. Both Hilo and Kona are important centers of commercial fishing, and most of the Hawaiian fisheries are directed at pelagic species within 32 km of the coast. The tuna fishery near the edge of the shelf is especially notable. In areas with a hard benthic substrate, bottom fisheries are important. In addition, potential fisheries for both sharks and shrimps may develop around the island of Hawaii in the future. Precious corals grow in certain areas at depths greater than 100 m around the island, and are commercially harvested. The shelf waters also represent important habitat for the humpback whales which overwinter there. Open ocean areas far offshore of the Hawaiian islands are also typical of tropical open ocean waters elsewhere (i.e., low primary productivity, low productivity of higher trophic levels, and low benthic biomass). The only pelagic fisheries of note are for tuna, but these are not localized in any specific area.

Pacific Northwest

Certain characteristics of the Pacific Northwest nearshore zone should be taken into account in selecting manganese nodule waste disposal sites in this region. Rocky coastlines of the Pacific Northwest provide important habitat for various marine plants and animals, many of which could be adversely affected by increased turbidity and sedimentation to be expected with nearshore disposal of these wastes. Several marine mammal species are known to frequent the nearshore areas. Permanent residents include Stellar sea lions and sea otters, while California gray whales pass through the area on their annual migrations between the Bering Sea and Baja California. One interesting characteristic of the benthic environment nearshore is that from the shoreline to a distance of approximately 20 km from shore, and between depths of 0-80 m, the benthic substrate consists of 100 percent sand-size

particles. This reflects the high wave energy in the overlying waters, especially during winter storms, and suggests that manganese nodule processing wastes, disposed of in this region, would be subject to resuspension. Important nearshore fisheries include commercial fisheries for salmon and Dungeness crab, and recreational fisheries for salmon.

Important characteristics of the outer continental shelf of the Pacific Northwest should also be taken into account in selecting potential manganese nodule waste disposal sites in this region. Of particular importance is the fact that the region is characterized by coastal upwelling during periods of northerly winds in summer. Deep water over the outer shelf moves inshore and toward the surface to replace surface water advected offshore. This inshore movement of water could result in the shoreward transport of manganese nodule processing wastes if they were disposed of over the outer continental shelf. Another consequence of the seasonal coastal upwelling in this region is the enhancement of primary production over the shelf, which in turn supports enhanced production at higher trophic levels. One result of this is that the shelf break area is highly productive, and the macroepibenthos and demersal fishes there are particularly abundant. Consequently, there is an important multispecies groundfish fishery over the outer continental shelf and upper continental slope (depths of 30-1,500 m), and a developing fishery for pink shrimp at depths of 91-183 m. There is also interest in the region for further expansion of the fisheries to harvest both pelagic and demersal species which are currently underutilized. The disposal of manganese nodule processing wastes over the outer continental shelf could adversely affect both the existing and potential fisheries of the region, especially for those species (e.g., Pacific halibut, Pacific cod) with demersal eggs, a stage in the life cycle particularly vulnerable to the effects of sediment deposition. Consideration should therefore be given to disposing of these wastes in a manner which will not adversely affect important Pacific Northwest fishery resources.

Open-ocean environments beyond the continental shelf and slope of the Pacific Northwest are also characterized by relatively low primary productivity and low productivity at higher trophic levels. The only pelagic fishery of note is the troll fishery for albacore, but it should be noted that this is a seasonal fishery dependent on warm water temperatures, and that it only develops in some years. The open ocean waters do provide important habitat for salmon, but there is currently no open ocean fishery for these fishes.

The importance of the outer continental shelf fisheries in the Pacific Northwest suggests that possible disposal options utilizing sites over the continental shelf should be critically evaluated for their potential adverse effects on these fisheries. Such considerations may decrease the likelihood of selecting such disposal options over other possible choices (e.g., open-ocean disposal).

Southern California

Rocky shorelines along the southern California coast provide substrate for both rocky intertidal habitats along the shore and kelp beds just offshore. Flora and fauna in both habitats are susceptible to adverse effects of increased turbidity, sediment deposition, and sediment scour which may occur with nearshore disposal of manganese nodule processing wastes. Squid spawn just offshore from kelp beds in southern California, and their demersal eggs may also be vulnerable to burial by these wastes. In the absence of anthropogenic stresses, it is possible that marine mammals, once native to the mainland coast and now restricted to the offshore islands, could return to their former habitat along the rocky coastlines. California gray whales also transit the area during their annual migrations between the Bering Sea and Baja California. Whether the disposal of manganese nodule processing wastes would have adverse effects on marine mammals is unknown, however. Nearshore submarine canyons may receive consideration as potential sites for the disposal of manganese nodule wastes, since they serve as conduits for the transport of sedimentary material into deeper waters offshore. As discussed above, however, these canyons are unique biological habitats with a characteristic benthic fauna. Possible adverse effects on these organisms should be considered in selecting a site for the disposal of these wastes. As is the case for the Pacific Northwest, strong coastal upwelling could serve as a mechanism for shoreward transport of wastes.

Several features of the California borderland could make this area more attractive for the disposal of manganese nodule processing wastes than more typical continental shelf areas in other regions. The presence of deep basins with a depauperate benthic fauna attributed to depressed oxygen concentrations suggests that these areas could serve as disposal sites with minimal impact on benthic organisms. Due to the narrowness of the southern California shelf, groundfish fisheries are limited. The primary fisheries in the southern California Bight are for pelagic species, so disposal methods which introduce the wastes deep in the ocean (e.g., surface dump or subsurface dispersal) would be expected to have a minimal impact on southern California fisheries. Demersal species, especially those with demersal eggs (e.g., California halibut) could still be affected, however. Pelagic species, especially those whose larvae are dependent on adequate concentrations of planktonic organisms (e.g., jack mackerel, anchovies) would tend to be more susceptible to adverse effects of manganese nodule waste disposal if the wastes were dispersed at the surface. It is important to note the presence of sensitive offshore hard bottom banks, however. These areas represent unique habitats which are probably highly sensitive to solids deposition.

Open-ocean environments beyond the continental slope off southern California are similar in many respects to open-ocean environments in other regions. Pelagic fisheries are limited, and manganese nodule waste disposal would not be expected to have adverse effects on the wide-ranging target species (e.g., tuna, albacore). The biomass of benthic fauna on the deep-sea floor is sparse since the terrigenous sediments and their associated organic fraction are currently being deposited in the deep basins

of the continental borderland, and are not being transported to the deep sea by turbidity currents as in other regions. Open-ocean disposal of manganese nodule processing wastes in this region would therefore be expected to have relatively minor ecological effects.

EVALUATION OF DISPOSAL OPTIONS

The relative effects of general disposal areas (nearshore, shelf, and deep ocean) on the significance of environmental considerations is evaluated in Table 34. Based on relative deposition rate, dilution, and potential effects on fisheries, the nearshore disposal options have a relatively high potential for impact. This potential is counteracted, however, by the limited area affected and the generally lower sensitivities and higher recovery potential of nearshore organisms. In the deep ocean, high dilutions and low deposition rates can be maintained; however, the organisms are probably more sensitive to a given concentration or depositional rate.

Within a general disposal area, there are several environmental considerations relative to the specific disposal options. In nearshore areas, the submarine outfall would generally have a higher potential for impact than surface dumping. Because of construction constraints and associated costs, outfalls generally discharge very near the shoreline. Hence, the potential exists for shoreward transport of the wastes. For reject material, the potential for initial dilution of the waste would be considerably less for an outfall relative to surface dumping. Moreover, the outfall must be located in an area where bottom slope would result in an initial offshore transport of discharged material. Submarine canyons, such as those occurring in southern California and Hawaii, may offer an efficient mechanism for offshore transport of waste discharged near the canyon head through an outfall. However, such environments may contain a unique fauna compared to other coastal areas, resulting in significant environmental considerations for canyon discharges.

The environmental advantages of an outfall are associated with the confinement of the waste to bottom waters. Thus, potential impacts on plankton and pelagic fishes are minimized.

Surface dumping in nearshore areas could be conducted farther from shore than potential outfall lengths, resulting in a lower potential for effects on shoreline marine communities. Higher dilution could also be achieved prior to reject deposition. Whereas an outfall discharge would continually contact the same bottom area, dumping could be spread over a large area if such a procedure was determined to be environmentally advantageous. Dumping in nearshore areas would result in contact of the waste plume with water column organisms. If very small particles were present in the waste, surface or subsurface plumes could exist for extended periods.

Three basic disposal options are available for offshore areas over the continental shelf or in the deep ocean: dumping, surface dispersal, or subsurface dispersal. Each of these disposal options has advantages and disadvantages which are dependent upon specific environmental concerns. The

TABLE 34. EFFECTS OF DISPOSAL AREA ON FACTORS RELATED TO POTENTIAL IMPACTS OF WASTE DISPOSAL

Disposal Area	Relative Deposition Rate	Relative Area Affected	Potential Dilution	Relative Organism Sensitivities	Recovery Potential	Trophic Link with Fisheries
Nearshore	High	Limited	Limited	Low	High	High
Shelf	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate to high
Deep ocean	Low	Extensive	High	High	Low	Very limited

use of surface dumping or subsurface dispersal would minimize potential effects on epipelagic plankton and fishes. The transit time of a waste plume in the surface layer is limited with a surface dump. Thus, the contact time with the waste and the spatial extent of the plume are minimized. Of the three options, dumping would result in the highest particle deposition rate per unit bottom area. Thus, potential effects on benthic organisms occurring within the depositional area are highest for that technique. Dumping offers the environmental advantage of confining potential effects to a smaller area than would be potentially affected by dispersal. Moreover, subsequent monitoring would be simplified by reducing the depositional area.

Surface dispersal techniques could be used to provide a high initial dilution of wastes in addition to a lower depositional rate per unit area. Thus, concentrations of reject material would be less in the water and on the bottom. However, the total areal extent of potential effects would be greater.

The environmental considerations for each disposal alternative are also dependent upon the specific biological and oceanographic characteristics of the disposal site. The general disposal options for each representative disposal area are evaluated in Table 35. The ranking follows the previously described generic pattern whereby disposal in nearshore areas has a greater environmental significance than disposal in deeper, offshore waters. The greater significance in nearshore areas results from the following factors:

- High productivity
- Limited dilution and dispersal
- Commercial and recreational fisheries
- Sensitive or unique habitats
- Higher ratio of potentially affected habitat to total available habitat.

It should be emphasized, however, that, although the deep ocean waters have been given a lower relative significance in this ranking procedure, there are several factors which could modify this relationship. The greater sensitivity of deep-ocean organisms to anthropogenic stress, from a documented and theoretical perspective, could alter these relationships when site-specific data are examined in detail and organisms' tolerances to actual reject material are studied. The great difficulty and expense of monitoring deep ocean communities results in high uncertainty of detecting and documenting effects if they occur. Moreover, the high dispersion potential of the open ocean results in considerable uncertainty associated with the ultimate fate of reject material.

For the nearshore disposal options, there are some differences in the ranking of environmental considerations relative to representative disposal sites. The differences are mainly associated with the regional fisheries,

TABLE 35. EVALUATION OF THE ENVIRONMENTAL SIGNIFICANCE OF DISPOSAL AREA OPTIONS WITHIN EACH REPRESENTATIVE DISPOSAL AREA

	Nearshore		Shelf	Deep Ocean
	Outfall	Dump	Dump	Dump
Pacific Northwest	4	3	2	1
Southern California	3	3	2	1
Hawaii	2	2	N/A	1
Western Gulf of Mexico	N/A		3	1

Note: Each disposal option is ranked from 1 to 4, with a rank of 4 representing the greatest environmental significance.

importance of demersal organisms (i.e., those species most susceptible to impact), the potential for offshore transport of discharged or dumped material, and the water depth available nearshore. Based on such considerations, the nearshore waters of Hawaii, specifically the windward coast, would have a lower relative significance than southern California or the Pacific Northwest.

Selection of the most appropriate disposal technique from an environmental perspective would require information on the potential toxicity of the waste to marine organisms and development of reliable methods to predict the dispersion and fate of waste material. With such information, the advantages and disadvantages of each disposal technique could be evaluated for the following attributes:

- Area affected
- Severity of effects
- Duration of effects
- Populations at risk.

8. RESEARCH AND STUDY REQUIREMENTS FOR ASSESSING REJECT OCEAN DISPOSAL

Research and study requirements for assessing the impact of ocean disposal of manganese nodule processing waste are based upon the requirements of the ocean dumping or discharge regulations (Chapter 2) and upon the significant environmental concerns developed in the previous chapter.

Manganese nodule processing waste may be acceptable for ocean disposal based upon the information developed in this report. However, because representative pilot-scale processing plants are currently not in operation, it is presently not possible to adequately assess the toxicity and bioaccumulation potential of the waste.

The physical fate of dumped or discharged processing wastes must be predicted to enable calculation of initial dilution and estimation of subsequent transport and deposition. While techniques are readily available to accomplish portions of the various predictive tasks required, standardized methodologies should be developed.

The recommendations presented in this chapter describe further research which may be needed to assess the acceptability of manganese nodule processing waste for ocean disposal. Wastes from representative pilot-scale (or prototype plants, if possible) operations of each processing plant proposed should be evaluated in accordance with the recommendations below. Although comments are provided on the need for baseline studies of proposed disposal sites, this report is not intended to provide detailed recommendations on disposal site selection studies. Such recommendations should be site specific and are beyond the scope of this report.

BASIS FOR RECOMMENDATIONS

Regulatory Requirements

Research on the effects of ocean disposed wastes has not been of high priority in recent years because the original objectives of the Marine Protection, Research, and Sanctuaries Act and the London Dumping Convention were to terminate consideration of the oceans as a waste disposal option. For instance, the National Ocean Pollution Research and Development and Monitoring Planning Act of 1978 (PL 95-273) assigns a low priority to studying the effects of dumping of sewage sludge, because the MPRSA "requires that all ocean dumping of sewage sludge be phased out by 1981." However, through recent activities including a court decision which ruled that the MPRSA did not authorize EPA to ban the dumping of sludge without considering the alternatives to ocean dumping, NACOA's recommendations for ocean disposal, and industrial and public concern,

suggests that ocean disposal policies in the future may allow for various types of wastes to be permitted for ocean disposal.

Based upon the review of existing ocean disposal regulatory policies, it appears that future research programs need to be established to fill some of the existing data gaps in describing the composition and fate and effects of manganese nodule processing wastes. From a regulatory viewpoint, research activities should be directed in the following areas:

- Chemical characterization - Complete characterization of the processing wastes to trace levels is needed. Studies may need to investigate waste components availability in the ionic form. State of the art procedures for these determinations also need to be developed.

- Physical characterization - Research in this area is needed to define appropriate methodologies to determine the various parameters necessary to predict the fate and initial dilution of the material to be disposed of.

- Biological characterization - Based upon the proposed modifications to the ocean dumping regulations, standard procedures need to be developed to determine bioaccumulation potential and chronic effects on "appropriate sensitive marine organisms" and "appropriate sensitive benthic marine organisms." These tests need to be designed for phytoplankton and zooplankton species, crustacean or molluscan species, fishes, and benthic organisms including filter feeders, deposit feeders and burrowing species. These organisms must be representative of those living in or near the proposed disposal site. The biology of the deepwater species is not well documented and greater research is essential.

While these are the primary research areas, the following areas also need to be investigated:

- Technologies appropriate for the reuse or recycling of manganese nodule processing wastes

- Further treatment methodologies to reduce the concentration of potentially harmful constituents

- Cost effective, innovative monitoring methodologies (i.e., acoustics, remote sensing, etc.).

Major Environmental Concerns

As described in detail in the preceding chapter, the potential environmental impacts of the marine disposal of manganese nodule processing wastes are quite diverse, and they can be expected to vary considerably with the receiving environment and with the disposal method. With regard to

subjects which can be recommended for further study in order to assess the feasibility of the marine disposal of these wastes, certain potential impacts must be considered to be of greater concern than others. In particular, impacts associated with organisms inhabiting the water column must be deemed of lesser concern, simply because the wastes will settle out of the water column and the exposure of these organisms to the wastes will consequently be limited. On the contrary, potential impacts of the disposal of these wastes on benthic organisms are of greater concern, simply because the wastes are expected to accumulate on the sea floor, and therefore benthic organisms may be buried or smothered by the wastes or they will have to continue to exist in the presence of these wastes for extended periods.

The location of the disposal site will have a large influence on whether or not appropriate scientific studies can be designed to assess the potential for environmental impact of the marine disposal of these wastes. Effects of the open-ocean disposal of these wastes on the deep-sea benthos will be particularly difficult to analyze. Very little is known about the life histories, physiology, biochemistry, and physical/chemical tolerances of deep-sea benthic organisms. The technological problems of bringing back live, representative samples of these organisms, without subjecting them to radical changes in temperature and pressure, preclude performing meaningful experiments with them. In addition, there would be severe problems with even detecting the responses of deep benthic communities to waste disposal, should they occur. Jumars (1981) has discussed the similar problems involved in detecting impacts on benthos of manganese nodule mining. For predictions of potential effects of waste disposal on deep-sea benthic organisms, it may have to suffice to estimate the depth of deposition of these wastes on the deep-sea floor and to judge whether such a deposit is likely to have any effect on the benthos. While such predictions of biological effects are somewhat arbitrary, they may be the only option for assessing potential impacts on the deep-sea benthos. It should be recognized, however, that future technological advances in deep ocean sampling methods may enable reliable assessment of impacts on these communities.

On the continental shelves and nearshore, it may be possible to collect representative benthic organisms, perform experiments and bioassays on them, and thereby estimate the potential for adverse impacts of waste disposal on these organisms. Beyond the physical effects of simply smothering and killing the benthic organisms, two potentially significant impacts of the wastes are related to their chemical characteristics. These are direct toxic effects due either to the metals or other chemical constituents within the wastes, and bioaccumulation of either metals or other potentially-toxic substances contained within the wastes. The latter is especially important when the subject organisms are in food chains leading to humans, as are many of the shelf and nearshore species. Routine laboratory analyses (to be outlined below) exist for the quantification of both toxic effects and bioaccumulation.

While there is certainly cause for concern regarding potential impacts of manganese nodule waste disposal on pelagic organisms, it is more difficult to simulate such effects in the laboratory. Larger organisms

(e.g., pelagic fishes, marine mammals) are likely able to avoid areas subject to high turbidity during disposal operations, and hence are not liable to be adversely impacted by the marine disposal of these wastes. Smaller organisms (e.g., phytoplankton, zooplankton) are of course not able to evacuate areas of high turbidity, and hence may be potentially affected by manganese nodule waste disposal. In the open ocean, the small temporal and spatial scale of their exposure to the wastes will tend to minimize the ecological implications of such impacts, if they occur. In neritic environments, however, the potential for resuspension of the particulate wastes is much greater, and therefore these small organisms are potentially subject to more temporally and spatially extensive impacts of these wastes. It will, therefore, be worthwhile to include phytoplankton and/or zooplankton in any laboratory studies designed to assess the potential impacts of marine manganese nodule processing waste disposal.

Laboratory procedures which can be utilized to examine either toxic effects of the wastes or the biological availability of trace metals or other potentially-toxic substances in the wastes will be described below. Also included below are recommendations for the establishment of baseline environmental conditions in any area being considered for the disposal of manganese nodule processing wastes.

BIOLOGICAL ASSESSMENT

Assessment of the Potential for Toxicity

In order to predict toxic impacts of the marine disposal of manganese nodule processing wastes, it may be necessary to conduct laboratory bioassays using representative organisms from each of the potential disposal sites. Bioassay requirements under current regulations are described in Chapter 2. These bioassays should be conducted using wastes from a pilot-plant process, with the understanding that they may not be exactly the same as the wastes from a commercial-scale plant. Bioassays are currently required for the liquid, suspended particulate, or solid phases of the wastes (as defined in a manner analogous to that used for dredged material bioassays; cf. Environmental Protection Agency/Corps of Engineers, Technical Committee on Criteria for Dredged and Fill Material 1977).

The liquid phase of the wastes may be evaluated in either of two ways. Where there is concern about specific substances that may be released in soluble form, the liquid phase may be analyzed chemically and the results evaluated by comparison to water quality criteria for those substances, after allowance for initial mixing. If certain potentially toxic constituents of the wastes are not included in the water quality criteria, or if there is reason to be concerned about possible synergistic effects of certain constituents, liquid phase bioassays may aid in evaluating the importance and the total net impact of the dissolved chemical constituents of the wastes. Although comparison of waste constituent concentrations with water quality criteria may be required from a regulatory standpoint, this will provide little information of predictive value in assessing potential adverse effects.

The liquid phase bioassays should be conducted with appropriate sensitive marine organisms from each of the proposed disposal areas, whenever possible. Adverse impacts of dissolved constituents of the wastes would likely only occur near the surface since dilution of the liquid fraction of the wastes would be great at depths below the surface layer (>100 m). Hence, it is probably only necessary to conduct liquid phase bioassays with benthic organisms from any nearshore areas considered for disposal. Bioassays may also be performed on appropriate water column organisms such as sensitive phytoplankton or zooplankton species. Considering the varying sensitivity of open-ocean neritic phytoplankton species discussed in the preceding chapter, it is important to emphasize that separate bioassays should be conducted using organisms collected in each of the proposed disposal areas. Guidelines for conducting liquid phase bioassays are found in EPA/COE (1977). Using these techniques, the effects of the liquid phase on phytoplankton will be evidenced as an inhibition of growth, the measured effect on zooplankton will be the death of the test organisms. It is important to note that it is difficult to predict the ecological consequences of the death of a certain fraction of the local population of a particular species. The environmentally protective approach is to regard any statistically significant increase in mortality compared to the controls as potentially undesirable. It is also important, however, to evaluate sublethal effects such as changes in behavior, reproduction, or growth.

The suspended phase bioassays will provide information on potential toxic effects due to either the physical presence of the particulates or to chemical effects of any biologically-active constituents of the particulates. These bioassays should also be conducted with appropriate sensitive marine organisms from each of the proposed disposal areas, whenever possible. It is difficult to conduct and interpret the results of suspended phase bioassays using phytoplankton (EPA/COE 1977), so it is herein recommended that a sensitive zooplankton species from each environment be chosen for analysis. Precedents for examining the effects of suspended particulate wastes on zooplankton can be found in the work of Hirota (1981) on potential effects of manganese nodule mining on macrozooplankton, and in the work of Paffenhofer (1972), who examined effects of "red mud" on copepods. While adult pelagic fishes are likely to avoid areas of increased turbidity (Barry 1978), consideration may be given to assessing the effects of the suspended particulates on larval fishes, which are much more susceptible to impact (cf. Rosenthal 1971). In addition, it would seem appropriate to utilize benthic suspension feeders for these bioassays, since their feeding is potentially threatened by elevated concentrations of inorganic particulate matter. Standard procedures for conducting suspended phase bioassays can be found in (EPA/COE 1977).

Solid phase bioassays are perhaps the most important since there is a greater potential impact on benthic organisms than on pelagic organisms, simply because these organisms live and feed in and on the deposited solid phase for extended periods. The major evaluative efforts should therefore be placed on the solid phase. Bioassays using the solid phase are especially important because they provide an indication of the speciation

(by determining bioavailability) of the chemical substances found in the wastes.

The solid phase bioassays should also be conducted with appropriate sensitive benthic organisms from each of the proposed disposal areas, whenever possible. It is herein suggested that species be selected to include one filter-feeder, one deposit feeder, one burrowing form, and one demersal fish from the outer continental shelf and from the nearshore region. Representative types might include a crustacean, an infaunal bivalve, and an infaunal polychaete (EPA/COE 1977). Standard procedures for conducting solid phase bioassays can be found in (EPA/COE 1977). A bioassay technique for testing acute (10-day) toxicity of settleable components of ocean wastes is described by Swartz et al. (1979). Using this technique for several infaunal species, infaunal amphipods were identified as a sensitive species appropriate for most analyses.

These bioassays measure the mortality of the organisms as a function of exposure to the wastes, although finding a statistically-significant impact in the laboratory does not necessarily imply that an ecologically important impact would occur in the field. Once again, the environmentally protective approach is to regard any statistically significant increase in mortality compared to the controls as potentially undesirable.

Current regulations require the assessment of significant mortalities or significant adverse sublethal effects, including bioaccumulation. In order to adequately assess overall potential toxic impacts of reject material, it may be necessary in the future to conduct more extensive chronic and/or sublethal bioassays prior to ocean disposal of reject material. Such studies, with specific objectives associated with chronic exposures, may also be required as a result of future changes in the applicable ocean disposal regulations.

Chronic studies of reject exposures are probably most appropriate for infaunal or epifaunal invertebrates or for demersal fishes since these organism groups could be expected to have sustained contact with settled reject material in a disposal area.

One of the primary concerns with regard to chronic effects is related to the appropriateness of settled reject material as a substrate for benthic invertebrates. Deposition of substantial layers of reject material over the normal substrate could conceivably have significant effects on normal benthic community structure and function. Infaunal invertebrates are particularly susceptible to substrate modifications, and most species have well-defined habitat requirements associated with sediment grain size and organic material content. Thus, longer term, life cycle bioassays may be appropriate to evaluate the suitability of deposited reject material as habitat for infaunal species, with emphasis on food availability and larval settlement characteristics.

It may also be appropriate to evaluate sublethal effects of bioaccumulation such as reproductive impairment or reduced growth or production. Such studies would require the exposure of test organisms for one or more generations in a chronic exposure regime.

Prolonged contact with contaminated sediments has been shown to cause abnormalities in demersal fishes, primarily associated with liver/gill disease and fin erosion. Such effects would not be detected during short-term (e.g., 96 or 240 hour) exposures. Consequently, longer term exposures (e.g., 5 to 10 weeks) may be necessary to evaluate potential impacts of solid phase (i.e., deposited) reject material on demersal fishes.

Most of the available procedures for assessing the toxicity of wastes to be disposed into the marine environment involve acute, lethal bioassays using exposure times of 96 or 240 h. Although these tests may be valuable for determining the relative toxicity of a waste, they provide little basis for predicting the biological effects of waste disposal in the ocean. Two of the primary limitations are the use of short exposure times and the use of organism death as the response variable. Short exposure times may be appropriate for situations where the predicted in situ exposures are from hours to days (e.g., exposure to plankton). However, organisms which could potentially be exposed to deposited reject material for extended periods would require longer term (e.g., life cycle) tests for assessment of possible effects. As part of the Ocean Disposal Permit Program, life cycle toxicity tests have been described by the U.S. Environmental Protection Agency (1978) for three species: a mysid, Mysidopsis bahia; the grass shrimp, Palaemonetes pugio; and the sheepshead minnow, Cyprinodon variegatus. Long-term toxicity and reproductive tests for infaunal polychaete worms are described by Reish (1980).

Although mortality is usually used as an end point in toxicity studies because it is easily observable and quantifiable, natural marine populations may respond considerably to pollutant stress without experiencing lethal effects. Sublethal responses such as changes in behavior, reproductive rate, or physiological rates (e.g., respiration) may cause long-term changes in population levels at pollutant concentrations below lethal levels. Such responses should be evaluated as part of a toxicity assessment of reject material.

One of the most serious limitations of laboratory toxicity studies is the difficulties associated with using measured laboratory responses (lethal or sublethal) in predicting population or community-level responses. In most procedures, statistically or graphically determined response estimates (e.g., 96-h LC_{50}) are usually multiplied by an application factor for the determination of a "safe concentration." Factors used in these calculations may be highly arbitrary and could be expected to display considerable variation according to species and type of waste. Moreover, such results do not provide an indication of the areal effects of a given mortality rate (or other response) in the marine environment.

One of the major concerns related to ocean disposal of reject material is the effect of settleable components on benthic communities. Community-level responses are especially difficult to predict based on single-species bioassays. One experimental design for assessing pollutant effects on plankton-derived benthic communities is described by Hansen (1974) and Sheridan and Badger (1981). This approach may be valuable in the

study of reject effects because it could enable a long-term assessment of both the acute community response and subsequent recolonization of sediments enriched with reject material.

An additional assessment technique valuable in predicting overall community responses is the use of large enclosed ecosystems in field exposures. Such enclosures can be sustained over relatively long periods and contain naturally occurring organisms at several trophic levels. They also provide the additional advantage of enabling the study of the natural flux rates of pollutants among organisms, water, and sediment. The use of large enclosed ecosystems in marine pollution research is evaluated by Davies and Gamble (1979).

Assessment of the Bioaccumulation of any Potentially-Toxic Components

One of the primary environmental concerns with regard to the marine disposal of manganese nodule processing wastes is the bioaccumulation of trace metals or other potentially toxic substances in the wastes. In certain situations, bioaccumulation may occur within a food web to such an extent that it may be harmful to the ultimate consumer, which, especially in the case of neritic environments, is often man. This may occur without apparent harm to the intermediate organisms within that food web. Bioaccumulation can only be expected to occur where there is a long-term exposure to the wastes, and hence it may only be expected to be of concern for benthic organisms which will remain in the presence of the wastes for sufficiently long periods for bioaccumulation to occur.

In the case of manganese nodule processing wastes, the biological availability of trace metals or other potentially-toxic substances within the wastes is unknown, and represents one of the critical information requirements that will enable adequate assessment of potential adverse impacts. Thus, it may be necessary to conduct laboratory studies exposing appropriate sensitive marine organisms to pilot plant waste material. Experimental data from tests with other metalliferous waste materials indicate that:

1. The bulk metal content of the waste alone does not provide an adequate indication of the availability of the metal to organisms.

2. The chemical form of the metal and the physical/chemical composition of associated materials can affect the bioavailability of the metal.

3. Bioavailability of metals is highly dependent upon the animal species and upon the individual metal.

4. Bioavailability from sediments is much less efficient than from aqueous solutions.

Because the magnitude of the biological uptake of trace metals and other potentially toxic substances varies with the species of animal, it is not

feasible to conduct laboratory studies which will assess the overall potential for bioaccumulation within neritic food webs. Nevertheless, the ultimate intent of such studies is to assess whether or not the metals or other substances are bioavailable, and not to determine the level of uptake within all individual species. Uptake may either be directly from the particulate wastes or from solution, if the substance of interest leaches out of the particulate wastes over time.

Benthic species to be studied may include a filter-feeder, a deposit feeder, a burrowing form, and a demersal fish from the outer continental shelf and from the nearshore region. Representative studies of bioaccumulation for deposit-feeding bivalves include Luoma and Jenne (1977) and Luoma and Bryan (1978). Standard procedures for conducting laboratory assessments of bioaccumulation can be found in EPA/COE (1977).

The environmental interpretation of bioaccumulation data is even more difficult than for bioassays because in most cases it is impossible to quantify either the ecological consequences of a given tissue concentration of a substance that is bioaccumulated, or even the consequences of that body burden to the animal whose tissues contain it (EPA/COE 1977). [In the case of mercury, there is an FDA action level (1.0 ppm), so there would be cause for concern if the tissue concentration of mercury in commercial species of fish or shellish exceeded this level.] The environmentally protective approach is to regard any statistically significant bioaccumulation relative to control animals as potentially undesirable. Nevertheless, a statistically significant difference in the laboratory may not predict an ecologically important impact in the field, but only provides evidence of biological availability of that substance and suggests consideration of that fact in the decision making process of where to dispose of these wastes.

To be valuable from a predictive standpoint, bioaccumulation tests should be conducted in conjunction with detailed analyses of the physical/chemical exposure conditions. Special emphasis should be placed upon solubility of metals and sediment/water partitioning.

It may also be of value to assess the potential for food web transfer of metals contained in reject material. This could be accomplished, for example, by exposing phytoplankton cultures to reject suspensions followed by introduction of herbivorous zooplankton. Following the exposure period zooplankton could be analyzed for bioaccumulation of metals.

Establishment of Baseline Environmental Conditions

If a site is selected for the disposal of manganese nodule processing wastes, it will be important to establish baseline environmental conditions for that area, prior to commencing disposal of those wastes. Accurate baseline descriptions will be necessary in order to compare and contrast them with conditions at the site at some future date after wastes have been disposed there. If adequate environmental information for the site already exists, it may suffice to describe the baseline conditions from a thorough literature review. In many cases, however, information may be inadequate or incomplete, and therefore field surveys may be required to better describe the biological characteristics of the receiving environment.

Attention should focus on the benthos and on fishes of commercial or recreational importance. For reasons described above, it is probably not reasonable to expect a detailed field survey of the benthic communities in the deep sea, since it would be difficult to detect an impact there of the waste disposal, should one occur (Jumars 1981). Technological advances may, however, enable future assessment of the deep sea benthos. Field surveys of benthic habitats are currently appropriate, however, for the outer continental shelf and nearshore habitats. Consideration should be given to definition of any areas of special biological significance (e.g., spawning/nursery areas, migration routes, coral reefs, kelp forests, etc.), since it may be necessary to avoid waste disposal in such areas.

Monitoring programs should be designed to assess the potential impacts of reject disposal on susceptible marine communities, with emphasis on sensitive organisms, habitats of limited distribution, and commercially or recreationally important species. Other biotic groups which should be considered for inclusion in a monitoring program include: phytoplankton, zooplankton, demersal and pelagic fishes, and infaunal/epifaunal benthos.

It is important that biological studies be conducted in conjunction with physical/chemical studies to enable quantification of cause/effect relationships. Moreover, it is important that the fate of reject material be evaluated as part of the monitoring program to ensure that areas sampled for biological assessments are actually exposed to the reject material.

Monitoring surveys conducted during or after the period of disposal of manganese nodule wastes will permit evaluation of whether or not this practice has adversely impacted the environment at the disposal site. Optimal survey design will also include pre-disposal surveys of the designated disposal site and control areas.

CHEMICAL ASSESSMENT

Bioassay techniques are the most direct methods available for assessing the environmental impact of the ocean disposal of manganese nodule processing wastes. Chemical analysis of the waste is needed to determine the concentrations of waste constituents to which the bioassay organisms are exposed. Without adequate chemical analysis, bioassay results are of little value and subsequent monitoring of the waste composition cannot be interpreted.

The primary waste constituents of concern for regulatory purposes are those known to be in the waste and for which the EPA water quality criteria currently exist. These compounds include:

Arsenic	Mercury
Cadmium	Nickel
Trivalent chromium	Selenium
Hexavalent chromium	Silver
Copper	Thallium
Lead	Zinc

It is recommended that further analysis be performed to determine if any organic compounds classified by EPA as "priority pollutants" are present in the waste. This more complete analysis of the waste is also needed to evaluate which constituents may be responsible for any adverse responses noted in bioassay tests, and to determine which compounds should be analyzed in the bioaccumulation tests.

Other elements and compounds not currently listed as priority pollutants should also be evaluated because of their potential toxicity, their potential to control chemical speciation, or their nutrient properties. These constituents are listed below:

Potentially toxic constituents

barium, vanadium, beryllium, and molybdenum

Constituents which control chemical speciation (e.g., of dissolved forms of potentially toxic constituents)

iron and manganese

Nutrient compounds

nitrogen (ammonia, nitrite, nitrate) and silicon.

Future chemical analyses to characterize manganese nodule processing wastes and rejects must carefully evaluate the partitioning of the constituents between the dissolved and particulate phases. Concentrations of potentially toxic constituents in the dissolved state are expected to be very low. This is also true of ambient trace constituents dissolved in seawater. These low concentrations are generally below the detection limits of standard analytical techniques (cf. Bruland 1980) so that state-of-the-art analytical techniques will be required. Sample extraction procedures such as those developed by Bruland et al. (1979) will probably be necessary.

PHYSICAL ASSESSMENT

The research objectives concerning the fate of materials result in part from ocean dumping regulations and in part from the inadequacies of the present computer models. The recommendations are restricted to objectives which can be accomplished using existing experimental knowledge and physical theories. Others, which involve fundamental advances in the understanding of the relevant physical phenomena, are briefly mentioned but are beyond the scope of this report.

The present regulations concentrate on "initial mixing", which is defined as the diffusion of material that occurs within 4 hours after discharge. The model of Brandsma and Divoky (1976), its modification by Bowers and Goldenblatt (1978), and the model by Brandsma et al. (1980), as well as others, are all of potential use for the determination of initial

mixing. The instantaneous dump models suffer several inadequacies. The first is in the formulation of fluid entrainment into the cloud. Neither of the treatments contained in Brandsma and Divoky (1976) and Bowers and Goldenblatt (1978) are completely consistent with experimental results (cf. Krisnappan 1975; Bowers and Goldenblatt 1978). If, as is apparent from these results, the entrainment eventually stops (or decreases radically). then the determinations of initial dilution and equilibrium level may be tremendously in error. Errors in entrainment estimation could lead to serious underestimations of pollutant concentrations and the trapping depth. Another difficulty occurs in the determination of the fall velocity-probability distribution of the dumped solids. Morgan (1981) found that coagulation of fine particles was concentration dependent. Hunt (1980) also found coagulation to be an important factor controlling sedimentation rates. Inclusion of the effects of coagulation into a dumping model showed that a significant alteration of the particle size distribution occurred in the initial stages of the dump, and that omission of this alteration was likely to produce a significantly low estimate of particle settling rates.

Continuous discharge models are initially very dependent on the conditions describing entry of a sediment-laden jet into the water and the ambient ocean currents (such as the wake in the lee of an offshore platform). Brandsma et al. (1980) consider some of these in detail. A more fundamental problem is the effect on fluid entrainment of particles in the jet. Ditmars and McCarthy (1975) indicate that entrainment is retarded by the presence of such particles. Hence, initial dilution and trapping levels may be overestimated.

In both the instantaneous and continuous discharge models mentioned above, advection and passive diffusion are computed numerically in some fashion. The behavior of bottom surges is rough. However, the ability to quantitatively predict the dynamics of such surges is not readily available in the literature.

The three numerical models discussed above are all complex and, with proper "adjustments", able to make predictions in complex environments. However, the monetary costs of producing results for a single set of conditions for a short time is relatively high and the results are presented in forms not readily useful for compliance with the proposed regulations. A useful product, not currently available, would be a semi-analytical - semi-numerical model which would predict initial dilution and pollutant concentration contours as a function of time and space. The oceanographic conditions could be simplified; for example, the current speed, u, could be assumed to be a function of depth only, or perhaps a function of depth and time [expressed by a mathematical equation, for instance $u(t,z) = a(z) \cos(t)$]. The model would execute at a low cost (dollars, or fractions of dollars) and could incorporate advances in the state of the art, such as the work of Morgan (1981), as they become publicly available. With such a model, a wide range of conditions could be investigated which would be useful in understanding strategies for disposal. Predictions made for direct comparison with field data should probably be made with the more complex models previously mentioned or their subsequent modification.

The long term fate of suspended particles requires other approaches. Numerical models of the Brandsma-Divoky type are prohibitively expensive to run for long periods of time and would require extensive computer memory if used in their present form. Analytic formulations, using idealized currents for example, offer approaches which would simulate the expected fate of particles over long periods of time at low (computer) cost. Lavelle and Oztergut (1980) present predictions for a single layer. Multiple layers are necessary for many situations, however. Also important are the effects of zooplankton. As indicated earlier, these animals ingest very fine particles and excrete fecal pellets of larger diameter. Thus, inclusion of these effects in a model may remove the very fine particles in the upper layers of the water column much more efficiently than physical means. A multiple layer analytic model can be written which incorporates transport, vertical (and horizontal) diffusion, and biological transformation of particles with methods available at the present time. Since the analytic expressions would most likely be in the form of infinite series, these could be evaluated by computer methods at relatively low cost.

GLOSSARY

acute toxicity - Causing death or severe damage to an organism by poisoning during a brief exposure period, normally 96 hours or less, although there is no clear line of demarcation between acute and chronic toxicity.

amphipod - Laterally compressed crustaceans, most of which are epibenthic or infaunal.

benthic - Pertaining to the bottom of the ocean and the organisms living there.

bioaccumulation - The accumulation of a substance in an organism's tissues resulting from exposure to the substance in the food, surrounding water, or sediments.

bioavailability - The availability of a substance for incorporation into an organism's tissue.

biomagnification - Increase in the concentration of a substance as a function of trophic level.

bioturbation - Mixing of bottom sediments by organisms.

chronic toxicity - Causing death or damage to an organism by poisoning during prolonged exposure, which, depending on the organism and the test conditions and purposes, may range from several days to weeks, months, or years.

contiguous zone - The entire zone established or to be established by the United States under Article 24 of the Convention of the Territorial Sea and the Contiguous Zone. This zone extends from the seaward boundary of the territorial seas (3 miles out) to a distance of 12 miles seaward of the inland boundary of the territorial sea (line of ordinary low water).

convective descent - For an instantaneous dump cloud, this is the portion of the fall of the cloud from discharge to the trapping level.

copepod - Small crustaceans most of which are free living and planktonic.

cumacean - Small infaunal crustaceans with distinctive enlarged head and thorax.

deep ocean - That portion of the ocean lying at depths greater than the deepest portion of the continental slope of the adjacent land masses.

demersal - Pertaining to organisms living in close association with the ocean bottom.

discharge - (NPDES) when used without qualification means the "discharge of a pollutant," which means:

(a)(1) Any addition of any "pollutant" or combination of pollutants to "waters of the United States" from any "point source," or (2) Any addition of any pollutant or combination of pollutants to the waters of the "contiguous zone" or the ocean from any point source other than a vessel or other floating craft which is being used as a means of transportation.

(b) This definition includes additions of pollutants into waters of the United States from: surface runoff which is collected or channelled by man; discharges through pipes, sewers, or other conveyances owned by a state, municipality, or other person which do not lead to a treatment works; and discharges through pipes, sewers, or other conveyances leading into privately owned treatment works.

This term does not include an addition of pollutants by any "indirect discharger."

disposal - The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous wastes into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground waters.

dumping - "Dumping" is defined in the regulations as any disposition of material provided that it does not encompass several exceptions including: effluents from discharges covered by the Clean Water Act, Rivers and Harbor Act, or Atomic Energy Act of 1954, routine effluents from vessels; the construction of artificial islands or intentional placement of any device, oyster shells, fish wastes, or any other material for fisheries development.

dynamic collapse - Transformation of the cloud when it reaches the trapping level until the particles in the cloud behave independently.

electrowinning - Reductions of metal from a solution by means of electrochemical processes. When sufficient voltage is applied, metallic ions in solution are reduced and deposited at the cathode.

epifauna - Benthic animals living on the sediment surface or on a hard-bottom substrate.

equilibrium level - Synonym for trapping level.

euphotic zone - The surface water layer where available light allows photosynthesis to be greater than or equal to plant respiration.

hydrometallurgical - Pertaining to hydrometallurgy, the treatment of ores, concentrates, and other metal-bearing materials by wet processes, usually involving the solution of some component, and its subsequent recovery from the solution.

infauna - Animals living within sediments on the ocean bottom.

inner shelf - That portion of the continental shelf (or insular shelf in the case of Hawaii) extending from shore approximately one half way to the shelf break.

level of neutral buoyancy - Synonym for trapping level.

ligand - The anion or molecule which forms a coordination compound with a metal ion in solution.

lixiviant - A reagent to extract a soluble constituent from a solid mixture by washing or chemical leaching.

microgram per liter (ug/l) - The concentration at which 1 millionth of a gram (10^{-6}g) is contained in a volume of 1 liter. Also known as part per billion (ppb).

mid shelf - At a location approximately mid-way between the shore and the shelf break.

milligram per kilogram (ug/kg) - The concentration at which 1 thousandth of a gram (1 milligram) is contained in a mass of 1 kilogram. Also known as part per million (ppm).

milligram per liter (ug/l) - The concentration at which 1 milligram (10^{-3}g) is contained in a volume of 1 liter. Also known as part per million (ppm).

nearshore - That portion of the ocean extending from the shoreline out across the adjacent shelf, including both intertidal and subtidal benthic habitats and the overlying water column, to a distance of several kilometers from shore.

neritic - That region of the ocean overlying the continental shelf.

ocean - Any portion of the high seas beyond the contiguous zone.

open ocean - That portion of the ocean at greater distance from shore than the base of the continental slope of all adjacent land masses.

opportunistic - Short-lived, fast growing, and rapidly reproducing species; often the first to colonize disturbed habitats and enriched areas.

outer shelf - That portion of the continental shelf (or insular shelf in the case of Hawaii) extending from the shelf break approximately one half way to shore.

passive diffusion - Transport of particles by oceanic currents only (i.e., no internal dynamic forces in the cloud influence the motion of the particles in the cloud).

pelagic - Pertaining to the open water zone and organisms living there.

polychaete - Segmented worms with fleshy appendages and bristles. One of the most abundant groups of marine infauna.

pregnant liquor - A value-bearing solution in a hydrometallurgical operation.

production - Net production refers to the synthesis of organic matter by plants (primary production) or the growth increment of animals (secondary production) over some time period. Gross production is represented by the total energy and nutrients assimilated, i.e., net production plus metabolic losses.

raffinate - The solvent-lean, residual feed solution, with one or more constituents having been removed by extraction or ion exchange.

regulation - The ability of an organism to control tissue concentrations of a substance by the processes of absorption, metabolism, and excretion. If a substance is not regulated, tissue concentrations will be directly dependent upon the concentrations in external media (i.e., water or sediments).

rejects - That portion of manganese nodule processing wastes which consists of leached manganese nodule particles.

sessile - Organisms that are stationary or permanently attached to a substratum; opposite of freely moving or motile.

speciation (chemical) - The actual form in which a molecule or ion is present in solution. For example, iodine in aqueous solution may conceivably exist as one or more of the species I_2, I^-, I_3^-, HIO, IO^-, IO_3^-, or as an ion pair or complex, or in the form of organic iodo compounds.

territorial seas - The belt of the seas measured from the line of ordinary low water along that portion of the coast which is in direct contact with the open sea and the line marking the seaward limit of inland waters, and extending seaward a distance of 3 miles.

trapping level - Depth at which the density of the descending plume or cloud equals the density of the ambient seawater. If the plume or cloud is always heavier than the ambient seawater, then the plume or cloud impacts the bottom, in which case the trapping level is set equal to the water depth.

TABLE OF CHEMICAL SYMBOLS USED IN THIS REPORT

Element	Symbol
Aluminum	Al
Antimony	Sb
Arsenic	As
Barium	Ba
Beryllium	Be
Bismuth	Bi
Boron	B
Cadmium	Cd
Calcium	Ca
Cesium	Cs
Chromium	Cr
Cobalt	Co
Copper	Cu
Iron	Fe
Lanthanum	La
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Molybdenum	Mo
Nickel	Ni
Selenium	Se
Silicon	Si
Strontium	Sr
Silver	Ag
Thallium	Tl
Titanium	Ti
Vanadium	V
Zinc	Zn

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APPENDIX A

SUMMARY OF LONDON DUMPING CONVENTION

The overall objective of the London Dumping Convention is to prevent marine pollution caused by ocean dumping. The Convention requires signatory states to prohibit the dumping of any wastes or other matter in whatever form or condition except as otherwise specified. However, the Convention does not intend to bar any dumping but that of pollutants listed in Annexes I and II, shown in Tables 36 and 37.

Annex I (Table 36) of the Convention contains those wastes whose dumping would be prohibited under normal conditions. These wastes include: organohalogen compounds, mercury and mercury compounds, cadmium and cadmium compounds, persistent synthetics, oil, high-level radioactive waste and chemical and biological warfare products. However, these substances may be disposed of in the ocean if they are rapidly degradable and do not endanger health or make edible organisms unpalatable. Annex II (Table 37) contains materials which includes heavy metals, lead, copper, zinc, cyanides, fluorides, waste containers, and medium- and low-level radioactive wastes.

The rules for the control system established by the Convention are contained in Article IV(1). Under this provision it states:

> "In accordance with the provisions of the Convention Contracting Parties shall prohibit the dumping of any wastes or other matter in whatever form or condition except as otherwise specified below:
>
> a. the dumping of wastes or other matter listed in Annex I is prohibited,
> b. the dumping of wastes or other matter listed in Annex II requires a prior special permit,
> c. the dumping of all other wastes or matter requires a prior general permit" (Timagenis 1980).

The major element of the control system is the concept of special and general permits. A special permit is required for the dumping of matter listed in Annex II, is required for every single case of dumping, is granted only upon an application and is subject to the criteria of Annexes II and III (Tables 37 and 38). A general permit is required for the dumping of all other matter and may relate to a series of dumping operations, can be issued without an application (through general regulations) and is subject to the requirements of Annex III only.

The responsibility and authority for issuing permits is left to the discretion of States or Parties, except where permits are issued by an

TABLE 36. LONDON DUMPING CONVENTION ANNEX I

1. Organohalogen compounds.

2. Mercury and mercury compounds.

3. Cadmium and cadmium compounds.

4. Persistent plastics and other persistent synthetic materials, for example, netting and ropes, which may float or may remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation or other legitimate uses of the sea.

5. Crude oil, fuel oil, heavy diesel oil, and lubricating oils, hydraulic fluids, and any mixtures containing any of these, taken on board for the purpose of dumping.

6. High-level radio-active wastes or other high-level radio-active matter, defined on public health, biological or other grounds, by the competent international body in this field, at present the International Atomic Energy Agency, as unsuitable for dumping at sea.

7. Materials in whatever form (e.g. solids, liquids, semi-liquids, gases or in a living state) produced for biological and chemical warfare.

8. The preceding paragraphs of this Annex do not apply to substances which are rapidly rendered harmless by physical, chemical or biological processes in the sea provided they do not:

   (i) make edible marine organisms unpalatable, or
   (ii) endanger human health or that of domestic animals.

   The consultative procedures provided for under Article XIV should be followed by a Party if there is doubt about the harmlessness of the substance.

9. This Annex does not apply to wastes or other materials (e.g. sewage sludges and dredged spoils) containing the matters referred to in paragraphs 1-5 above as trace contaminants. Such wastes shall be subject to the provisions of Annexes II and III as appropriate.

10. Paragraphs 1 and 5 of this Annex do not apply to the disposal of wastes or other matter referred to in these paragraphs by means of incineration at sea. Incineration of such wastes or other matter at sea requires a prior special permit. In the issue of special permits for incineration the Contracting Parties shall apply the Regulations for the Control of Incineration of Wastes and Other Matter at Sea set forth in the Addendum to this Annex (which shall constitute an integral part of this Annex) and take full account of the Technical Guidelines on the Control of Incineration of Wastes and Other Matter at Sea adopted by the Contracting Parties in consultation.

TABLE 37. LONDON DUMPING CONVENTION ANNEX II

The following substances and materials requiring special care are listed for the purposes of Article VI(1)(a).

A. Wastes containing significant amounts of the matters listed below:

arsenic
lead
copper
zinc
and their compounds

organosilicon compounds
cyanides
fluorides
pesticides and their by-products not covered in Annex I.

B. In the issue of permits for the dumping of large quantities of acids and alkalis, consideration shall be given to the possible presence in such wastes of the substances listed in paragraph A and to the following additional substances:

beryllium
chromium
nickel
vanadium
and their compounds

C. Containers, scrap metal and other bulky wastes liable to sink to the sea bottom which may present a serious obstacle to fishing or navigation.

D. Radio-active wastes or other radio-active matter not included in Annex I. In the issue of permits for the dumping of this matter, the Contracting Parties should take full account of the recommendations of the competent international body in this field, at present the International Atomic Energy Agency.

E. In the issue of special permits for the incineration of substances and materials listed in this Annex, the Contracting Parties shall apply the Regulations for the Control of Incineration of Wastes and Other Matter at Sea set forth in the Addendum to Annex I and take full account of the Technical Guidelines on the Control of Incineration of Wastes and Other Matter at Sea adopted by Contracting Parties in consultation, to the extent specified in these Regulations and Guidelines.

TABLE 38. LONDON DUMPING CONVENTION ANNEX III

Provisions to be considered in establishing criteria governing the issue of permits for the dumping of matter at sea, taking into account Article IV(2), include:

A. Characteristics and composition of the matter

1. Total amount and average composition of matter dumped (e.g. per year).
2. Form, e.g. solid, sludge, liquid, or gaseous.
3. Properties: physical (e.g. solubility and density), chemical and biochemical (e.g. oxygen demand, nutrients) and biological (e.g. presence of viruses, bacteria, yeasts, parasites).
4. Toxicity.
5. Persistence: physical, chemical and biological.
6. Accumulation and biotransformation in biological materials or sediments.
7. Susceptibility to physical, chemical and biochemical changes and interaction in the aquatic environment with other dissolved organic and inorganic materials.
8. Probability of production of taints or other changes reducing marketability of resources (fish, shellfish, etc.).

B. Characteristics of dumping site and method of deposit

1. Location (e.g. coordinates of the dumping area, depth and distance from the coast), location in relation to other areas (e.g. amenity areas, spawning, nursery and fishing areas and exploitable resources).
2. Rate of disposal per specific period (e.g. quantity per day, per week, per month).
3. Methods of packaging and containment, if any.
4. Initial dilution achieved by proposed method of release.
5. Dispersal characteristics (e.g. effects of currents, tides and wind on horizontal transport and vertical mixing).
6. Water characteristics (e.g. temperature, pH, salinity, stratification, oxygen indices of pollution--dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD)--nitrogen present in organic and mineral form including ammonia, suspended matter, other nutrients and productivity).
7. Bottom characteristics (e.g. topography, geochemical and geological characteristics and biological productivity).
8. Existence and effects of other dumpings which have been made in the dumping area (e.g. heavy metal background reading and organic carbon content).
9. In issuing a permit for dumping, contracting Parties should consider whether an adequate scientific basis exists for assessing the consequences of such dumping, as outlined in this Annex, taking into account seasonal variations.

C. General considerations and conditions

1. Possible effects on amenities (e.g. presence of floating or stranded material, turbidity, objectionable odour, discolouration and foaming).

TABLE 38. (Continued)

2. Possible effects on marine life, fish and shellfish culture, fish stocks and fisheries, seaweed harvesting and culture. 3. Possible effects on other uses of the sea (e.g. impairment of water quality for industrial use, underwater corrosion of structures, interference with ship operations from floating materials, interference with fishing or navigation through deposit of waste or solid objects on the sea floor with protection of areas of special importance for scientific or conservation purposes). 4. The practical availability of alternative land-based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

international authority under Article VI(1) of the Convention. The Convention contains certain criteria by which the granting of permits is guided and these criteria are legally binding for the States or Parties, although in practice they cannot strictly limit their discretion. Any permit is to be issued only after careful consideration of all factors set forth in Annex III. However, additional criteria may be established in national legislation.

The obligation to comply with the criteria and procedures is repeatedly stressed throughout the Convention in order to impress upon the appropriate authority the importance of doing so. The Environmental Protection Agency is the United States authority for implementing the international requirements for control of ocean dumping, and its statute, the Marine Protection, Research, and Sanctuaries Act, was amended in 1974 to bring the Act into conformance with the Convention (PL No. 93-254, 88 Stat. 50, 1974, 33 USC 1401, 1402, 1411, 1412).

APPENDIX B

TECHNICAL BASIS FOR METHODS TO PREDICT THE FATE OF OCEAN DISPOSED PROCESSING REJECTS

INTRODUCTION

Some methods useful in determining the fate of discharged material into the marine environment are discussed to explain the methodology presented in Chapter 3 and used in Chapter 6. Limitations on the understanding of the physical processes are also described. In some instances these limitations are serious, and may invalidate the results produced by the above methodologies, as well as those produced by the more complex numerical models.

OCEAN DUMPING

Disposal of waste material into the ocean using barges results in dumps of relatively short duration ranging from a few seconds for a split hull barge to several minutes for a hopper barge. The discussions which follow consider only instantaneous dumps in water deep enough for the dump material to be considered as a hemispherical cloud. Dumps in relatively shallow water where the duration of release is comparable to the time required for the cloud to impact the bottom are described elsewhere (see Barnard 1978). If the water depth is not sufficiently great, the plume of waste material impacts the bottom before equilibrium of the plume and the surrounding seawater is reached and surges along the bottom.

The physical processes which govern the behavior of the dumped material in deep water are divided into 3 phases: the convective descent, the dynamic collapse, and the passive diffusion. The division of the processes into these three phases is found in the modeling efforts of Koh and Chang (1973) and Brandsma and Divoky (1976). The plume can be represented as a hemispherical cloud. During the convective descent, the cloud falls at a rate determined primarily by its total mass and size and entrains ambient water. The sizes of the particles which compose the solid portion of the cloud are of secondary importance during this phase, although recent work on flocculation (Hunt 1980) suggests that the internal particle size distribution may change during the descent. The downward force on the cloud is its negative buoyancy, which decreases as it entrains ambient water. The resisting forces are primarily due to drag. The dynamic collapse phase occurs when the cloud has entrained sufficent water so that its density equals that of the surrounding water. Due to its downward momentum, the cloud continues to fall past the level of neutral buoyancy entraining water which results in the cloud becoming positively buoyant. The successive buoyancy changes produce a rise and fall oscillation about the position of neutral buoyancy. These oscillations cause the cloud to flatten and behave

more and more as individual particles. The passive diffusion phase begins at this point. The particles are advected by local currents and dispersed laterally by horizontal diffusion. The particles settle at a rate determined by their fall velocity and any vertical currents. If the particle size is small enough, vertical diffusion will alter the particles' rate of descent. These motions continue until the particle settles on the sea floor.

The convective descent phase is analyzed in the aforementioned models by a system of nonlinear first order differential equations. The basis for this formulation comes, in part, from the papers of Morton et al. (1956) and Turner (1960). One of the results of the former paper is the formula

$$d_{max} = A\left(\frac{V_s g'}{g\varepsilon}\right)^{1/4}$$

where:

d_{max} = maximum distance of fall
A = dimensionless constant = 2.66
V_s = volume of cloud
$g' = \left(\frac{\Delta\rho}{\rho}\right) g$
g = acceleration due to gravity
$\Delta\rho$ = density of cloud minus density of seawater
ρ = density of seawater
ε = $-1/\rho\ d\rho/dz$, normalized density gradient
z = vertical coordinate (positive upward).

A dimensional analysis derivation of this equation is also contained in Fischer et al. (1979).

For purposes of illustration, the cloud is assumed to be hemispherical and composed initially of 1/5 manganese nodule processing rejects having a density equal to 3.19 g/cm^3 and 4/5 freshwater with a density equal to 1.00 g/cm^3. This mixture is essentially that of the Cuprion process waste slurry tested by McKibbin (1981). With these assumptions d_{max} is dependent only on V_s and ε. Figure 25 shows the maximum fall distance plotted as a function of D_s (diameter of a hemispherical cloud having volume V_s) for various values of ε.

Typically, the density difference between the ocean water at the surface and at the pycnocline is several sigma-t units (1 sigma-t unit = 0.001 g/cm^3). For relatively shallow water depth [e.g., 60 m (197 ft)], the pycnocline might be at a depth of 40 m (131 ft) or less. Thus, a 2 sigma-t units density difference gives a value of $\varepsilon = 5 \times 10^{-5}$/m ($1.5 \times 10^{-5}$/ft). Hence only if the discharge volume of the cloud is less than approximately 6 m^3 (7.8 yd^3) will the cloud reach its equilibrium depth. In the deep ocean

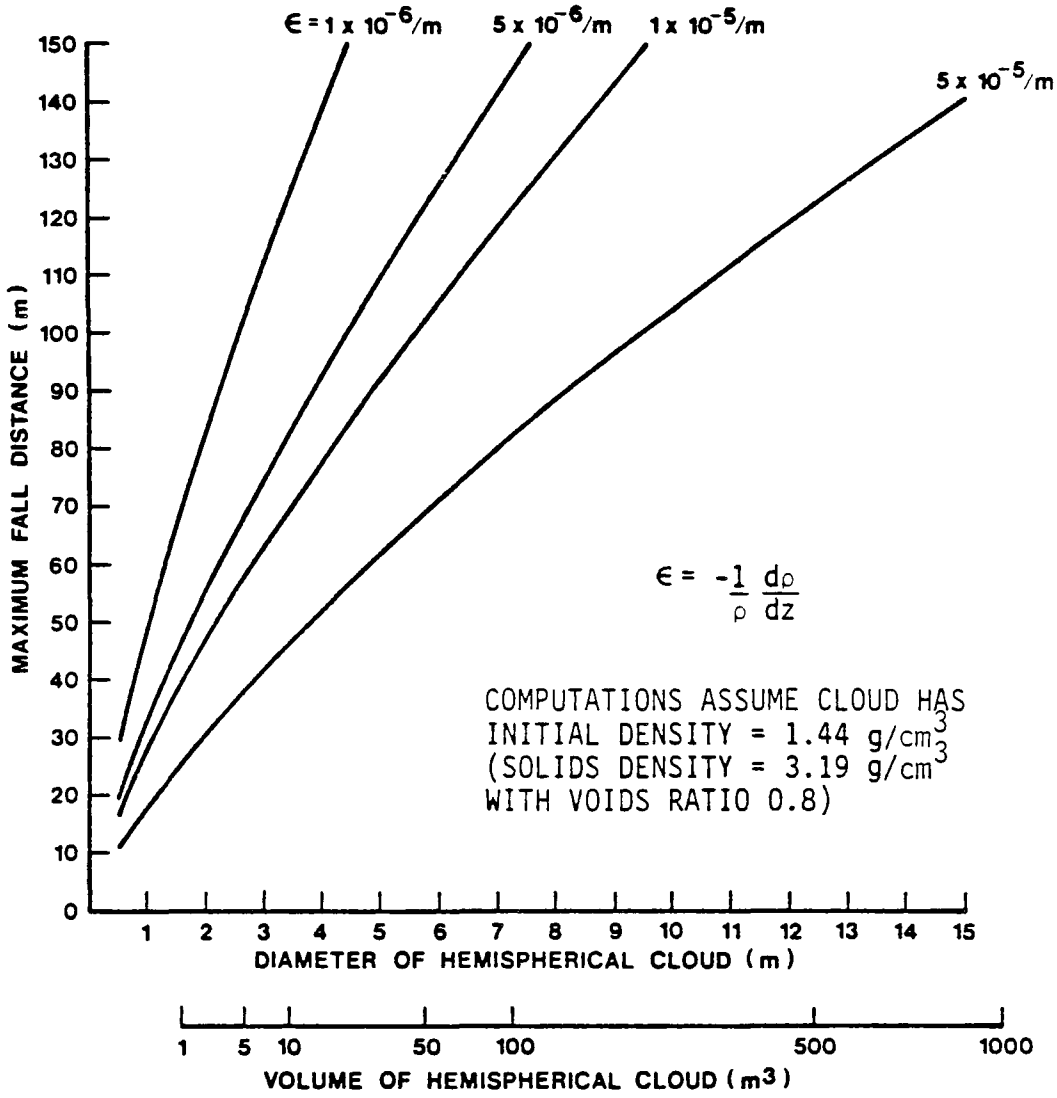


Figure 25. Maximum fall distance for various hemispherical cloud diameters and normalized density gradients ϵ when the initial cloud density = 1.44 g/cm^3.

the pycnocline may be at 150 m (492 ft) depth. In this case a 2 sigma-t unit difference gives ε a value equal to 1×10^{-5}/m (3.0×10^{-6}/ft). Hence, clouds having initial volumes up to 230 m^3 (301 yd^3) reach equilibrium depths less than the depth of the pycnocline. Since existing disposal barges have capacities beyond this range, there is little chance that the cloud will reach equilibrium for the more shallow depths, but could reach equilibrium in deeper water if the density gradients above and below the pycnocline are sufficiently large.

The mining waste slurry densities from other processes have densities up to 2.00 g/cm^3. Figure 26 shows the maximum fall distances assuming an initial density equal to 2.00 g/cm^3. A comparison of these distances with those previously shown in Figure 25 indicates a cloud of the higher initial density can have a mass of only 40 percent the mass of the cloud of the smaller density (1.44 g/cm^3) to fall the same distance under the same oceanographic conditions. This conclusion assumes that Morton's theory is valid for the heavier cloud. However, some experimental results (Pequegnat 1978) indicate that the heavier cloud, because of its lower initial water content, may sink with no appreciable entrainment.

The initial dilution achieved by the cloud when it reaches its equilibrium depth or has initially impacted the bottom is shown in Figure 27 as a function of depth for several dump volumes. These results use the dynamic descent equations of Brandsma and Divoky (1976) assuming an initial cloud density of 1.4 g/cm^3, and an unstratified ocean having density 1.025 g/cm^3. These curves indicate that when the cloud reaches moderately deep water the initial dilution becomes large as the depth increases, and consequently concentrations of material contained in the cloud become small. These results assume a constant entrainment coefficient. However, some experimental results (Krishnappan 1975) indicate that the entrainment coefficient eventually becomes very small (even approaching 0). If this is true, then the high initial dilutions shown above may be overestimated.

Quantitative estimates of the behavior of the cloud during the dynamic collapse phase are dependent on the exact mathematical formulation in a particular model. The interested reader should consult Koh and Chang (1973), or Brandsma and Divoky (1976) for a description of their methods.

The following comments on the passive diffusion phase implicitly assume that only one particle size is being dispersed. This is permissible since, although an actual discharged cloud has particle sizes of many different sizes (and hence fall velocities), particles behave independently at the inception of this phase (by definition).

Mathematically, passive diffusion of a material is usually described by the convective diffusion equations. Solving these equations in three dimensions and time can, in theory, predict the evolution of the cloud. For illustrative purposes, convection and diffusion are separated and discussed independently.

A simple procedure to compute horizontal diffusion of a patch of a pollutant is to assume that it diffuses radially relative to its center of

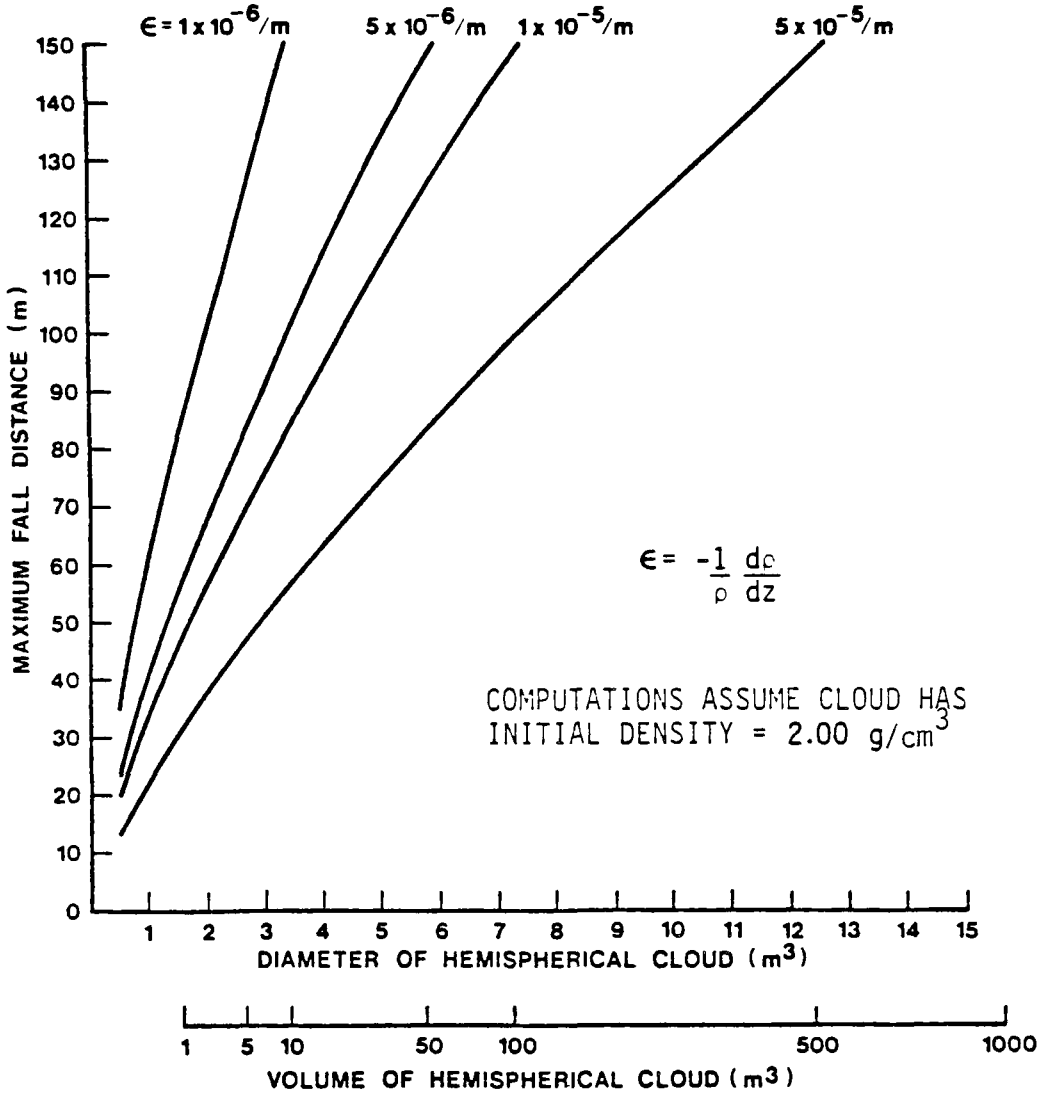


Figure 26. Maximum fall distance for various hemispherical cloud diameters and normalized density gradients ϵ when the initial cloud density = 2.0 g/cm^3.

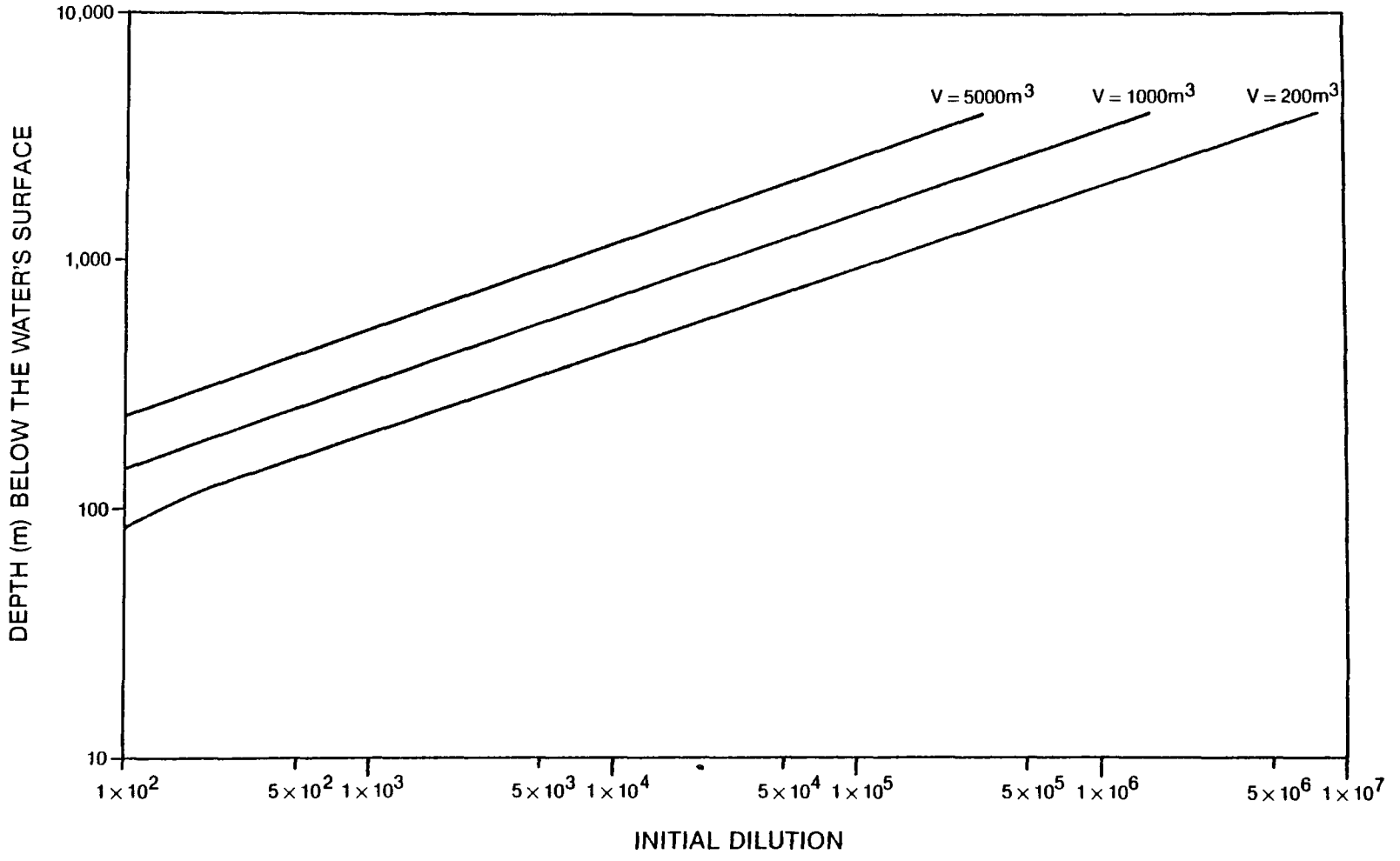


Figure 27. Initial dilutions for instantaneous dumps as a function of depth (based on convective descent equations of Brandsma and Koh 1976).

mass while the center of mass is transported by the horizontal currents. This procedure has been incorporated into several models.

In Gaboury and Stolzenbach (1979) for example, the patches are assumed to be Gaussian (normally distributed) in the horizontal plane. In models considering vertical variations, the patches can usually be assumed to have uniform thickness if the sediments in the patch have a uniform fall velocity. In this case

$$c(x,y,z,t) = \frac{a}{\sigma_x \sigma_y} \left[\exp - \left(\frac{(x-x(t))^2}{2\sigma_x^2} + \frac{(y-y(t))^2}{2\sigma_y^2} \right) \right] H(z,t)$$

where:

c = sediment concentration relative to the ambient concentration
a = constant
σ_x^2, σ_y^2 = x,y variances of the distribution
$x(t), y(t)$ = x,y coordinates of center of mass of patch
$H(z,t)$ = 1 for $z(t) \leq z \leq z_2(t)$
0 otherwise
$z_1(t) = z_1(0) - w_f t$
$z_2(t) = z_2(0) - w_f t$
w_f = sediment fall velocity.

The variances of the distribution are functions of time, and can be expressed as

$$\sigma_x = \sigma_u t$$
$$\sigma_y = \sigma_v t$$

(see Chen et al., 1975). Chen suggests that the constants σ_u and σ_v be determined by computing the x and y variances of observed horizontal currents. Since measurements probably do not exist at any particular site, an approximation must be used. Gaboury and Stolzenbach use Richardson's 4/3 law to compute:

$$\sigma_x^2 = \sigma_y^2 = \sigma_h^2 = 2E_h t + (\sigma_h^2)_{t=o}$$

where:

$E_h = L_o^{4/3}$
α = constant
L_o = initial diameter of the cloud at the trapping depth.

This formula for the x and y variances is used here in subsequent calculations.

In deep ocean dumping, vertical diffusion is often of critical importance. Horizontal currents may move materials laterally, but if the particles fall constantly, eventually they are removed from the water column. The relationship of vertical diffusion to the vertical fall of a negatively buoyant particle is important in the determination of vertical position of the particle at a given time. If the vertical diffusion is "large" in a region, then particles (in a statistical sense) will tend to be uniformly distributed in the region. If the vertical diffusion is "small," then a particle will tend to fall at a rate close to its fall velocity in quiescent seawater. The relative importance is governed by the parameter

$$K/w_f H$$

where:

K = vertical diffusivity
w_f = fall velocity of a particle
H = thickness of water layer having vertical diffusivity K.

Where $K/w_f H$ is large (i.e., much greater than 1), diffusion dominates fall velocity, while when $K/w_f H$ is small (i.e., much less than 1) the converse is true.

The following computations illustrate what may be expected in the present situation. The Cuprion process produces wastes having particle diameters between 1 um and 74 um which have (dry) density equal to 3.19 g/cm^3 (McKibbin 1981). Assuming that the seawater has temperature 5^o C (41^o F) and salinity 34 ppt, Stokes law gives

$$w_f = 7.14 \times 10^{-5} D^2$$

where:

w_f = fall velocity (m/sec)
D = particle diameter (micrometers).

The vertical diffusivity K can be computed by

$$K = \frac{4 \times 10^{-10}}{N^2} \quad \text{(Broeker 1981)}$$

where:

K = vertical diffusivity (m^3/sec)
N = buoyancy frequency (1/sec)
$= (-g/\rho \, d\rho/dz)^{1/2}$
g = gravitational acceleration
ρ = density of seawater
z = vertical coordinate (positive upward).

Table 39 shows the value of K/Hw_f for various particle velocities and

TABLE 39. VALUES OF K/Hw_f FOR VARIOUS PARTICLE FALL VELOCITIES AND BUOYANCY FREQUENCIES

D (microns)	w_f (m/sec)	N^2 (1/sec)	K (m^2/sec)	K/Hw_f H = 40 m	K/Hw_f H = 150 m
1	7.14×10^{-7}	10^{-7}	4×10^{-3}	140	37
		10^{-6}	4×10^{-4}	14	3.7
		10^{-5}	4×10^{-5}	1.4	0.37
		10^{-4}	4×10^{-6}	0.14	0.04
10	7.14×10^{-5}	10^{-7}	4×10^{-3}	1.4	0.37
		10^{-6}	4×10^{-4}	0.14	0.04
		10^{-5}	4×10^{-5}	0.01	0.004
		10^{-4}	4×10^{-6}	0.001	0.0004
74	3.91×10^{-3}	10^{-7}	4×10^{-3}	0.03	0.007
		10^{-6}	4×10^{-4}	0.003	0.0007
		10^{-5}	4×10^{-5}	0.0003	0.00007
		10^{-4}	4×10^{-6}	0.00003	0.000007

buoyancy frequencies of interest. Particles of diameter 10 um or larger are affected by vertical dispersion only by the smallest density gradients. However, particles having diameter 1 um or so are influenced by diffusive processes unless the density stratification is fairly strong. Since 50 percent of the material has a grain size less than 6 um for the Cuprion processes (McKibbin 1981), roughly this same percentage would be uniformly distributed in the mixed layer if the material were injected into the layer in a highly dilute form (for example, from a surface jet).

Several qualifications to the above must be made. First, the upward vertical current velocities have been ignored. Inclusion of these in the deep ocean would typically retard the settling rates by 10^{-7} m/sec. Even for the 1 um diameter particle, this would reduce the downward fall velocity by only 14 percent. However, during a period of coastal upwelling, a vertical current of 8×10^{-6} m/sec would be sufficient to reverse the negative buoyancy of particles having diameter less than 3.4 um, and thus particles of this size or less would tend to rise to the surface unless they were mixed by vertical diffusion. The other consideration is that the present papers on which the $K/w_f H$ discussion is based (Schubel and Okubo 1972; Lavelle et al., 1981) are single layer models in which the loss to a lower layer is not relevant or is ignored. This loss rate, which is unknown at the present time, may influence some of the above conclusions.

The present ocean dumping regulations are primarily concerned with the fate of the waste materials 4 hours after discharge. Even if the cloud impacts the bottom, only sand size or larger particulates are likely to have settled, and the finer particulates will be transported and diffused for much longer times. A procedure is developed to estimate the horizontal area, dilution, and average material thickness of the waste material, if it is assumed that it settles completely within 4 hours time. The convective descent equations of Brandsma and Divoky (1976) are used to predict dilution and (hemispherical) cloud radius as a function of water depth. At each depth, the cloud is allowed to horizontally disperse using the binormal distribution with the variance dependence of Gaboury and Stolzenbach (1979). Four hours after the trapping level is reached, the horizontal "area" of the cloud is computed and is equal to $\pi\sigma_h^2$. Inspection of the formula for σ_h previously given shows that the "area" is independent of the ambient current speed. The dilution is computed as the product of the dilution achieved during descent times the ratio of the "area" after 4 hours time to the area of the horizontal projection of the cloud at the end of the descent phase. The thickness is computed by dividing the initial volume of the dump by the "area" and multiplying this by the ratio of the relative initial density (with respect to seawater) of the cloud by the relative density of the solid material. Here, this density is assumed to be 3.4 g/cm^3. Figure 28 shows the "area" as a function of water depth for seven initial cloud volumes ranging from 200 m^3 to 5,000 m^3 (262 yd^3 to 6,540 yd^3). Although an initial cloud density of 1.4 g/cm^3 is used, the areas are almost independent of initial cloud density having reasonable values. Figure 29 shows the 4 hours dilution as a function of water depth for the seven initial cloud volumes. These dilutions are also essentially independent of initial cloud density. Figures 30 and 31 show the material "thickness" for initial cloud densities equal to 2.0 g/cm^3 and 1.4 g/cm^3 respectively.

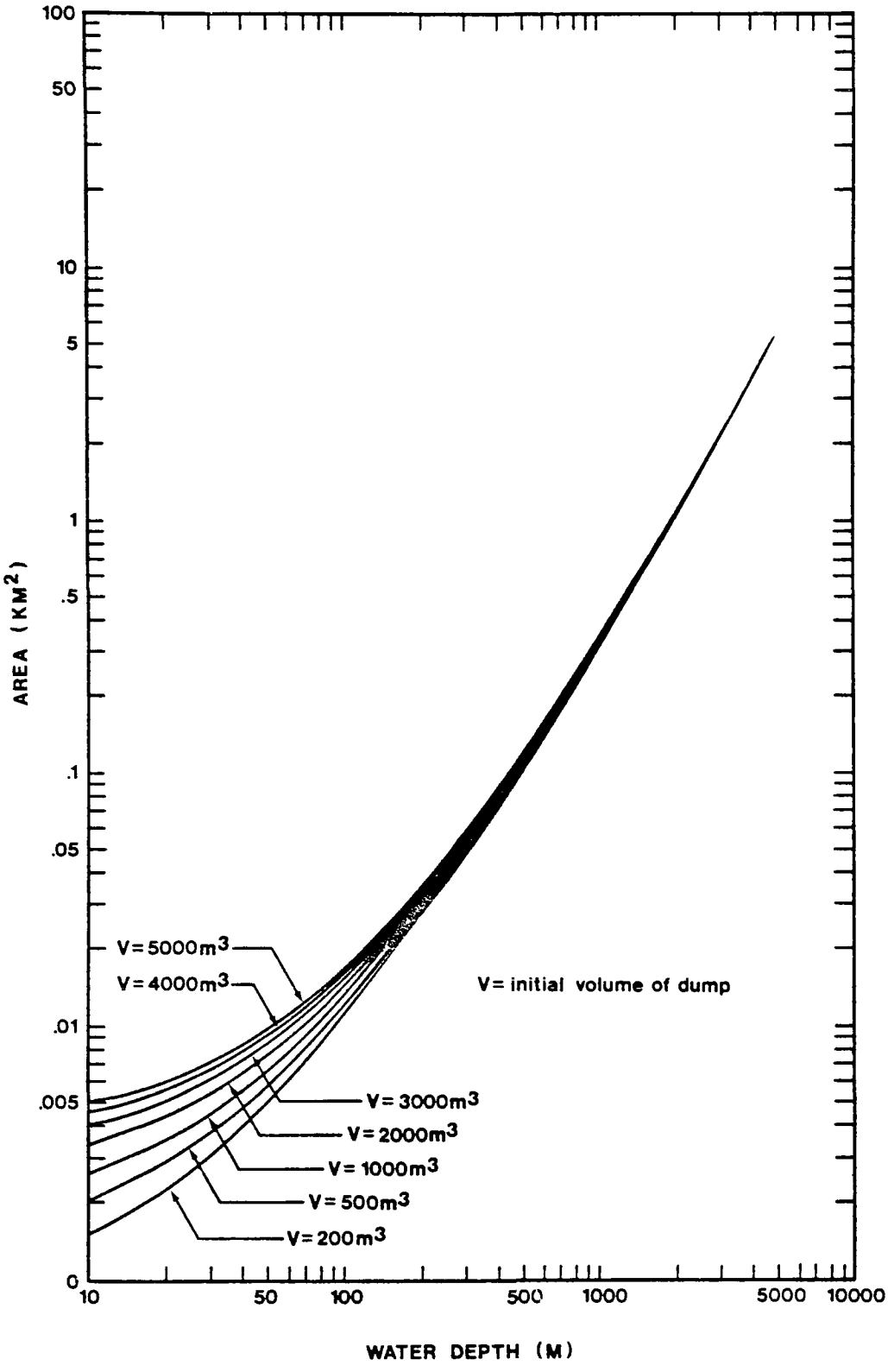


Figure 28. Horizontal area covered by instantaneous dump cloud 4 hours after dumping as a function of trapping level.

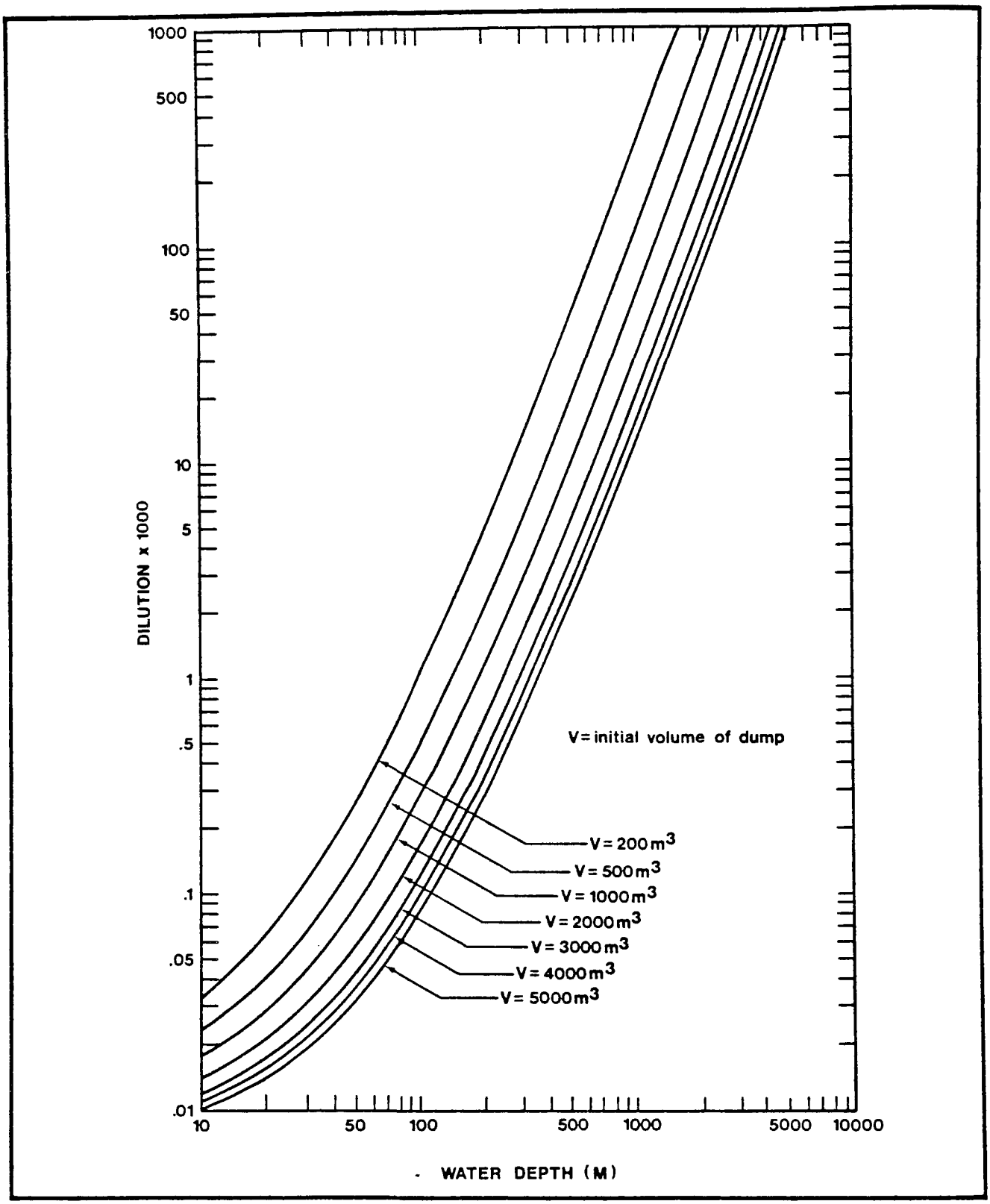


Figure 29. Dilution achieved by instantaneous dump cloud 4 hours after dumping as a function of trapping level.

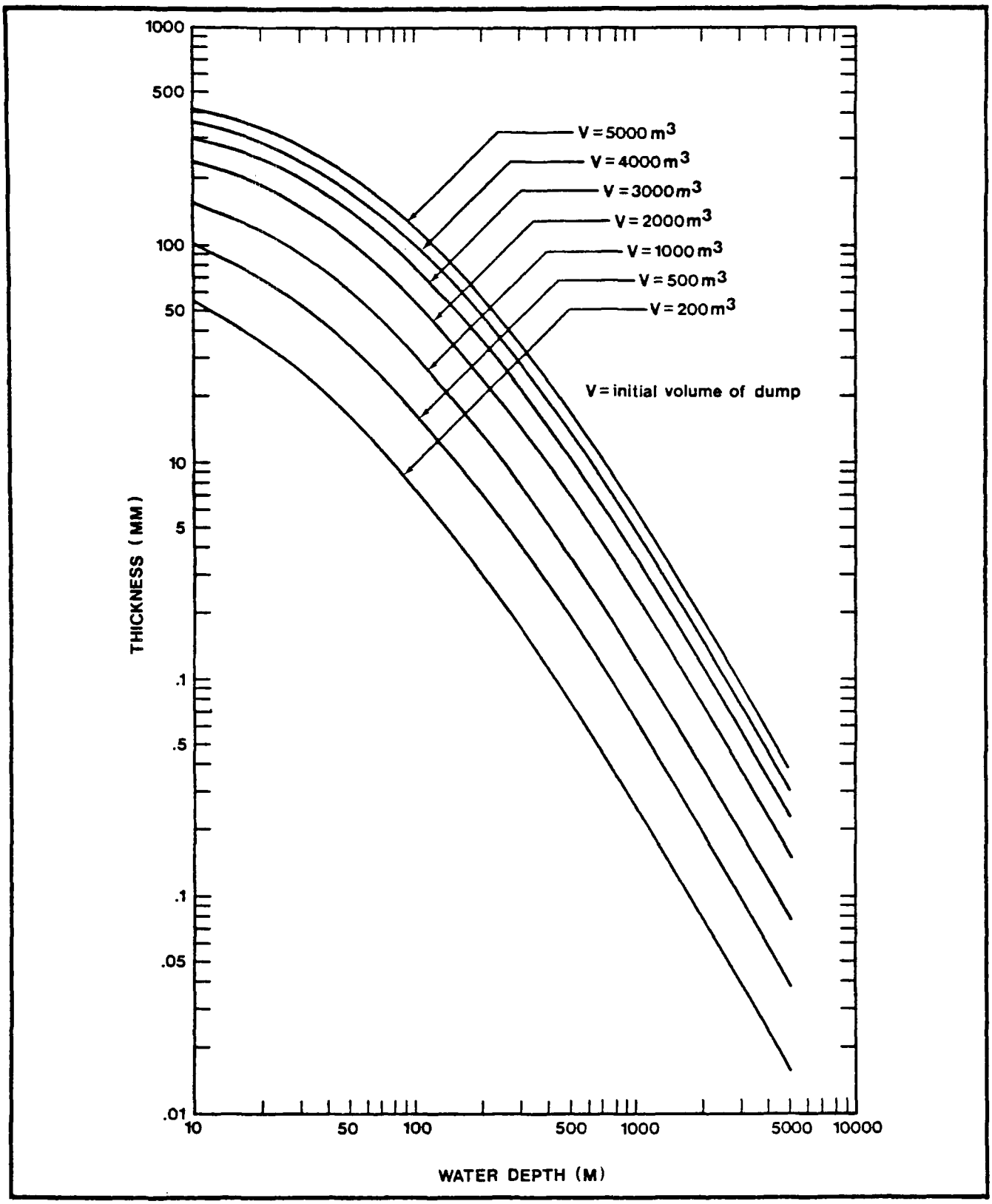


Figure 30. Thickness of sediment layer if the solids suspended in the dump cloud were to fall uniformly in the horizontal cloud area after 4 hours' time (initial cloud density = 2.0 gm/cm^3).

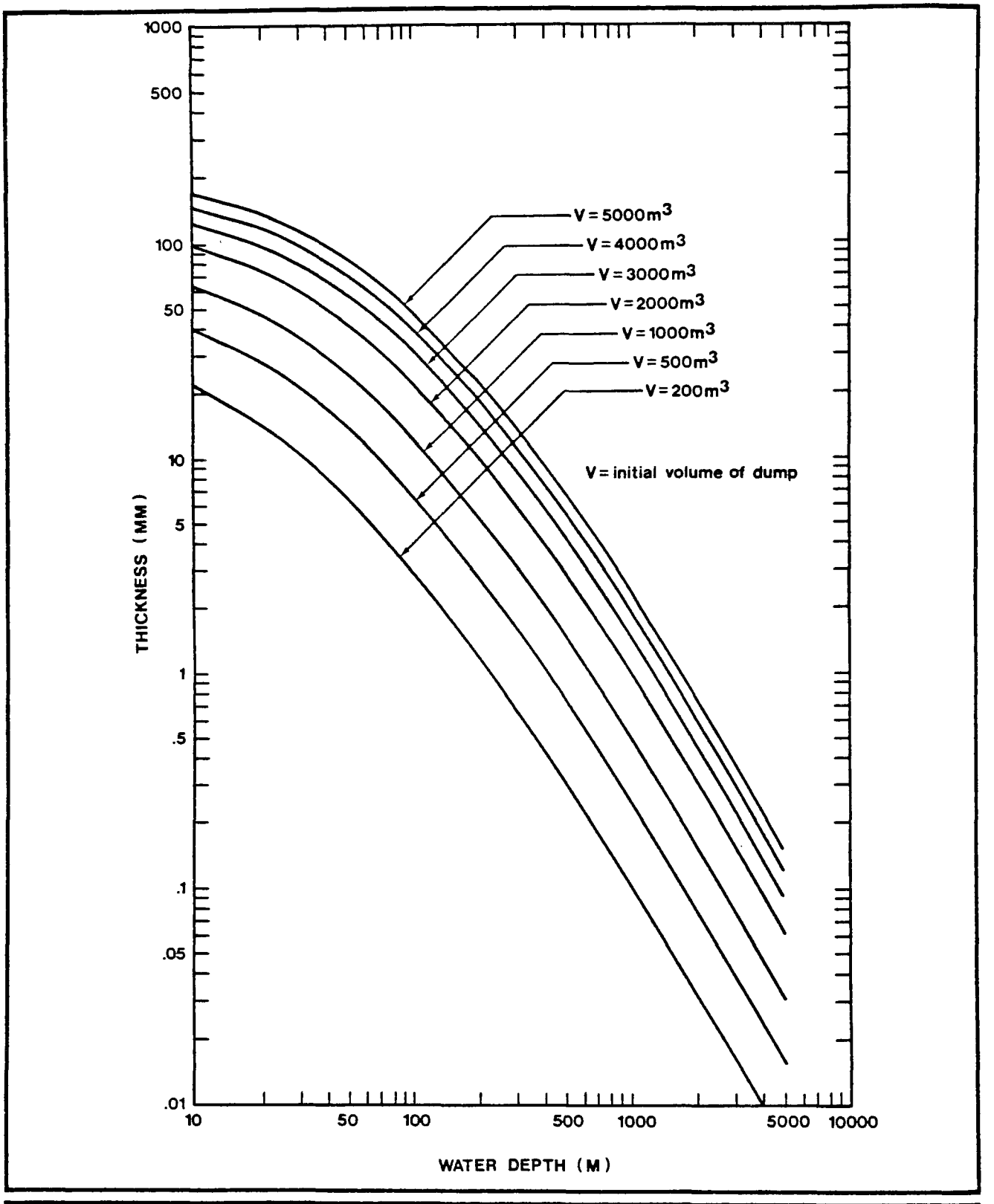


Figure 31. Thickness of sediment layer if the solids suspended in the dump cloud were to fall uniformly in the horizontal cloud area after 4 hours time (initial cloud density = 1.4 gm/cm^3).

Before using these results, several comments are in order. The density stratifications observed in the oceans in the regions of interest are rarely, if ever, sufficiently strong to trap a descending cloud at depths less than 100 m (328 ft). For depths less than this, the cloud impacts the bottom and a density surge forms. Since this surge is not considered, the predictions of "area" is probably low while the thickness is probably high. As the water depth increases the downward velocity decreases and the strength of the density surge decreases. In waters sufficiently deep and stratified to trap the cloud, two problems arise. The dynamic collapse phase, in which the cloud "flattens" out, has been neglected. Also, as mentioned previously, there is evidence that the entrainment rate eventually decreases (Krishnappan 1975). If this were to occur, then the cloud radius and dilution would be smaller at the larger depths. These two effects tend to offset each other, but a quantitative estimate of the combined effect is not possible at this time. The passive dispersion phase has also been extensively simplified. The "thickness" is the depth to which the solids would eventually settle if confined to the "area." Since 4 hours = 1.4×10^4 sec, only particles having diameter greater than 100 um would settle 1 meter during this time. In view of these difficulties, the predictions are not accurate enough to compare with field experiments, but should give a qualitative sense for the effects of oceanographic conditions and dump strategies.

Predictions using the preceding figures requires the calculation of the trapping level. This can be accomplished in shallow water using the linear stratified results presented in Figures 25 and 26, or in general using the convective descent equations in Brandsma and Divoky (1976). In the presence of no ambient current and no particle losses within the cloud these become:

$$\frac{d}{dt}\left(\frac{2\pi}{3} a^3 \rho\right) = E\rho_a$$

$$\frac{d}{dt}\left(C_m \frac{2}{3} \pi a^3 \rho w\right) = \frac{2}{3} \pi a^3 g(\rho - \rho_a) - 0.5\, \rho_a C_D \left(\frac{\pi a^2}{2}\right) |w| w$$

$$\frac{d}{dt}\left(\frac{2}{3} \pi a^3 (\rho_a(0) - \rho)\right) = E\,(\rho_a(0) - \rho_a)$$

where:

$$E = 2\pi a^2 \alpha |w|$$

a = (hemispherical) cloud radius
ρ = cloud diameter
w = vertical cloud velocity
g = acceleration due to gravity
$\rho_a(z)$ = ambient density
z = vertical coordinate (+ downward)

$C_m = 1$
$C_D = 0.5$
$\alpha = 0.235$ (no vorticity assumed)

The trapping depth predictions in Chapter 6 are computed using a computer program which integrates the above equations using a trapezoidal rule scheme.

The fate of materials for times greater than 4 hours is also of interest. Consider first the case in shallow and intermediate depth waters where an instantaneous dump does not reach its equilibrium level before it impacts the sea bottom. On impact a density surge is created which, on a horizontal bottom, will spread radially about the point of impact. The initial thickness of the surge is difficult to estimate, but should easily be on the order of meters, not less. If the sediment fall velocity-exceedence probability distribution of the Cuprion process (McKibbin 1981) is representative of manganese nodule processing rejects, then roughly half of the solids will settle to the bottom in a few days time or less. If the average horizontal current speed were but 0.2 cm/sec, which is far smaller than most oceanic currents, then particles would travel only a few kilometers at best. But roughly one half of the solids have diameters 6 um or less. For the above current speed, these particles would travel 10 km or more for every 1 m above the bottom. Thus the larger fraction would settle out within a few km^2 but the smaller diameter fraction would settle out within tens, if not hundreds of km^2.

The other possibility is that the wastefield reaches neutral buoyancy somewhere in the water column. For an instantaneous dump this level may be near the thermocline but is probably well below it. The equilibrium level for a continuous discharge near the surface is likely to be well above the thermocline. A 38 um diameter particle takes 116 days to fall 100 m (328 ft). In this time the particle travels 100 km if the average horizontal current equals 1 cm/sec. Smaller particles would travel much further. Hence the smaller particles which compose most of the waste travel tremendous distances in deep water. By then, however, horizontal diffusion would have scattered the particles over such large areas that the thickness would be very small (less than 0.001 mm = 10^{-5} m).

These conclusions neglect effects of vertical dispersion and biotransformations of suspended solids. Vertical dispersion retards the net settling rate of fine particles, especially above the thermocline. Zooplankton, however, ingest fine suspended particles and remove them by emitting fecal pellets of much larger diameter and hence higher fall velocity. The net effect of these two mechanisms is unknown. Below the thermocline, the zooplankton populations decrease exponentially with depth and the fecal pellet production becomes negligible. In deeper waters the settling time determinations are probably small due to the neglect of vertical dispersion.

PUMP DOWN

The dilutions achieved in the convective descent phase depend on a number of variables. The total flow, the output pipe diameter, the vertical angle of the pipe to the horizontal, the initial density of the jet as well as the ambient density stratification are all important in determining the trapping level and dilution of the jet. Hence, adequate predictions for the range of possible values for each of the above would require a moderately large number of figures, which is inconsistent with the level of detail contained elsewhere in this document. Thus no predictions for dynamic descent phase appear here.

Horizontal diffusion of a patch of suspended solids can more practically be computed using the method of Brooks (1960) for a line source. The horizontal diffusion constant ε_o is given by

$$\varepsilon_o = \alpha L_o^{4/3} \qquad [\varepsilon_o] = cm^2/sec$$

where:

α = constant
= 0.0015-0.049 $cm^{2/3}$/sec (Koh and Brooks 1975)
= 0.01 $cm^{2/3}$/sec commonly
L_o = initial width of the wastefield

Brooks computes, using a one dimensional convective diffusion equation, that

$$\frac{L}{L_o} = \left[1 + \frac{2}{3}\beta\frac{x}{L_o}\right]^{3/2}$$

$$\frac{c}{c_o} = \text{erf}\left\{\left[1.5 \Big/ \left[\left(1 + \frac{2}{3}\beta\frac{x}{L_o}\right)^3 - 1\right]\right]^{1/2}\right\}$$

where:

L = "width" of wastefield at distance x downcurrent
c_o = initial waste material concentration
c = centerline waste material concentration at distance x

$$\beta = \frac{12\varepsilon_o}{uL_o}$$

u = average current speed

$$\text{erf}(a) = \text{error function} = \frac{2}{\sqrt{\pi}} \int_0^a e^{-z^2}\, dz$$

The travel time t can be calculated by

$$t = x/u$$

Hence the ratios L/L_0 and c/c_0 are functions of $\alpha L_0^{-2/3} t$ only. These ratios are shown in Figure 32.

Quantitative estimates of the area over which the solids may settle can be obtained by integrating the L/L_0 equation of Brooks (1960):

$$A(t) = u \int_0^t L\, dt = \frac{u\, L_0^{5/3}}{20\alpha} \left[\left(1 + \frac{8\alpha t}{L_0^{2/3}} \right)^{5/2} - 1 \right]$$

where:

A = area
L = "width" of the wastefield at distance x downcurrent
L_0 = initial source width
u = average current speed
α = constant
t = travel time

The area influenced by a continuous discharge of an initial width at the end of 4 hours time is shown in Figure 33 for various current speeds and with $\alpha = 0.01$ $cm^{2/3}/sec$. As can be seen from this figure, the area impacted is relatively small unless the initial width (i.e., the jet width at the trapping level) is large or the ambient currents are large. It must be observed that little, if any, of the silt or clay particles will settle to the bottom during 4 hours time. The long term fate of continuously discharged material can also be obtained. Figures 34 and 35 show areas as a function of time for average (1 dimensional) current speeds equal to 0.001 m/sec and 0.01 m/sec respectively. In developing these curves a minimum value of α (0.0015 $cm^{2/3}/sec$), as reported by Koh and Brooks (1975) for depths up to 300 m (1,000 ft), is used and hence the areas computed are minimal with respect to α. These curves indicate that the area becomes less dependent on the initial source width, L_0, as time increases. Both of these figures indicate that for times exceeding 20 or 30 days the areas are on the order of 100 or more km^2. In developing these curves it is assumed that the material begins to settle immediately and that the thickness of the settling material is uniform. Actually, thicknesses are larger than the average for small settling times and smaller for large settling times.

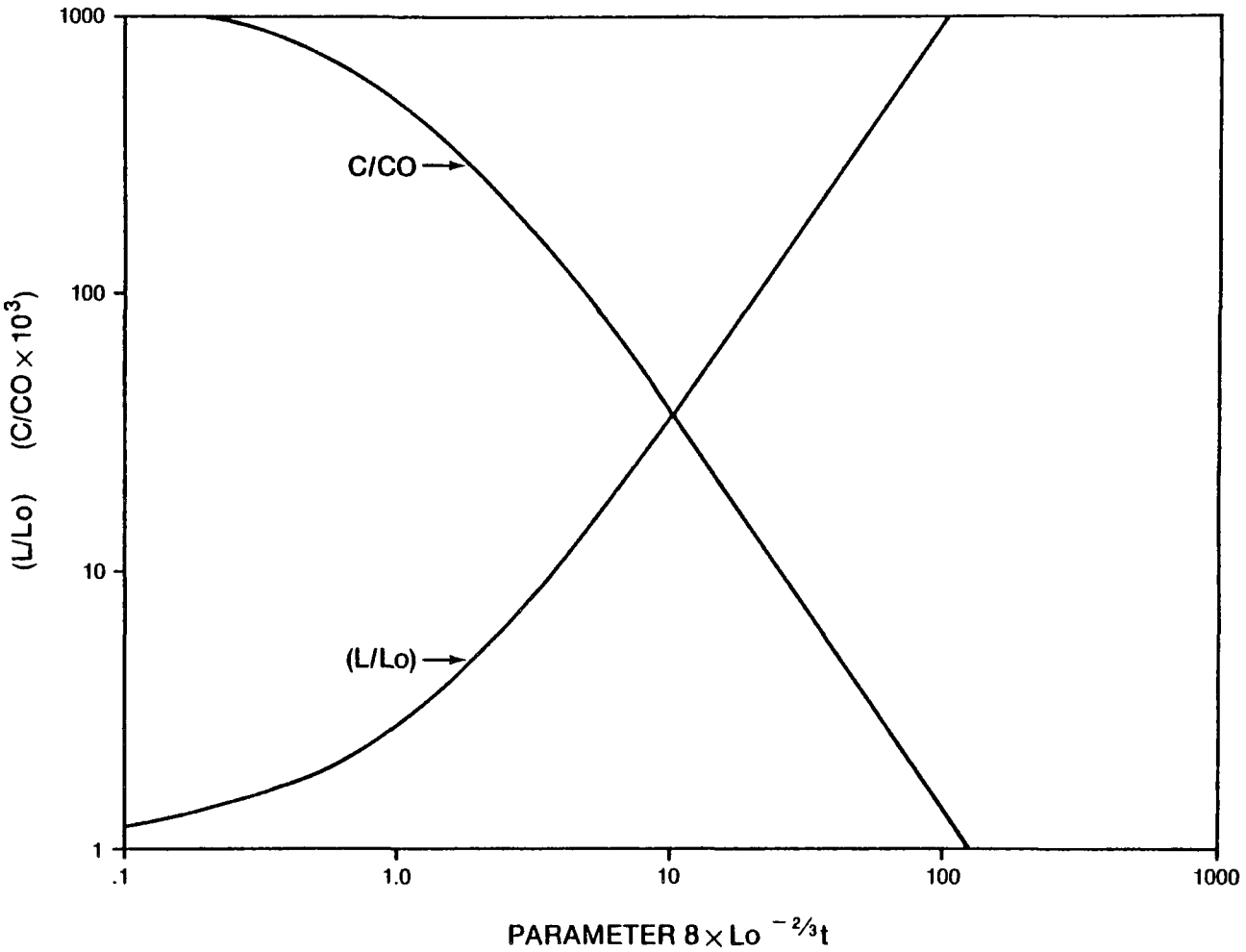


Figure 32. Width to initial width (L/Lo) and centerline concentration to initial centerline concentration (c/co) ratios.

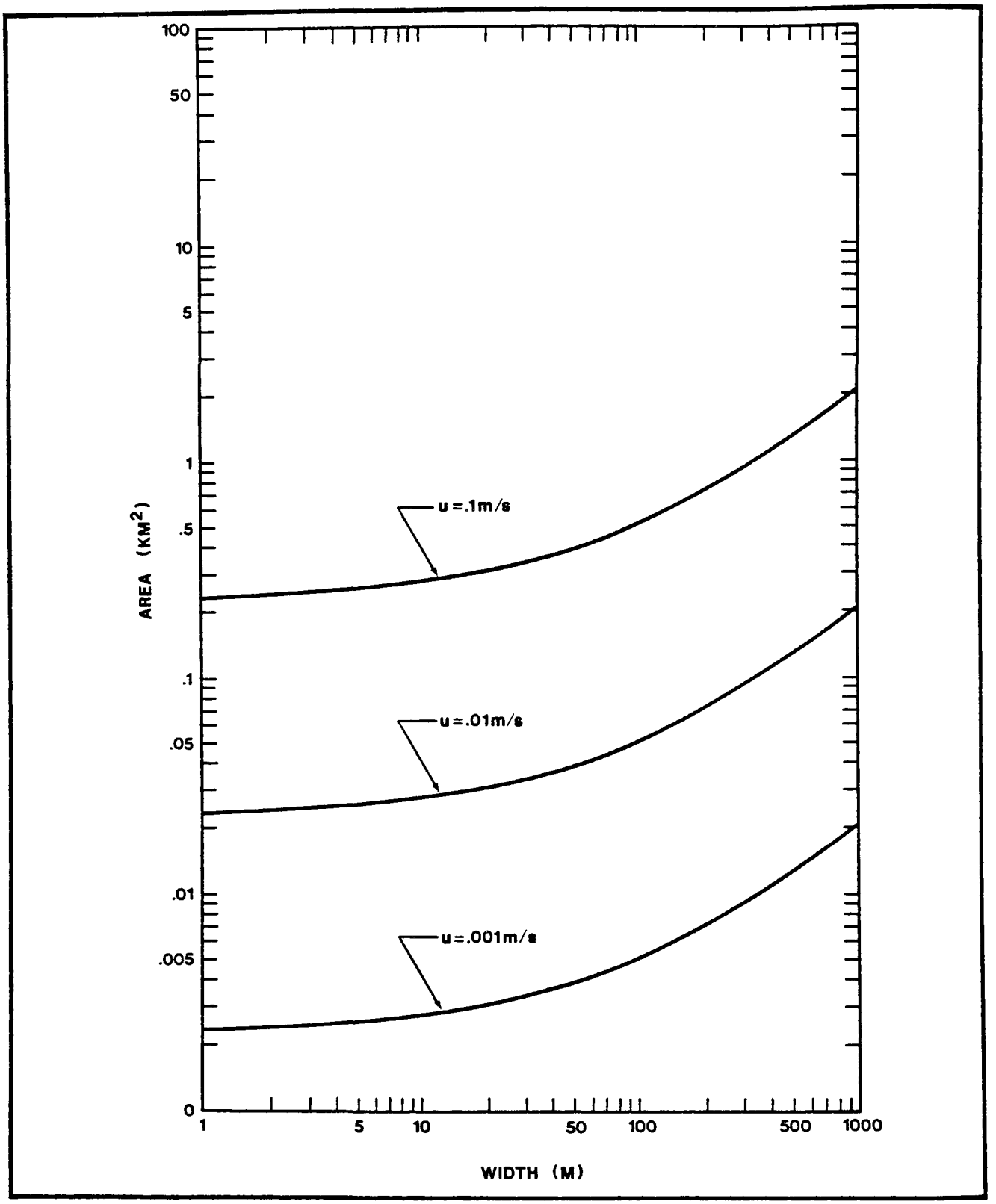


Figure 33. Area influenced by a continuous discharge after 4 hours time.

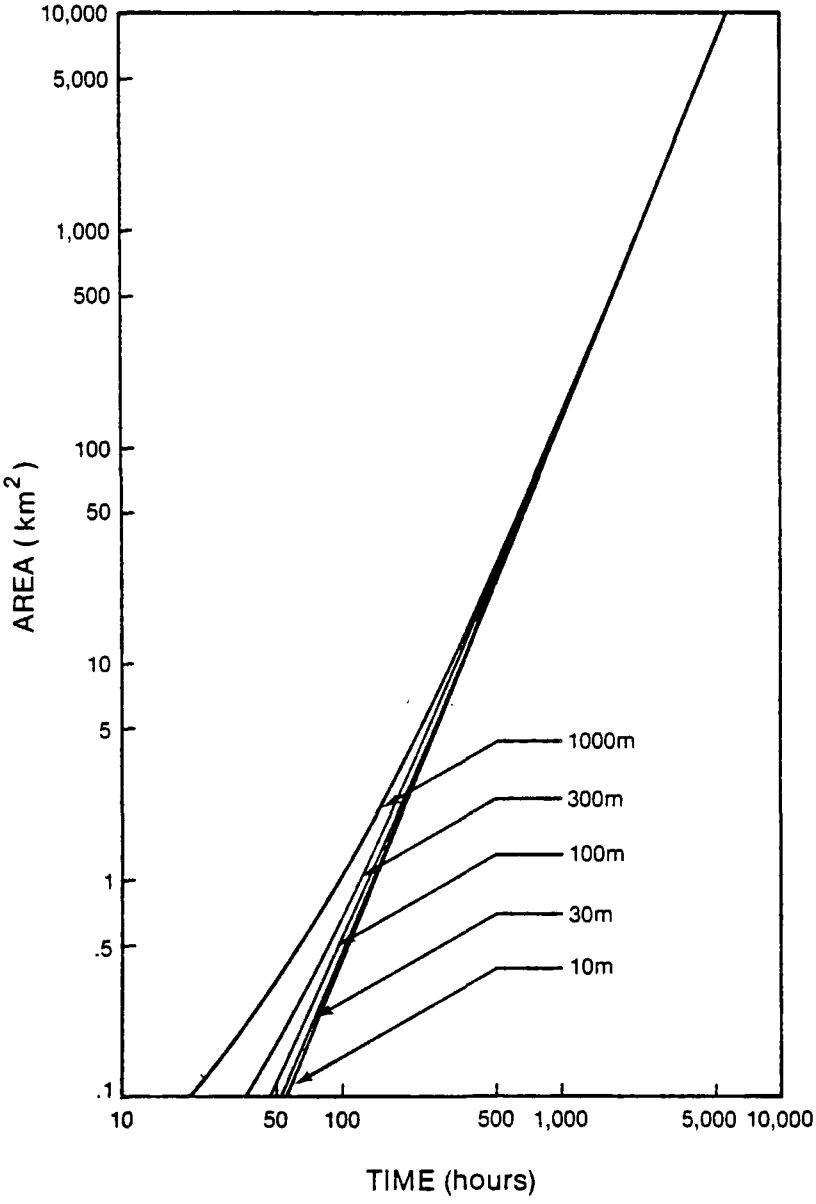


Figure 34. Area as a function of time for average current speed = 0.001 m/sec for various initial widths between 10 and 1,000 m.

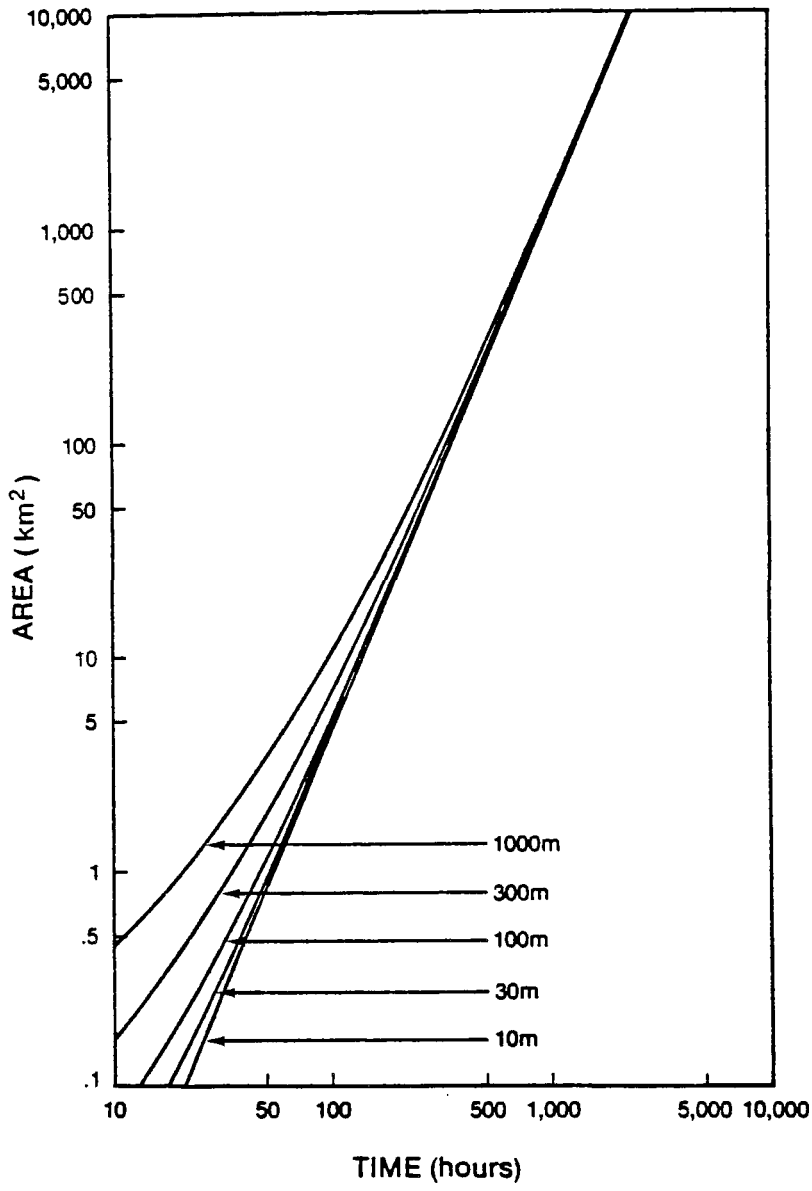


Figure 35. Area as a function of time for average current speed = 0.01 m/sec for various initial widths between 10 and 1,000 m.

In the event that the suspended particles are in a layer above the bottom, the minimum time to first impact the bottom must also be considered. If a layer of thickness T is composed of particles having fall velocity w_f and the bottom of the layer is at a height H above the sea floor, then the area over which particles will settle can be computed by

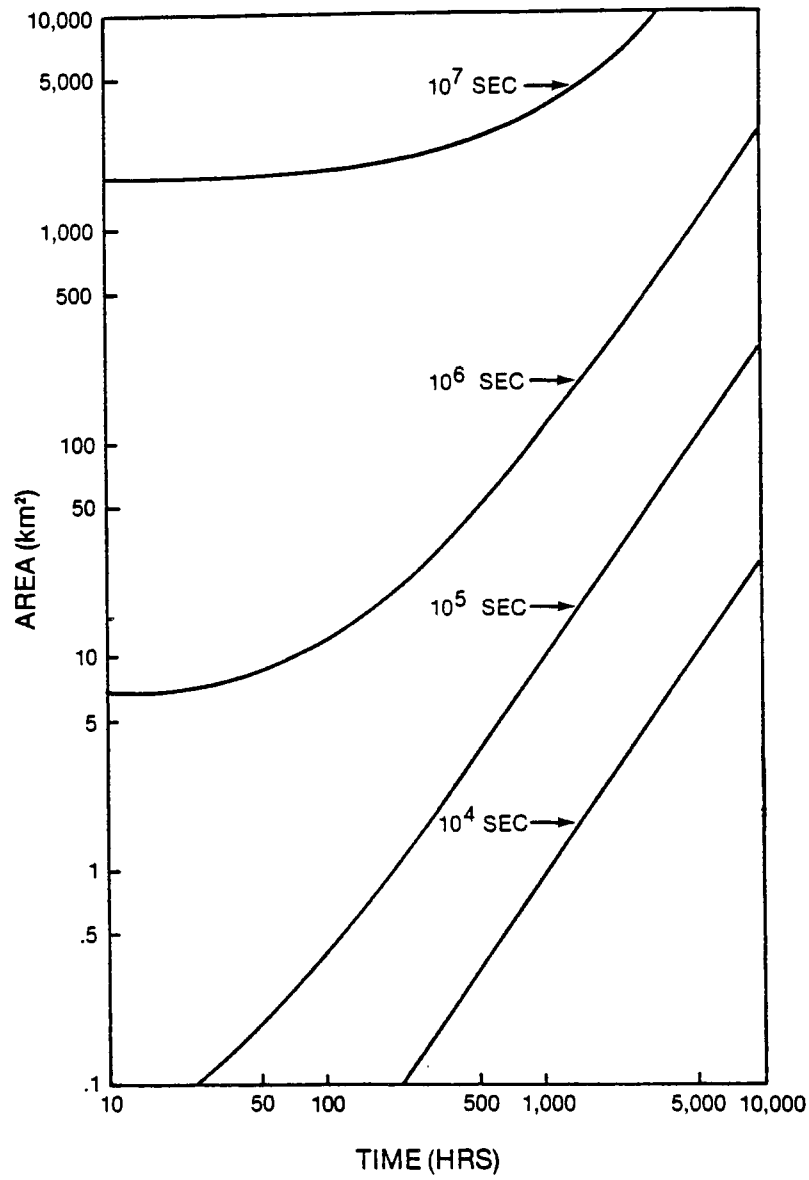
$$A\ (t + dt) - A\ (t)$$

where:

$$t = \frac{H}{w_f}$$

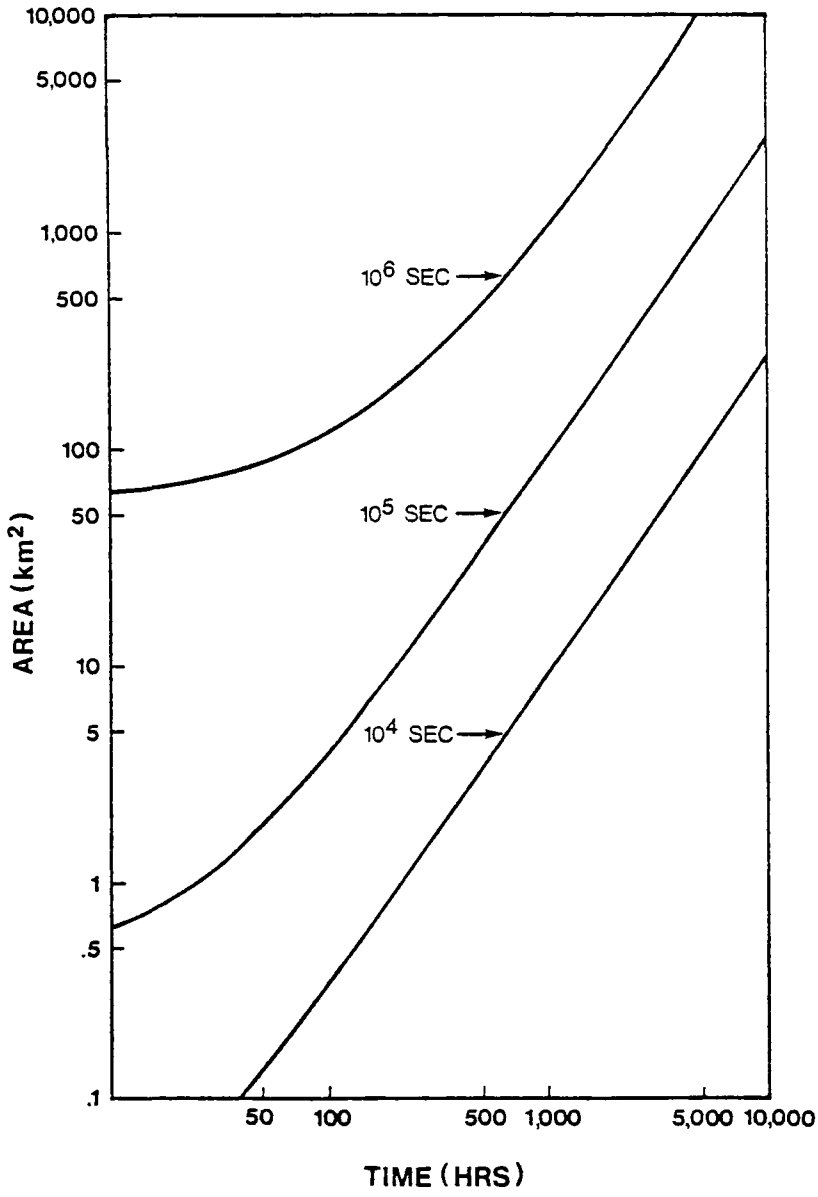
$$dt = \frac{T}{w_f}$$

Assuming an initial width equal to 100 m, Figures 36 and 37 show these areas as a function of time t for average current speeds of 0.001 m/sec and 0.01 m/sec respectively. The times dt shown range from 10^4 to 10^7 seconds. From Stokes Law, the times required for a 121 um, 38 um, 12 um, 3.8 um diameter particle to fall 1 m are 10^4, 10^5, 10^6, and 10^7 seconds. An examination of these figures shows that the larger particles may fall within small areas, but the fine particles having diameter greater than 12 um fall within large areas regardless of the initial height above the seabed. Since longitudinal diffusion is ignored in Brooks' method, these areas are underestimated.



10^N : TIME (SECONDS)
PARTICLES CONTINUOUSLY
SETTLE ON THE SEA FLOOR

Figure 36. Areas impacted by sediment first encountering the seafloor at a given time (horizontal current speed is 0.001 m/sec).



10^N: TIME (SECONDS)
PARTICLES CONTINUOUSLY
SETTLE ON SEA FLOOR

Figure 37. Areas impacted by sediment first encountering the seafloor at a given time (horizontal current speed is 0.01 m/sec).

APPENDIX C

CHARACTERISTICS OF WASTES SIMILAR TO MANGANESE NODULE PROCESSING REJECTS

This appendix presents a review of data describing wastes similar to manganese nodule processing rejects. A summary of this information has been presented in Chapter 5. A discussion of observed environmental effects related to some of these operations is presented in Chapter 7.

MINE WASTE DISCHARGES

Marine disposal of mining tailings and processing wastes is not uncommon in areas where ore bodies lie near the coast (Down and Mill 1978). A list of these operations for which any information is available is given in Table C-1. Although marine disposal is not uncommon, results of the literature search performed during this study substantiate the statement of Down and Mill (1978, p. 429) that "It must be regretted that although numerous examples of marine disposal exist, the literature is extremely sparse, and a freer interchange of data would undoubtedly be beneficial." For this reason, information in addition to that given in Table 40 is not immediately available for some of the mining operations listed.

Detailed information is available for the following types of mining operations: copper and copper-molybdenum, iron, lead-zinc, nickel processing, bauxite, and potash. Each of these types of mining operations will be reviewed below under a separate heading. Characteristics of tailings and processing wastes vary greatly between sites. The data in Table 41 illustrates that considerable between-site variation may exist in the grain size composition of tailings, even for similar types of ores. The proportion of residual metal in the tailings may also vary greatly (Table 42). Causes of between-site variations include differences in the type of ore, grade of ore, chemical bonding within the ore, and the mining and processing technique used at each site.

Copper Mines

The Island Copper Mine on Rupert Inlet, British Columbia (Figure 38) began operation in 1971 (Evans et al., 1972). Copper and molybdenum are separated from the ore by flotation, producing about 30,000 tons per day of tailings (Evans and Poling 1975). The Island Copper Mine effluent is 40 to 50 percent solids by weight (Goyette and Nelson 1977), with approximately 70 percent of the solids less than 74 um in diameter (Figure 39). Before discharge into Rupert Inlet, effluent is diluted with seawater drawn from a depth of 15 m (49 ft). The diluted effluent is then discharged at a depth of 50 m (164 ft) through a submarine outfall which extends 180 m (60 ft) offshore (Evans and Poling 1975).

TABLE 40. EXAMPLES OF MARINE DISPOSAL SYSTEMS

Company & Location	Tailings Quantity (dry tons/day) & Type	Disposal Method	Deposition Point
Utah Mines, Ltd., Island Copper Mine, Vancouver Is., B.C.[a]	30,480 Cu	Outfall pipe	Rupert Inlet. 250 m offshore 45 m depth
Anaconda, Britannia Mine, Britannia Beach, B.C.[b]	3,000 Cu (ceased operation 1975)	Outfall pipes	Howe Sound. Intertidal
Cowichan Copper Co., Ltd., Sunro Mine, Jordan River, Vancouver Is., B.C.[a]	1,525 Cu (ceased operation 1974)	Outfall pipe	Strait of Juan de Fuca. 300 m offshore, 3 m depth
Atlas Consolidated Mining & Development Corp., Cebu, Phillippines[a]	68,670 Cu	Outfall pipe	Tanon Strait, Ibo Point. 490 m offshore, 9 m depth
El Salvador Copper Mine, Chañaral, Chile[c]	25,000 Cu	Canal to shore	Chañaral Beach, 1938-1974; Caleta Palito, 1975 - present
Folldal Verk A/S, Repparfjord Mine, Norway[a]	1,600 Cu	Outfall pipe	Fjord. Offshore, 50 m depth
Ma On Shan Mine, Hong Kong[d]	? Fe	Dumping at shore	Tolo Harbor. Nearshore
Kennedy Lake Mine, British Columbia[e]	? Fe (ceased operation 1968)	Outfall pipe	Toquart Bay. Nearshore
Greenex A/S, Greenex Mine, Greenland[f]	1,400 Pb-Zn	?	Agardlikavsa Fjord. 25 m depth
Nabalco Pty., Ltd., Gove Joint Venture, Australia[g]	2,700 Red Mud	Outfall pipe to red mud pond; supernatant liquor to sea	Drimmie Arm. Nearshore

TABLE 40. (Continued)

Amax/Kitsault Molybdenum Mine, Alice, Arm, British Columbia[h]	12,000 Mo	Outfall pipe	Near the head of Alice Arm, 110 m offshore, 50 m depth
Cleveland Potash, Ltd., Boulby, Yorkshire, United Kingdom[a]	4,200 (94% as salts in solution)	Outfall pipe	North Sea. 1820 m offshore, 25 m depth
British Aluminum Co., Ltd., Marseille, France[a]	2,000-3,000 Fe	?	Mediterranean Sea. 2000 m offshore, 350 m depth
Polaris Mine, Little Cornwallis Island, Northwest Territories, Canada[i]	Lead - Zinc (Commenced Nov., 1981)	Thickened tailings pulp discharged through outfall	Super-saline lake discharging to marine waters
Societe Minère et Metallurgique de Peñarroya, S.A. Roberto Mill, Cartagena, Spain[a]	6,100 Pb-Zn-Fe	Outfall pipe	Near Portman Bay
Marcopper Mining Corp., Marinduque, Phillippines[a]	25,400 Cu	Outfall pipe	Calancan Bay. 2440 m offshore, 5 m depth
Yabulu Nickel Refinery, near Townsville, Queensland, Australia	Nickel Laterite 17,500 M^3/day of liquid waste after tailings settling	Outfall pipe	Halifax Bay, 2000 m offshore

TABLE 40. (Continued)

Fosdalens Bergverks A/S, Malm, Norway[a]	510 magnitite-pyrite	Coarse tailings barged offshore; fine tailings laundered to shore	Fjord. Offshore at 60 m depth & near-shore
Norsk-Neflin, Sternøy Mine, Norway[a]	400 syenite Fe_2O_3	Outfall pipe	Altafjord at shallow depth, 650 m water depth

[a] Data from Table 2 of Down and Mill (1978).

[b] Goyette (1975).

[c] Castilla and Nealler (1978).

[d] Wong et al. (1978).

[e] Levings (1975).

[f] Indian and Northern Affairs, undated.

[g] Baseden (1976).

[h] Burling, McInerney, and Oldham (1981).

[i] Kuit (1982).

[j] Reid (1980).

TABLE 41. SIZE FRACTIONS OF TAILINGS FROM VARIOUS MINES[a]

Tailings Source	Mesh Openings (um)	Percent Not Retained
Pebble phosphate mine, Florida, U.S.A.	44	97
Taconite mine, U.S.A.	208	"most"
Taconite mine, U.S.A.	74	46.5
	44	31
Cu Mine, U.S.A.	74	87
	44	73
Pb/Zn mine, U.S.A.	74	90
	44	86
21 gold mines, California, U.S.A.	150	3.9-99.2
Cu mine, Michigan, U.S.A.	351	50
Pb/Zn flotation tails, U.S.A.	74	48
Limestone (sand tails), U.S.A.	147	39
Pb/Zn mine, U.S.A.	147	99
	74	20-89
Iron ore mine, Quebec	74	10
4 Cu mines, British Columbia, Canada	74	60-66
3 Mo mines, British Columbia, Canada	74	40-70
	43	56
Cu/Fe mine, British Columbia, Canada	74	55
W mine, British Columbia, Canada	74	45
Cu/Mo mine, British Columbia, Canada	295	90
	74	45
Fe mine, British Columbia, Canada	74	70
5 Cu mines, U.S.A.	74	6.1-59.5
	43	6.7-15.3
Au mine, South Africa	74	56.7
Pb/Zn mine, Germany	60	50
Tin mine, Cornwall, U.K.	75	60-66

[a] Data from Table 3 of Down and Stocks (1977).

TABLE 42. RESIDUAL METALS IN RECENT TAILINGS SAMPLES[a]

Type of Tailings	Residual Metals	(% by wt.)
Pb/Zn, U.S.A.	Pb	0.13 - 0.17
	Zn	0.18 - 0.41
	Fe	3.04 - 10.73
Cu, U.S.A.	Cu	0.02 - 0.37
	TiO	0.02 - 2.0
Taconite, U.S.A.	Fe	15 - 20
PO Slimes, U.S.A.	P_2O_5	9 - 17
Red Muds, U.S.A.	AT_2O_3	13 - 26
	Fe	10.7 - 52.5
Uranium, U.S.A.	U_3O_8	0.045
	V	0.3 - 0.5
Cu, British Columbia	Cu	0.04 - 0.1
	Pb	0.01 - 0.06
	Zn	0.01 - 0.55
	Sn	0.01
	Ni	0.1
	Fe	0.1 - 10.0
	Mo	0.01
Pb/Zn, British Columbia	Pb	0.1
	Zn	0.1
	Fe	20.0
Cu/Mo, British Columbia	Cu	0.005 - 0.04
	Fe	2.0
	Mo	0.03 - 0.04
Cu/Fe, British Columbia	Cu	0.06
	Fe	12.0
Ni/Cu, British Columbia	Cu	0.04
	Ni	0.2

[a] Data from Table 4 of Down and Stocks (1977).

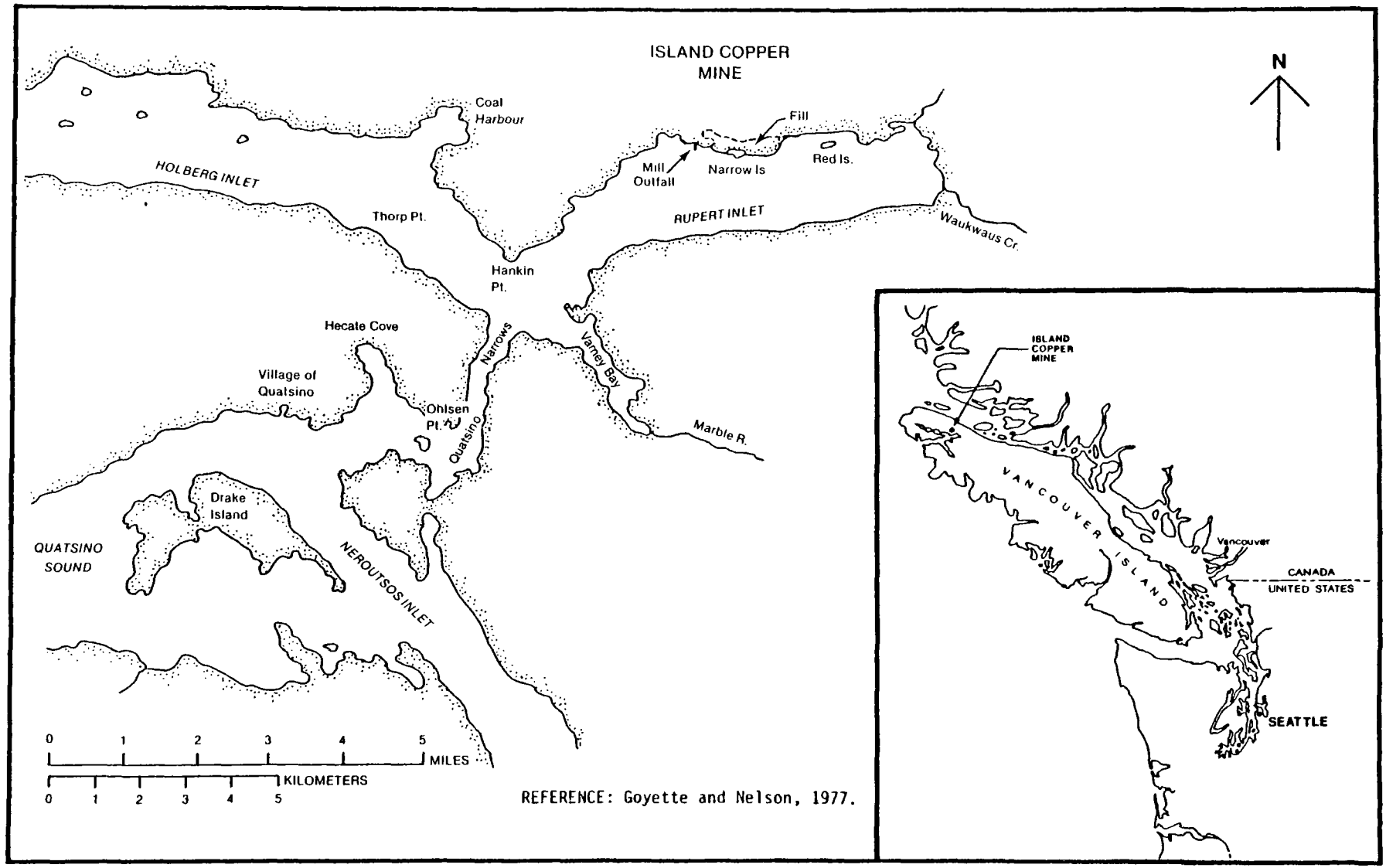
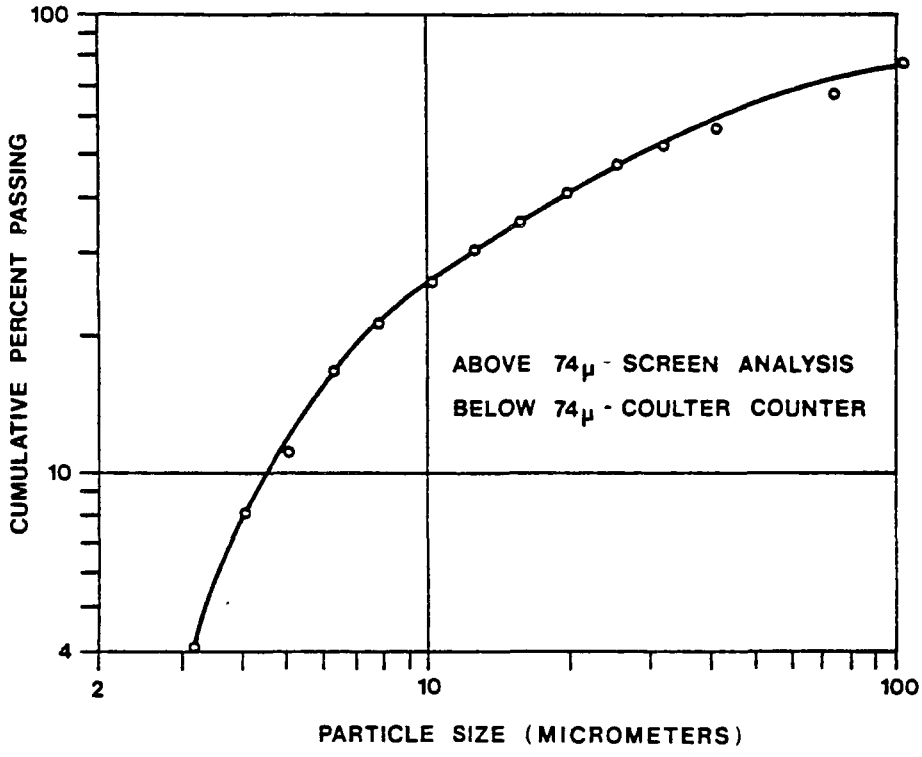


Figure 38. Location of the Island Copper Mine and submarine outfall into Rupert Inlet, British Columbia.



REFERENCE: Evans and Poling, 1975.

Figure 39. Typical size distribution of tailings solids discharged into Rupert Inlet.

Monitoring data for the Island Copper Mine discharge are maintained by the Province of British Columbia, Ministry of the Environment. Data for 1979 were selected from those provided by the Ministry[a] to characterize the chemical composition of the waste discharge. Mean concentrations and ranges of metals in the discharged solids are given in Table 43, while Table 44 shows the concentrations of dissolved metals in the liquid fraction of the effluent.

Copper was also mined in British Columbia at the Britannia Mine on Howe Sound (Figure 40). The mine operated from 1899 to 1975 and produced 3,000 tons per day of tailings (Goyette 1975). Tailings were discharged into Howe Sound through two outfall pipes located within the intertidal zone (Goyette 1975), while acid mine waters were discharged into Britannia Creek, which carried them into Howe Sound (Thompson and McComas 1974). Detailed information on the physical and chemical characteristics of the tailings and acid mine wastes prior to discharge were not available at the time of this writing.

The third copper mine for which detailed information is available is the Jordan River Mine, located on the north shore of the Strait of Juan de Fuca (Figure 41). This mine operated intermittently from 1960 to 1974, the most recent operational period being 1972 to 1974 (Ellis 1978). During the first three operational periods (1960-1972) the mine discharged 1,525 tons of tailings daily to a location 900 m (3,000 ft) offshore at a depth of 12 m (40 ft) (Down and Mills 1978, Ellis 1978). Following a pipe failure, tailings were discharged 300 m (1,000 ft) offshore at a depth of 0-3 m (0-10 ft) below the low tide mark (Ellis 1978). This shallow discharge was in operation during the last period of mine operation from 1972-1974 (Ellis 1978). Details of the physical and chemical characteristics of the mine wastes prior to discharge were not available at the time of this writing.

One of the largest copper mining and milling operations which discharges tailings to the marine environment is the Atlas Mining and Development Corporation, located on the island of Cebu, the Philippines. This operation has a milling capacity of about 70,000 tons of ore per day, from which about 35,000 tons of tailings are produced daily from two concentrators, Dascon and Bigacon (Salazar and Gonzales 1973). The tailings effluent is pumped through four separate outfall pipes to a common location off Ibo Point, on Tannon Strait (Salazar and Gonzales 1973). The four outfall pipes extend 490 m (1,600 ft) offshore at a depth of 9 m (30 ft) below the surface. Water depth at the point of discharge is 30 m (100 ft).

The tailings slurry is about 40 to 50 percent solids by weight, and has a pH of 7.6 to 7.8. The solids have a specific gravity of 2.65 (Salazar and Gonzales 1973). Grain size distribution of the tailings is given in Table 46. At the time of this writing, no additional information on the physical or chemical characteristics of the tailings effluent were available.

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[a] Letter from Dr. M.J.R. Clark, September 28, 1981.

TABLE 43. ISLAND COPPER MINE DISCHARGE
CHEMICAL COMPOSITION OF THE SOLID PHASE (1977 DATA)

	Number of Observations	Average Concentrations mg/kg	Range
As	5	4.1	2.2 to 6
Cd	6	0.23	0.14 to 0.3
Cr	6	8.6	4.9 to 13.9
Cu	6	248	170 to 370
Fe	2	16,400	15,800 to 17,000
Hg[a]	3	0.0017	<0.00005 to 0.005
Mn[a]	3	209	78 to 325
Mo	3	9.1	5.4 to 15.8
Ni	1	9.3	
Pb	6	5.1	3.9 to 6.7
Zn	6	34.1	26.9 to 49.9

[a] Data from 1980.

Reference: Letter from Dr. M.J.R. Clark, September 28, 1981.

TABLE 44. ISLAND COPPER MINE DISCHARGE
CHEMICAL COMPOSITION OF LIQUID FRACTION (1979 DATA)

	Number of Observations	Average Concentrations ug/l	Range
Al	1	1,030	
As	54	40	14 to 88
Cd	57		<0.1 to <0.5
Co	45	1.1	<0.1 to 4
Cr	47	1.2	0.6 to <5
Cu	57	11	3 to 280
Fe	47	56.9	8 to 1,200
Hg	52	0.11	<0.1 to 0.24
Mn	45	1.6	1 to 4
Mo	55	153	100 to 300
Ni	46	1.5	<1 to <10
Pb	57	2.5	<1 to 5
Zn	49	6.8	0.8 to 170

Reference: Letter from Dr. M.J.R. Clark, September 28, 1981.

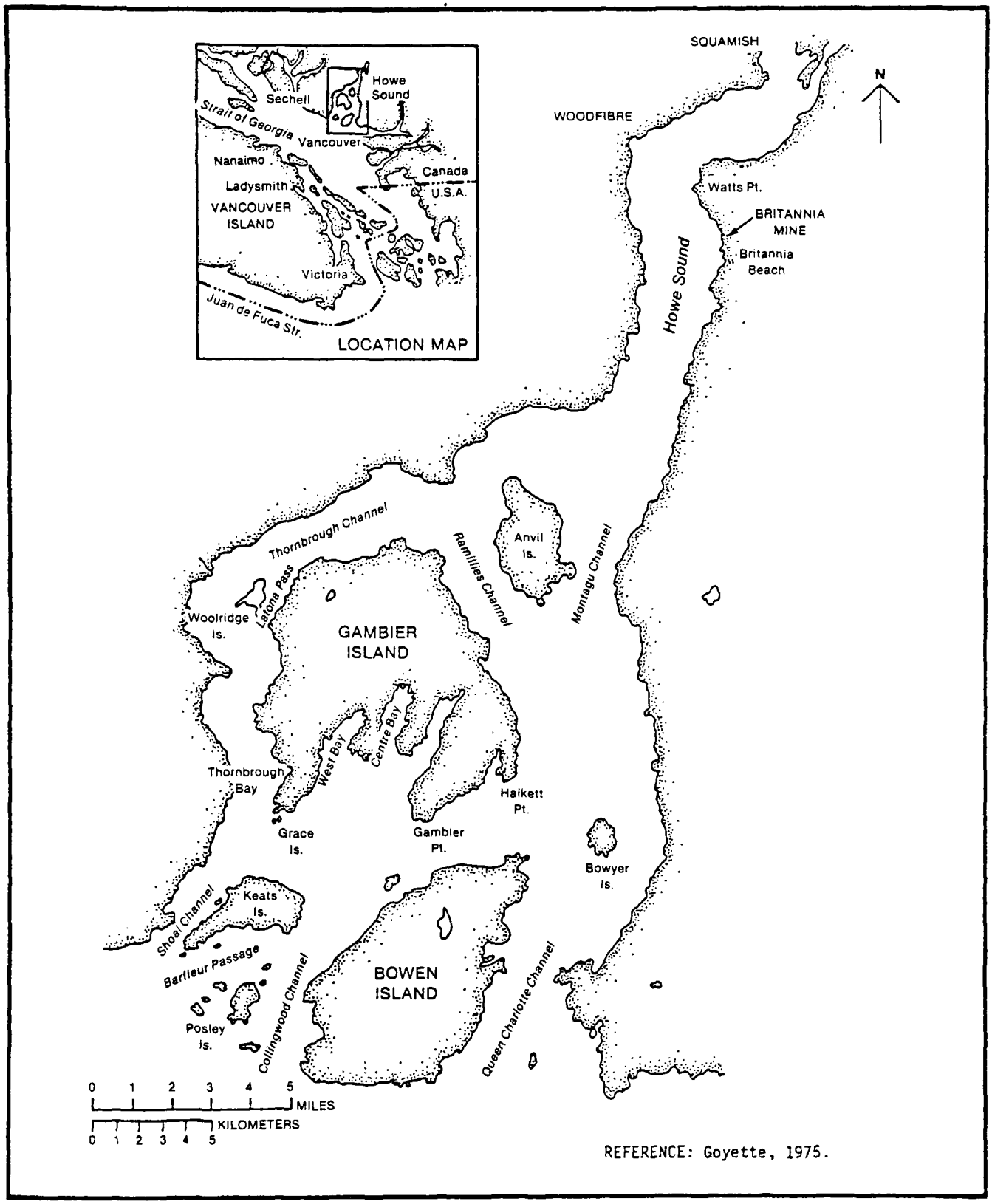


Figure 40. Location of the Britannia Mine on Howe Sound, British Columbia.

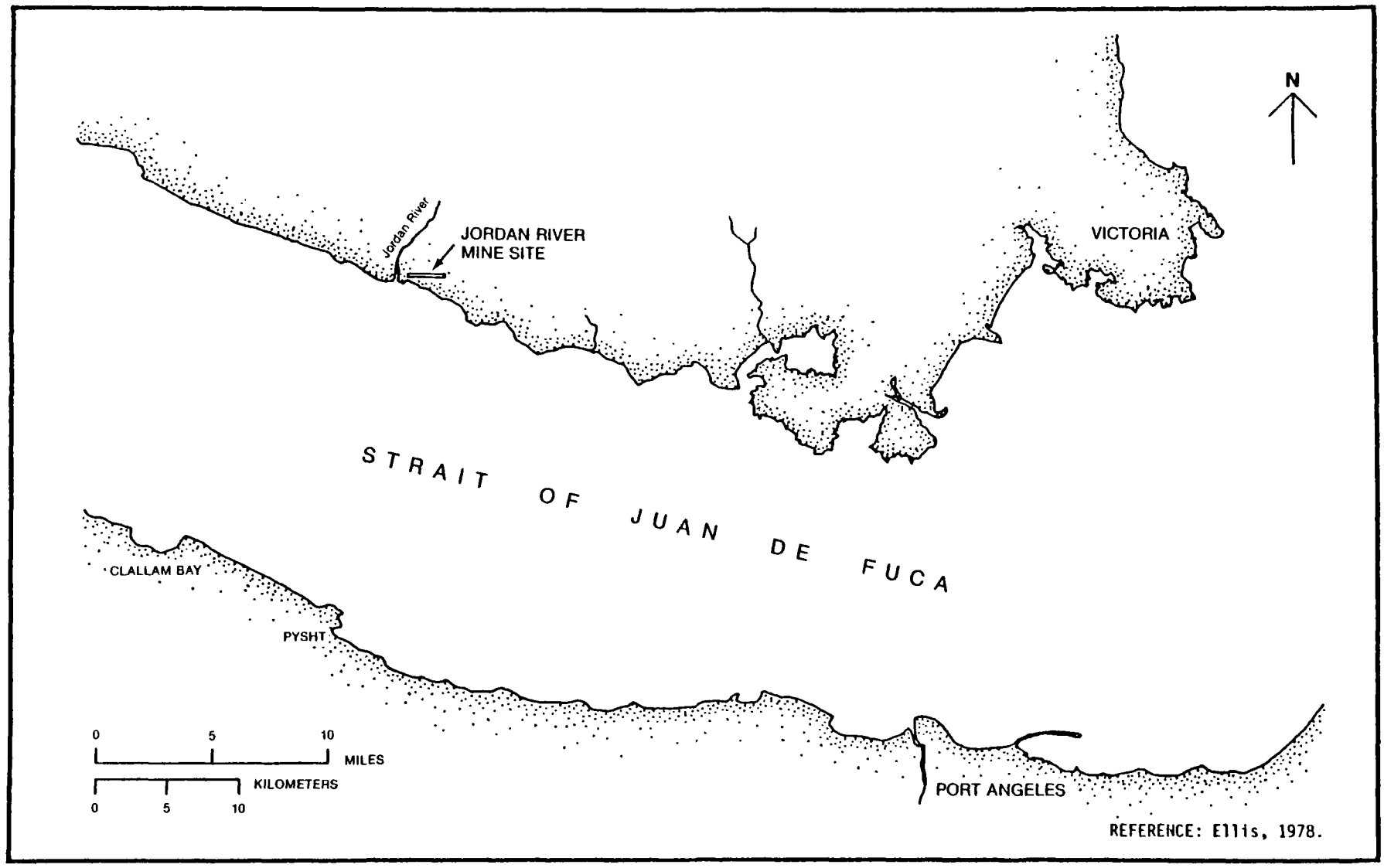


Figure 41. Location of the Jordan River Mine, British Columbia.

TABLE 45. SIZE DISTRIBUTION OF TAILINGS SOLIDS FROM THE DASCON AND BIGACON CONCENTRATORS AT CEBU, PHILIPPINES[a]

Particle Size (micrometers)	Average Percent Retained	
	Dascon Tailings	Bigacon Tailings
297	11.2	13.0
210	18.5	22.6
149	26.4	33.2
74	43.1	50.6
44	49.9	58.9
Less than 44	100.0	100.0

[a] Adapted from Salazar and Gonzales (1973).

Several additional mining operations are located in the Philippines which discharge indirectly via rivers or directly to marine waters. No published information describing these operations is available however.

At the El Salvador Copper Mine in Chile, two nearshore sites have been used for the disposal of mine tailings (Figure 42). The first site at Chanaral Beach was in use from 1938 to 1974. Thereafter, tailings were discharge into the second disposal area at Caleta Palito, a practise which continues to the present (Castilla and Nealler 1978). About 25,000 tons of tailings are transported per day to the disposal area via a tailings canal. Wastes carried by the canal include flotation tailings from copper and molybdenum concentration plants and treated domestic wastewaters from the El Salvador Sewage treatment plant (Castilla and Nealler 1978). At the time of this writing, no additional information on the physical or chemical characteristics of the tailings or effluent were available.

The last copper mine for which information is presently available is the Repparfjord Mine in Norway (Figure 43), which produces 1,600 tons of flotation tailings per day. The tailings are discharged into Repparfjord at 50 m (164 ft) depth via an outfall pipe (Down and Mill 1978). They contain 0.05 percent residual copper (Doughty 1975). No additional information on the physical or chemical characteristics of the tailings are presently available.

Iron Mines

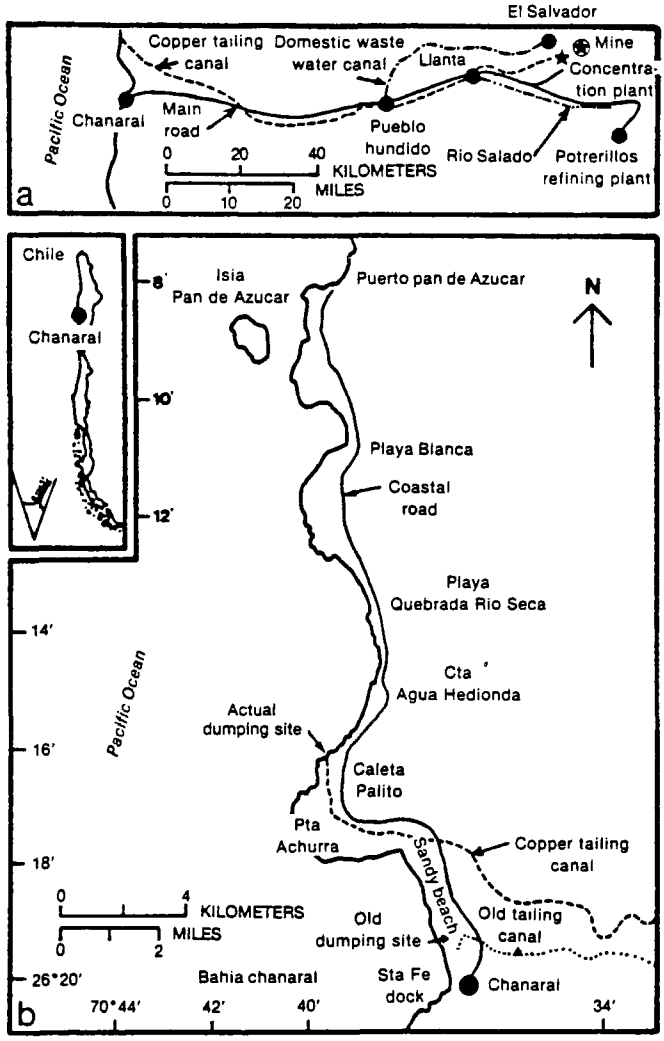
The Ma On Shan Iron Mine has been disposing of iron ore tailings along the eastern bank of Tide Cove, Tolo Harbour, Hong Kong since 1906 (Figure 44). Iron is extracted from the ore using a "wet magnetic separation process" (Wong and Tam 1977), and the tailings are deposited behind dams in the nearshore area (Wong et al., 1978). Through time the tailings have overflowed the dams and entered the nearshore marine environment. Historically, tailings were first deposited in Region I, then Region III, and finally Region II as shown in Figure 45. Data on grain size and chemical composition of the tailings are given in Tables 46 and 47, respectively.

The Kennedy Lake Iron Mine in British Columbia (Figure 46) disposed of iron ore tailings into Toquart Bay until 1968, when the operation ceased. Iron was separated from the ore by the wet magnetic separation process, and tailings were transported to the beach via a pipeline (Levings 1975). No additional information on the quantities or physical and chemical characteristics of the tailings are presently available.

Lead-Zinc Mines

Detailed information is available for one lead-zinc mine which discharges tailings into marine waters, the Greenex Mine in Greenland (Figure 47). A marine discharge was also considered for the Nanisivik Lead-Zinc Mine on Baffin Island, Canada, but this disposal option was dropped prior to commencement of mining operations in 1976[a]. Since 1973,

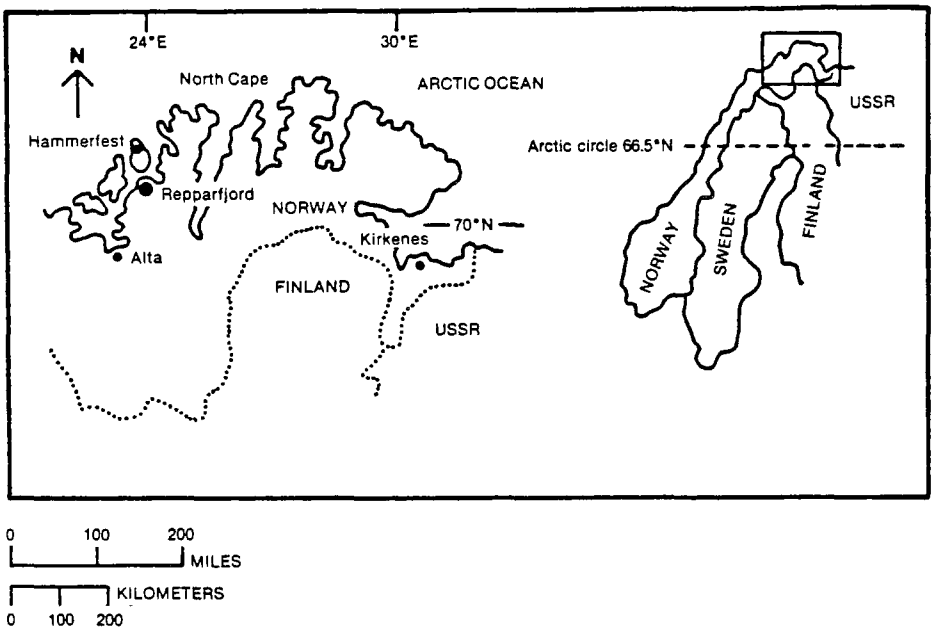
[a] Letter from Dr. D.V. Ellis, University of Victoria, British Columbia, dated February 3, 1982.



(a) Locations of the copper mine, city of Chanaral, tailings canals, domestic wastewater discharge, and bed of Rio Salado. (b) Shoreline from Puerto pan de Azucar to Chanaral, indicating new and old tailing disposal sites.

REFERENCE: Castilla and Nealler, 1978.

Figure 42. Location of the El Salvador Copper Mine, Chile.



REFERENCE: Doughty, 1975.

Figure 43. Location of the Repparfjord Copper Mine in northern Norway.

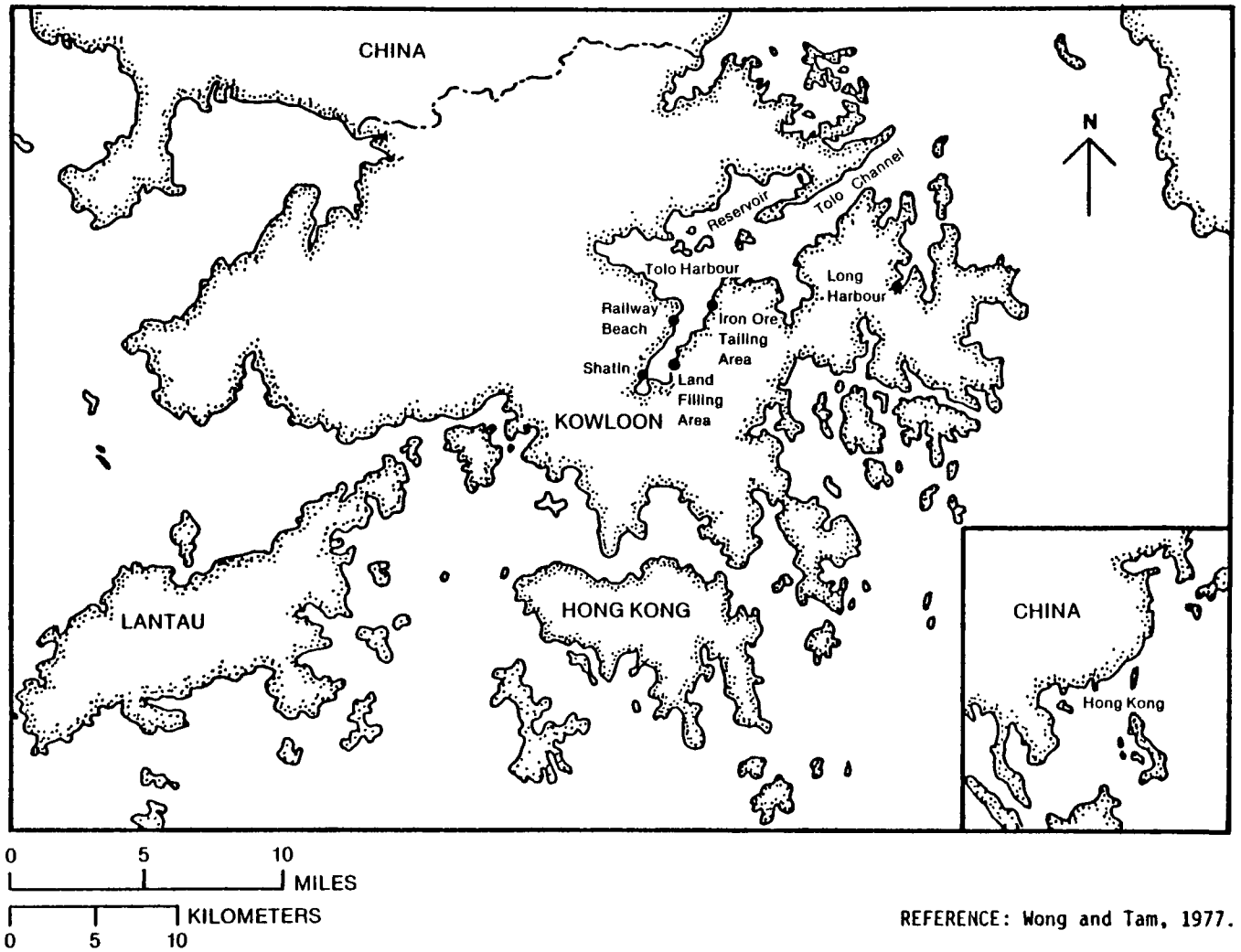


Figure 44. Locations of the Ma On Shan tailing disposal area, Railway Beach, and Long Harbour, Hong Kong.

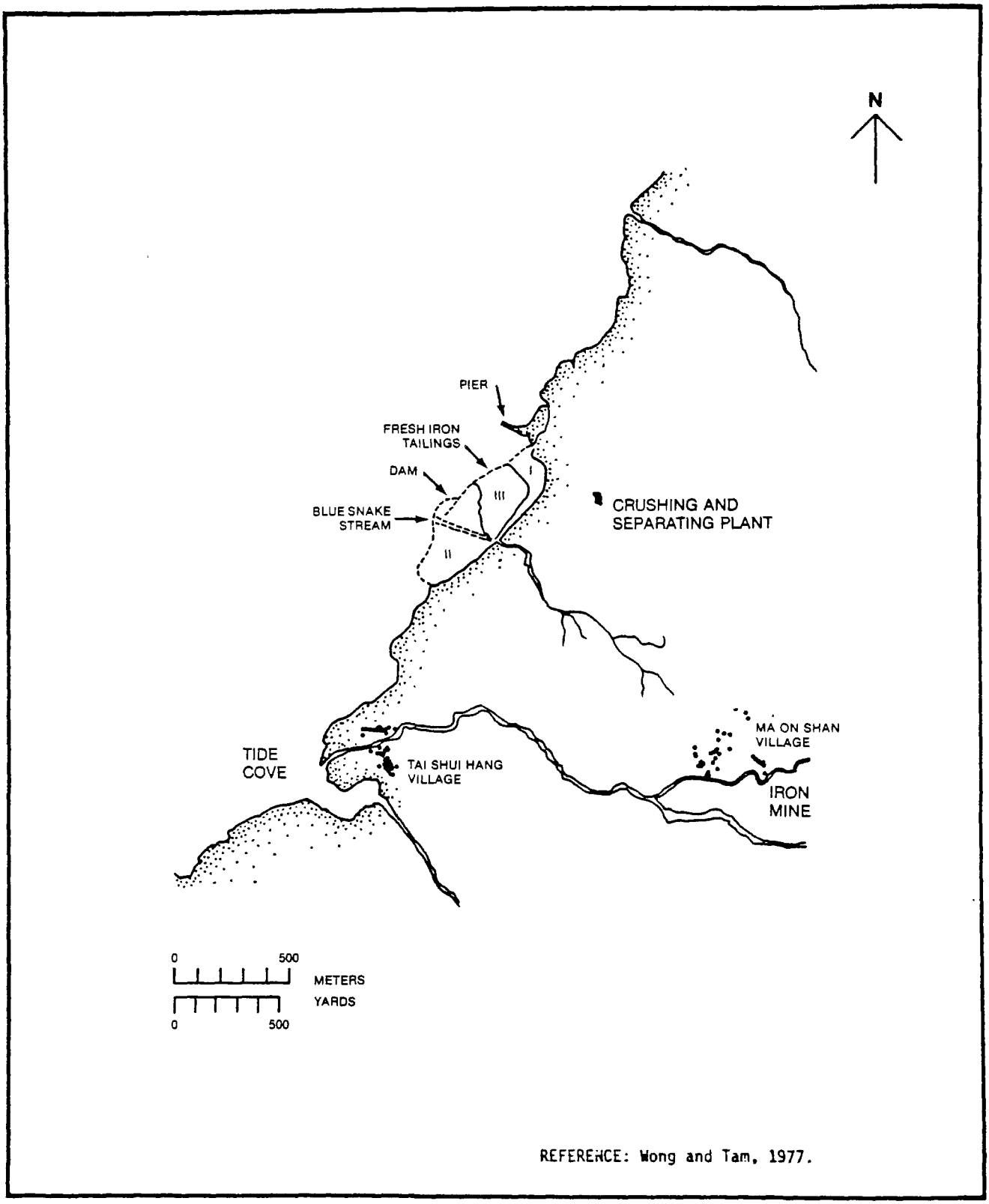


Figure 45. Map of the Ma On Shan tailing disposal site, Tolo Harbour, Hong Kong.

TABLE 46. CUMULATIVE CURVE DERIVATIVES FOR THE ANALYSIS OF SEDIMENT[a] NEAR THE MA ON SHAN DISPOSAL AREA

Stations	Median Diameter ø	Median Diameter mm	ø Quartile Deviation	ø Quartile Skewness
Iron Ore Tailings				
Zone I				
Upper	+1.15	0.45	+1.28	-0.22
Middle	+1.27	0.41	+0.94	-0.20
Lower	+1.51	0.35	+1.06	-0.17
Zone II				
Upper	+2.28	0.22	+1.42	-0.38
Middle	+2.59	0.17	+1.48	-0.85
Lower	+2.43	0.19	+1.65	-0.78
Zone III				
Upper	+1.31	0.40	+1.05	-0.04
Middle	+1.02	0.49	+1.45	-0.23
Lower	+1.22	0.43	+1.19	+0.02
Railway Beach				
Upper	-0.16	1.12	+0.88	+0.02
Middle	+0.29	0.82	+1.43	+0.07
Lower	+0.76	0.59	+1.57	+0.32
Long Harbour				
Upper	+0.13	0.91	+1.21	+0.17
Middle	+0.67	0.63	+1.26	+0.09
Lower	+0.83	0.56	+1.29	+0.02

[a] The data are expressed as the means of triplicate samples. The data are from Table 3 of Wong et al. (1978).

TABLE 47. CHEMICAL CHARACTERISTICS OF TAILINGS AND SEDIMENTS FROM RAILWAY BEACH AND LONG HARBOUR[a]

	Iron Ore Tailings[b]									Railway Beach[b]			Long Harbour[b]		
	Zone I			Zone II			Zone III								
	U	M	L	U	M	L	U	M	L	U	M	L	U	M	L
pH	8.05	8.10	8.13	8.71	8.31	8.32	8.35	8.31	8.39	7.81	8.10	7.71	8.08	8.01	8.05
Organic carbon (%)	0.54	0.79	1.80	0.20	0.13	0.74	0.95	0.98	1.06	0.86	1.32	5.17	0.76	0.90	4.65
Total nitrogen (%)	0.09	0.10	0.17	0.09	0.09	0.16	0.10	0.12	0.18	0.13	0.16	0.20	0.21	0.25	0.26
Available phosphate (ppm)	0.17	0.21	0.34	0.23	0.35	0.53	0.29	0.26	0.39	0.34	1.60	2.32	0.80	0.98	0.99

[a] The data are expressed as the means of duplicate samples. The data are from Table 2 of Wong et al. (1978).

[b] Abbreviations used: U = uppershore, M = middle shore, L = lower shore.

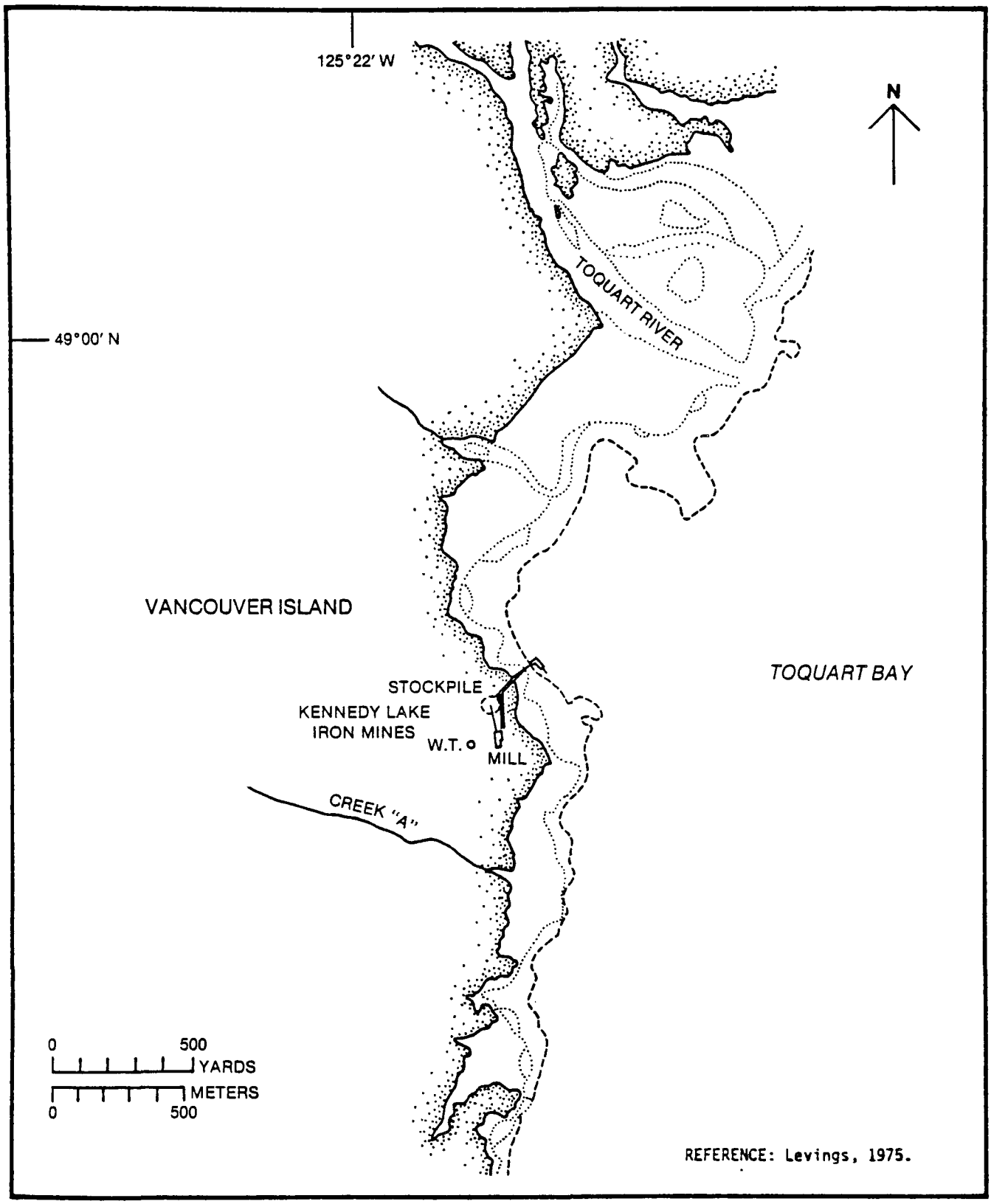


Figure 46. Location of the Kennedy Lake Iron Mines on Toquart Bay, British Columbia.

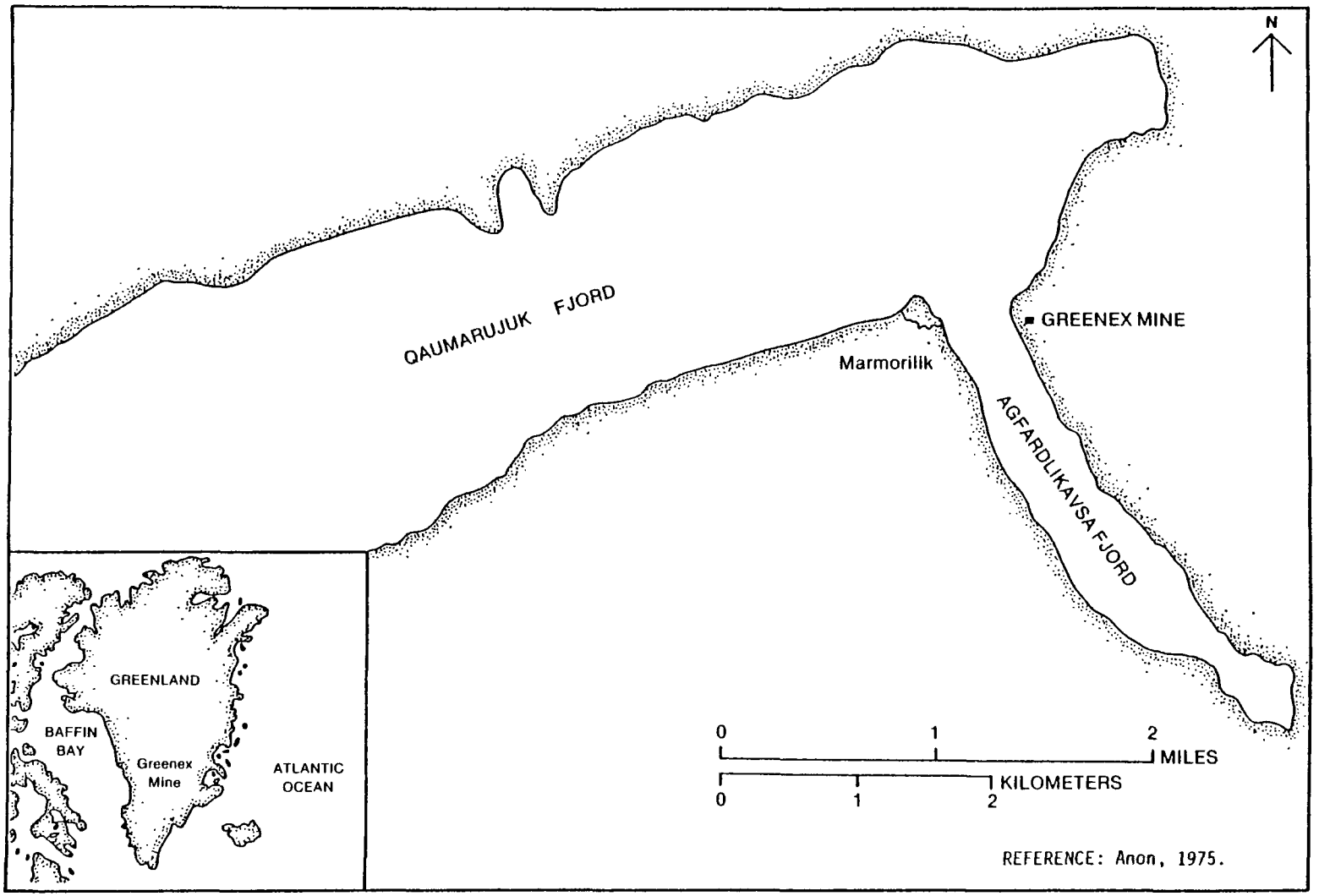


Figure 47. Location of the Greenex Lead-Zinc Mine, Greenland.

tailings from the Greenex Mine have been discharged into Qaumarujuk and Agfardlikavsa Fjords at a depth of 25 m (82 ft) (Anon 1975). Approximately 1,400 tons of tailings are discharged into the fjords daily. Residual lead and zinc constitute 0.4 percent and 0.1 percent of the tailings solids, respectively (Anon 1975). Additional information on the physical and chemical characteristics of the Greenex Mine wastes are not presently available.

Nickel Processing

The Yabulu nickel refinery is located on Halifax Bay approximately 24 km (15 mi) northwest of Townsville, Queensland (Figure 48). The refinery treats about 2,200,000 tonne/yr of lateritic ore which is delivered by train from the Greenvale Mine, about 225 km (140 mi) west of the refinery (Reid 1980).

Nickel is recovered through an hydrometallurgical process (ammonia/ammonium carbonate leach) following grinding and reduction roasting. The waste produced by this process is an approximately 50 percent slurry of tailings particles of which 60 percent are less than 44 um in diameter. Tailings solids account for 98.5 percent of the ore processed (Reid 1980).

Tailings are discharged to a settling pond and approximately 17,500 m^3/day (4.6 MGD) of decanted liquid is discharged to Halifax Bay. Effluent is discharged through a 2,000 m (6,600 ft) outfall pipe which terminates in a three-port diffuser (Reid 1980).

No data are available on the chemical composition of solids content of the effluent, however, Reid (1980) has presented the effluent limitations established by the Water Quality Council as shown in Table 48.

Bauxite Mines

Approximately five million tons of bauxite ore are processed yearly (Lillehagen 1980) at the refinery on the Gove Peninsula in Northern Australia (Figure 49).

The red mud slurry has a pH of 10.2 to 12.4 and a "silt-like texture," since 95 percent of the solids have a diameter of less than 0.06 mm (Baseden 1976). The solids are primarily composed of iron, aluminum, silicon, and titanium, and oxides of sodium and calcium. Traces of zinc (3 ppm), copper (3 ppm), and manganese (11 ppm) are also present (Baseden 1976). The alkaline supernatant liquor is neturalized with sea water prior to leaving the second of two sluice boxes and entering the estuary. Neutralization causes the complete precipitation of the carbonate and hydroxide ions through the formation of calcium and magnesium compounds (i.e., hydroxides and carbonates). The supernatant liquor discharged to the estuary contains less than 0.5 ppm of dissolved zinc, copper, or manganese (Baseden 1976).

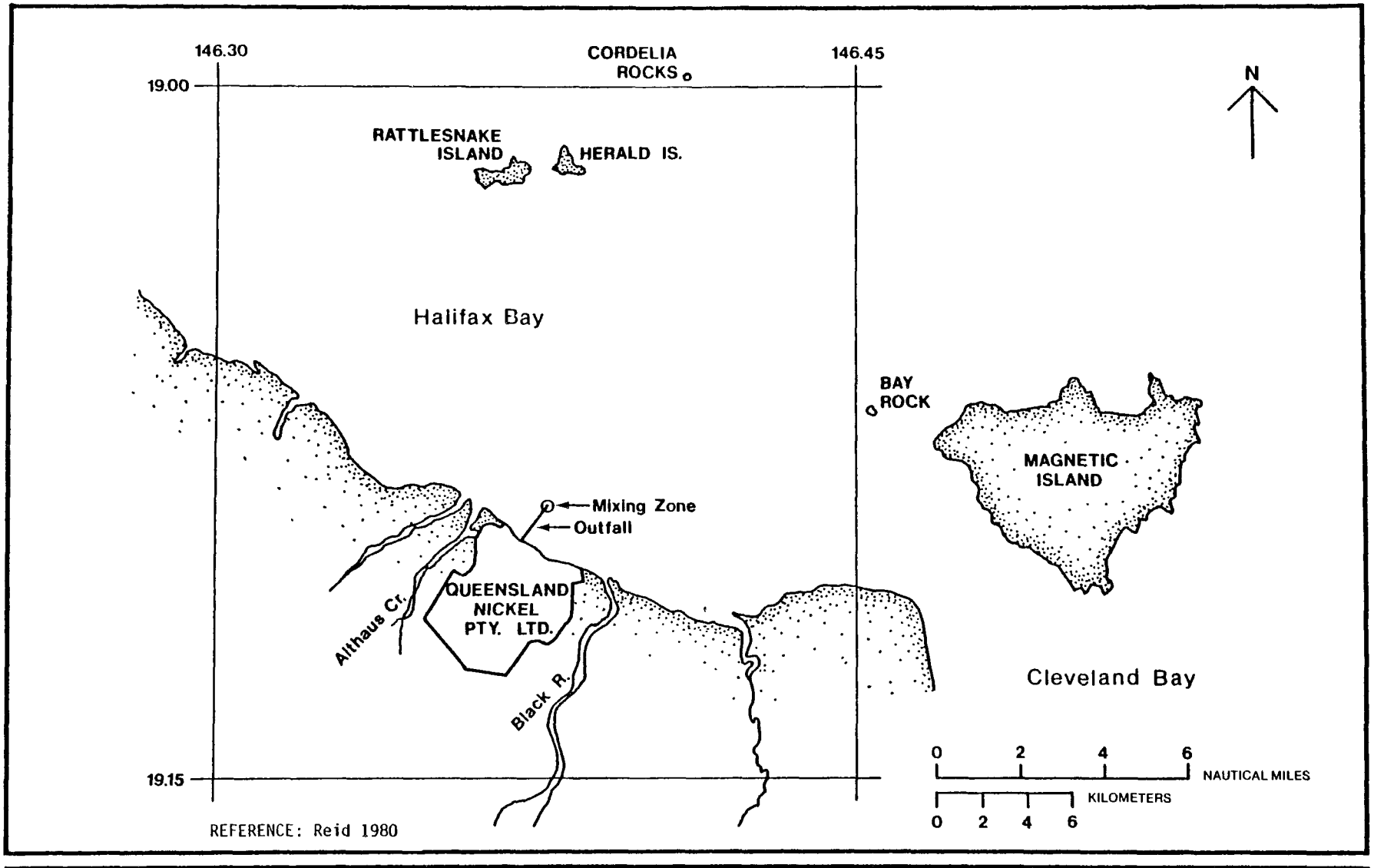


Figure 48. Location of Yabulu Nickel Refinery Outfall.

TABLE 48. YABULU REFINERY EFFLUENT LIMITATIONS FOR DISCHARGE TO HALIFAX BAY, AUSTRALIA

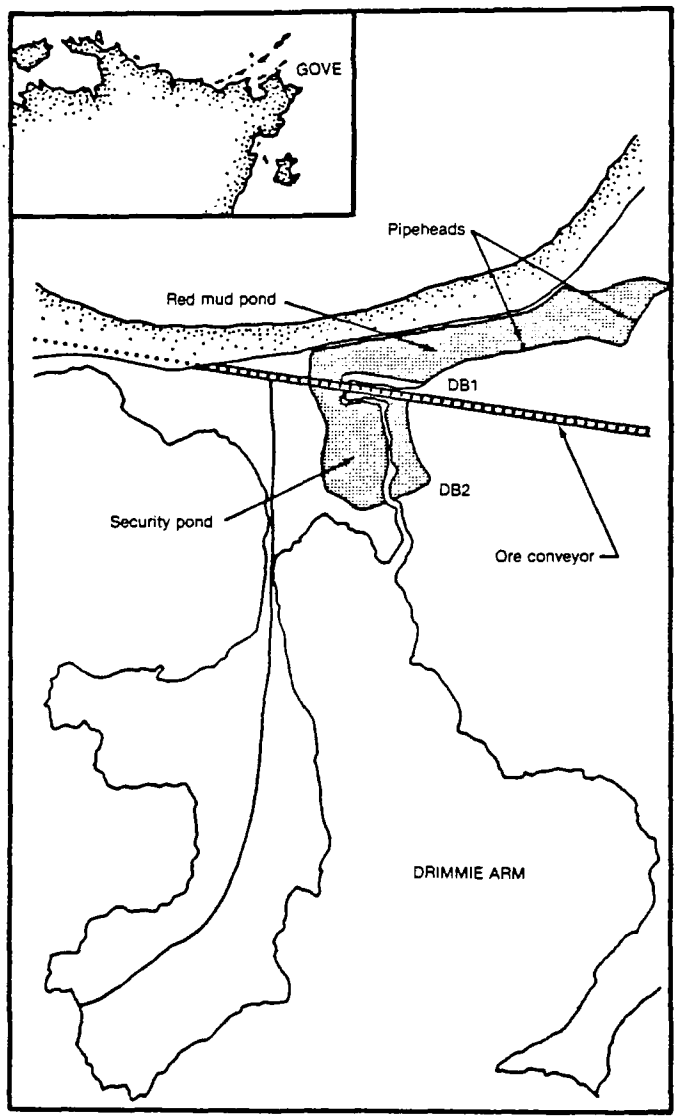
Parameter	Maximum Effluent in Effluent
Flow, m^3/day	17,500
pH, range in units	6.5 to 8.5
Total ammonia-N, mg/l	500
Free ammonia-N, mg/l	100
Total nickel, mg/l	1
Total cobalt, mg/l	0.1
Total iron, mg/l	5
Total manganese, mg/l	5
	Maximum Allowed after Dilution[a]
Total ammonia-N, mg/l	1
Total nickel	0.05
Total cobalt	0.01

Biological Effects

The discharge of effluent shall have not deleterious effect on the marine environment.

[a] Within a mixing zone of 400 m (1,300 ft) radius.

Reference: Reid 1980.



REFERENCE: Baseden, 1976.

Figure 49. Locations of the bauxite refinery and red mud settling ponds at Gove, Australia.

Potash Mines

The Cleveland Potash Mine in Boulby, Yorkshire, England disposes of about 240 tons per day of insoluble tailings to the marine environment (Figure 50). The tailings are carried offshore via a submarine outfall pipe which is located within a submarine tunnel (Figure 51). The tunnel and discharge pipe extend about 1.8 km (1.1 mi) offshore (Cleasby et al., 1975). Intake pipes located in the tunnel provide sea water for mixing a weak tailings slurry which is discharged through nozzles at a depth of 25 m (84 ft).

The primary constituent of the tailings is halite. Sylvite, anhydrite, calcium and magnesium carbonates, quartz, clay minerals, pyrite, and hematite are also present in small quantities (Cleasby et al., 1975). The halite, sylvite, and anhydrite are soluble in seawater, and dissolve in the outfall pipe or shortly after discharge. The remaining 6 percent of the tailings which are insoluble are dispersed by strong currents at the discharge site (Cleasby et al., 1975).

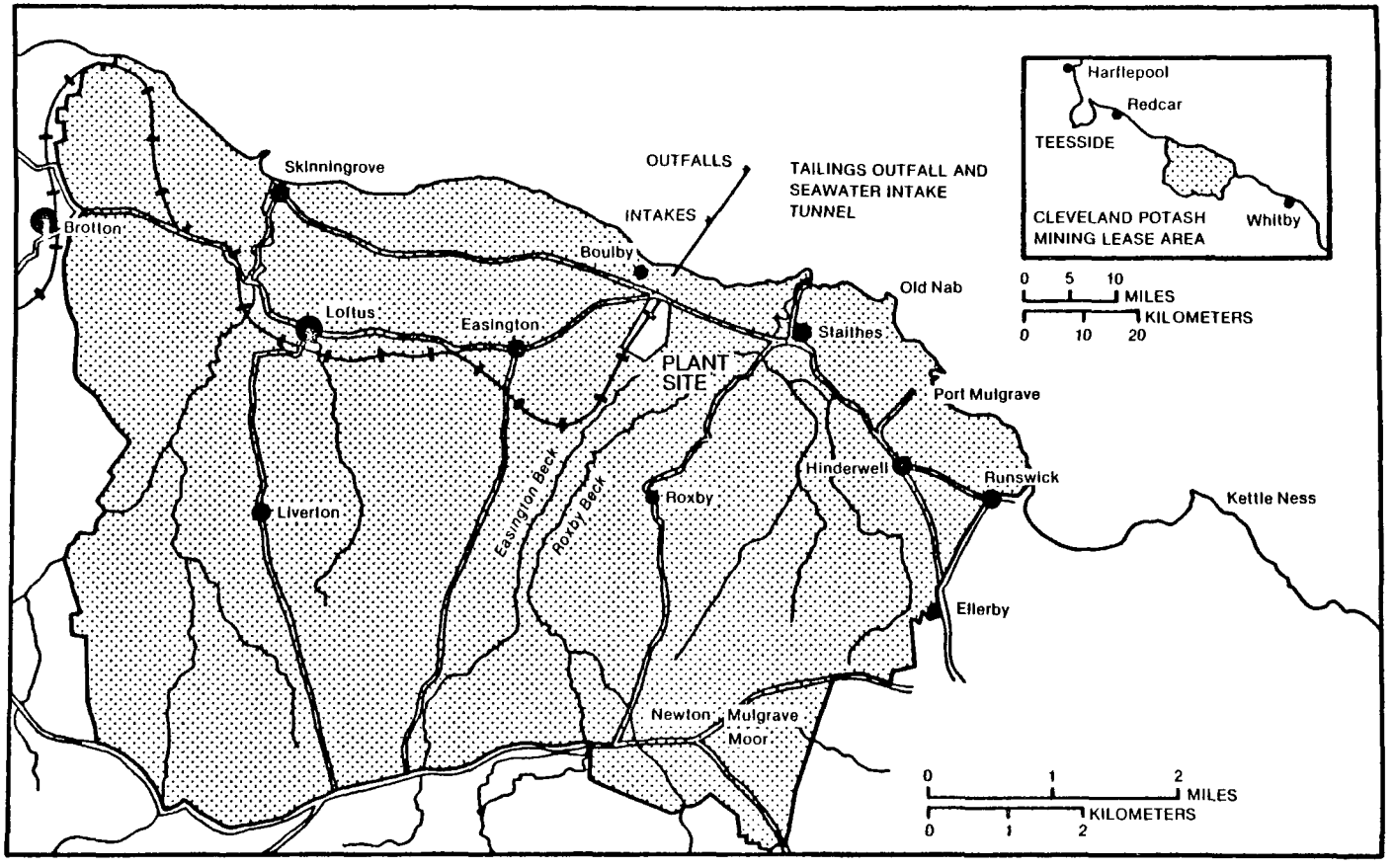
DREDGED MATERIAL

Dredged material consists of a wide range of natural and anthropogenic materials. In terms of textures, dredged materials can range from nearly all clay-size particles to clean sands and gravels. The size characteristics of the sediments generally reflect the energy level of the environment from which they are dredged. Sediments in coastal and inland waters subject to high water velocities or wave energy contain only small fractions of silt- and clay-size particles because of the lack of opportunity to settle. In quiescent waters, fine-grained particles can settle. If a source of silt and clay exists, sediments will likewise be predominantly fine grained.

In 1979, the New York District, Corps of Engineers reported the percentage of sand, silt, and clay for 25 dredging projects which involved ocean disposal of the dredged material (COE 1980). These projects involved 3.1 million m^3 (4.1 million yd^3) or 31 percent of all dredged material dumped in the U.S. waters of the Atlantic Ocean in 1979. The means of the reported grain-size distributions were 34 percent sand, 43 percent silt, and 23 percent clay.

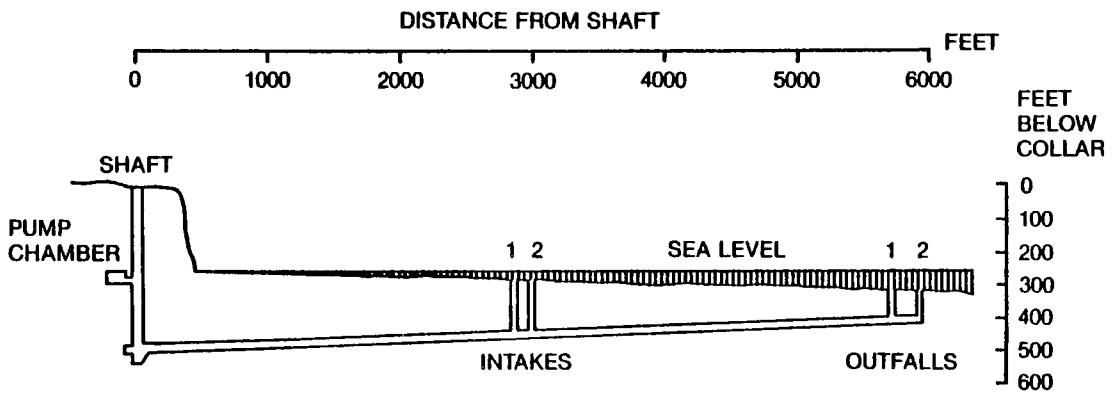
The chemical composition of dredged material also covers a wide range, again generally related to the energy level of the environment from which the sediments are dredged. Metals, present as contaminants, are generally transported to the sediments with settling organic and inorganic solids. Because surface adsorption is the common mechanism for bonding of the metal ions to particles, the smaller particles which present the greatest surface area per unit volume are the most efficient transporting medium. For this reason, sediments with high percentages of organic materials and clay-size particles generally contain higher concentrations of pollutants.

The U.S. Army Corps of Engineers prepares reports of all ocean dumping of dredged materials. Many of these reports, required by the London Dumping



REFERENCE: Cleasby et al., 1975.

Figure 50. Locations of the Cleveland Potash Mine and submarine outfall in Boulby, Yorkshire, England.



REFERENCE: Cleasby et al., 1975.

Figure 51. Diagram of submarine tunnel used for the discharge of potash mine tailings by Cleveland Potash, Ltd., Yorkshire, England.

Convention, include information on the dredged sediments chemical composition. All results of bulk analyses performed on sediments dumped in the ocean during 1978 and 1979 are summarized in Table 49.

Table 50 reports the results of elutriate tests performed on some of the same sediments. The elutriate test is a leaching test designed to simulate the characteristics of the material as it is discharged from a hydraulic dredge. The test is performed by mixing one volume of sediment to be dredged to four volumes of water from the dredge or disposal site. The mixture is thoroughly mixed and allowed to settle. The liquid fraction of the sample is then analyzed. The elutriate test thus provides an estimate of the metals discharged in the dissolved state. The standard analytical methods used does not, however, distinguish between truly ionic and non-ionic species.

DRILLING MUDS AND CUTTINGS

The drilling of offshore oil and gas wells produces waste rock (cuttings) from the hole and drilling fluids which are discharged to the marine environment. Their physical and chemical characteristics vary widely. The composition of the cuttings depends upon the rock and fluids being encountered by the drill bit. The introduction of drilling muds to the hole achieves many purposes but mainly serves to reduce friction, remove solids, and maintain down-hole pressure.

Drilling mud is, in general, composed of 80 to 90 percent barite ($BaSO_4$), 10 to 20 percent clay, and small quantities of special purpose additives (Kalil 1980). The American Petroleum Institute (1978) has compiled a list of drilling fluid additives, of which there are 43 generic varieties of additives and at least 231 proprietary formulations. At any given well, depth, and time, a dozen or more additives may be used to control downhole conditions (API 1978). Petrazzulo (1981) has provided a detailed review of drilling fluids and their usage.

Analyses of used drilling muds and cuttings have been reported by Liss, et al. (1980), Ayers, et al. (1980), and Sauers (1981). The range of metals concentrations in the whole muds are shown in Table 51.

Table 51 also presents the results of analyses of the "mud aqueous fraction" of four used drilling fluids performed by McCulloch, et al. (1980). The mud aqueous fraction was composed of one part drilling mud mixed with nine parts artificial seawater. The mixture was stirred thoroughly and allowed to settle for 20 hours. The liquid fraction was then analyzed. These results provide an indication of the concentration of dissolved metals associated with the discharge. As with the dredged material, the actual amount of metal in true ionic form is not known.

TABLE 49. METALS CONCENTRATIONS IN DREDGED MATERIAL SOLIDS DUMPED AT SEA - 1978 AND 1979

	Number of Observations	Average Concentrations mg/kg	Range
As	52	4.0	0.03 to 23
Be	23	0.89	0.25 to 3
Cd	57	1.2	0.02 to 7
Cr	52	33.0	0.25 to 190
Cu	55	30.4	0.23 to 449
Fe	39	8,417	100 to 95,000
Hg	61	0.3	0.01 to 2.7
Mn	7	316	188 to 570
Ni	52	15.0	1.2 to 82
Pb	61	29.6	0.25 to 600
V	20	10.6	0.25 to 82.2
Zn	61	68.8	0.25 to 1,246
Percent Volatile Solids	27	7.2	0.4 to 18

TABLE 50. ELUTRIATE ANALYSIS OF DREDGED MATERIAL DUMPED AT SEA - 1978 AND 1979

	Number of Observations	Average Concentrations ug/l	Range
As	25	4.9	1 to 24
Cd	29	1.6	0.2 to 2.9
Cr	23	4.8	0.5 to 30
Cu	24	2.7	1 to 8
Fe	17	17.6	2.5 to 33
Hg	28	0.3	0.01 to 1.8
Mn	9	1,038	30 to 2,300
Ni	23	6.8	2 to 21
Pb	24	6.8	0.9 to 12.5
Zn	29	32.5	10 to 70

TABLE 51. OBSERVED COMPOSITION OF USED DRILLING MUDS AND CUTTINGS

	Whole Mud[a] Concentration Range, mg/kg	N[b]	Mud Aqueous Fraction[c] Concentration Range, ug/l	N[b]
As	<1.0 to 3	6		
Ba	2,800 to 202,000	11		
Cd	<1.0 to <2.0	9	60 to 80	4
Cr	2 to 1,007	12	<100 to 1,080	4
Cu	2 to 28	9		
Pb	<1 to 24	9	<500	4
Hg	<1 to 2.2	9		
Ni	1 to 21	9		
V	6 to 35	9		
Zn	12 to 236	9	60 to 230	4

[a] Data from Liss, et al. (1980), Ayers, et al. (1980), and Sauers (1981).

[b] N = number of analyses.

[c] McCulloch et al. (1980).

APPENDIX D

DETAILED DESCRIPTION OF THE OCEANOGRAPHIC CHARACTERISTICS FOR REPRESENTATIVE DISPOSAL AREAS

This appendix provides a detailed description of the oceanographic characteristics for the representative disposal areas previously identified in Chapter 6 of this report. In that chapter the information presented summarized the physical and biological oceanographic conditions at each area. The information presented in this appendix is the basis from which that summary is extracted.

In general, the disposal areas represent typical nearshore, midshelf, and deep water areas within each primary region (with the exception of Hawaii for which only one area is identified). For each region, general physiography, bathymetry and circulation patterns are presented to provide a regional setting. Generalized profiles of temperature, salinity, density, dissolved oxygen, and currents are provided for the representative areas within each region. In addition, biological oceanographic descriptions of each region with particular emphasis on the specific areas are provided. This is followed by a discussion of important fishing locations.

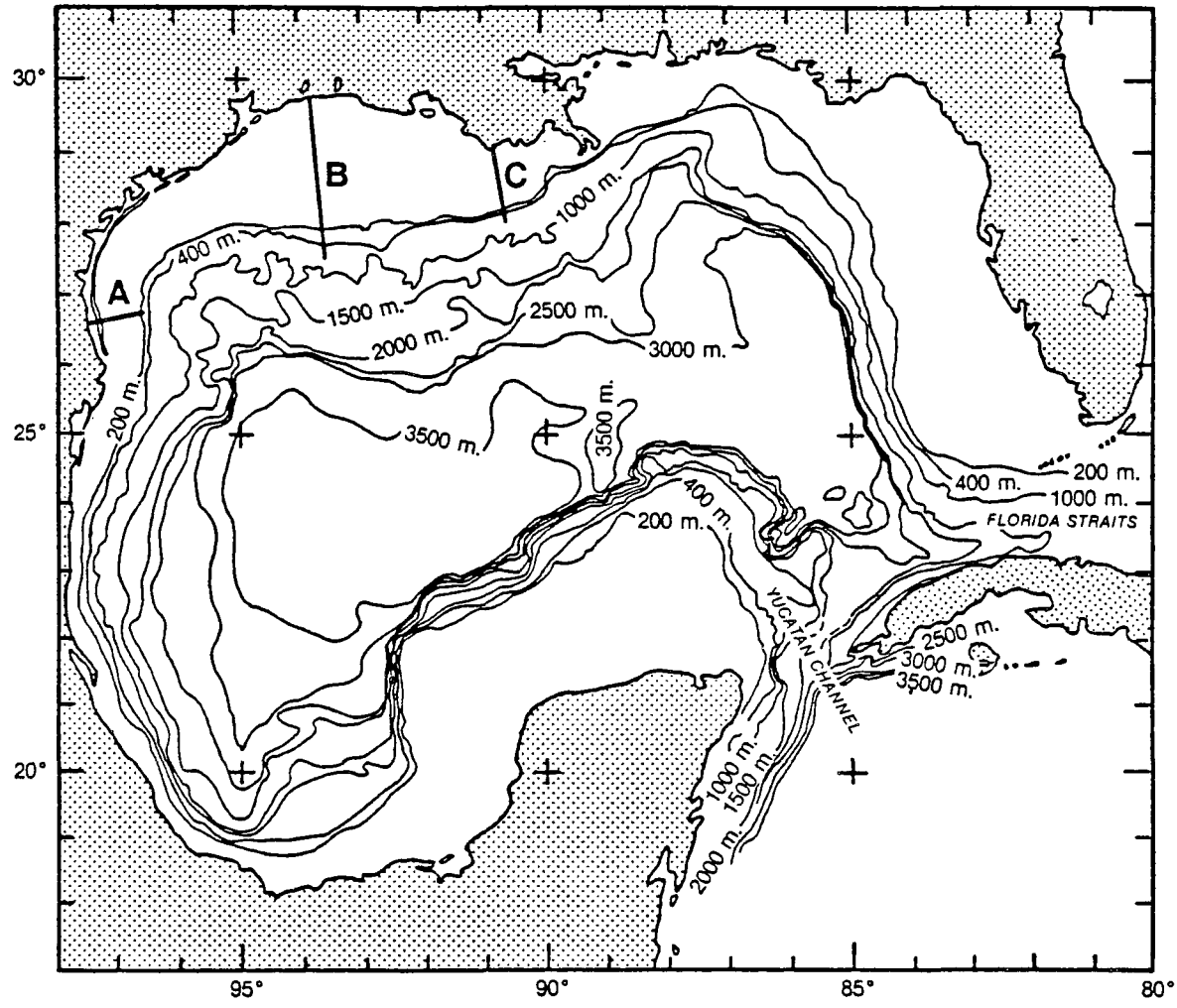
WESTERN GULF OF MEXICO

Physical Characteristics

The Gulf of Mexico is a relatively shallow (3,600 m maximum depth) semi-enclosed water body connected to the Atlantic Ocean by the Florida Straits and the Yucatan Channel (Figure 52). Basin physiographic features (Figure 53) include the shelves of East Mexico, Texas, Louisiana, and Western Florida; an upper continental slope; the Mississippi Cove; the Campeche, Sigsbee, and West Florida escarpments; the continental rise; the abyssal plain and the Sigsbee Knolls. The Gulf does not contain any major ridge or trench systems but does present a variety of geological structures including salt domes, mud diapirs, escarpments, submarine canyons, abyssal fans, channels and terraces, and coral reefs.

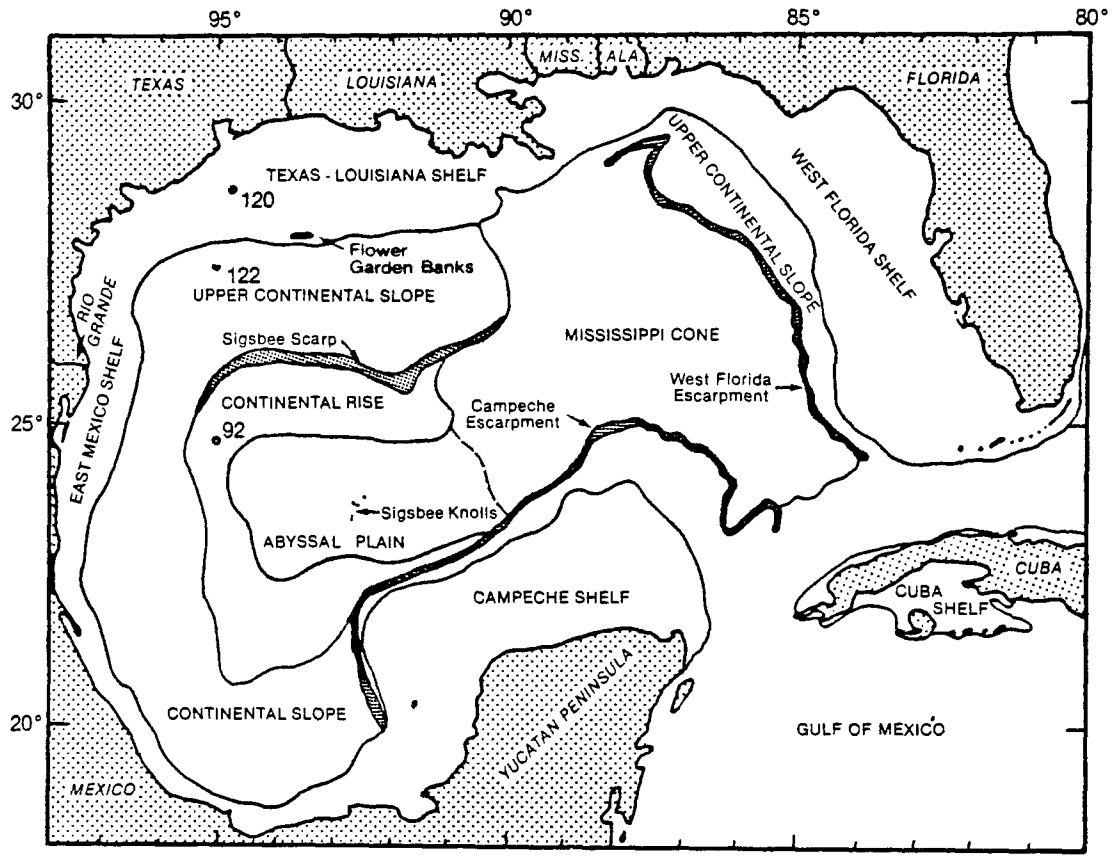
Bathymetry--

The continental shelf along the northwestern Gulf of Mexico between the Mexican border and the Mississippi Delta is a gently sloping, smooth, sediment-covered plain interrupted by occasional hills or banks (Curray 1960). The shelf width ranges from approximately 90 km (56 mi) near the Rio Grande in Texas to about 200 km (124 mi) south of the Texas-Louisiana boundary.



REFERENCE: Nowlin 1972

Figure 52. Bathymetry of Gulf of Mexico.



REFERENCE: after Ewing et al., 1958.

Figure 53. Physiographic subdivisions of the Gulf of Mexico and selected stations of Hidalgo 62-H-3 cruise of March 22-27, 1962.

Further east, approaching the Mississippi Delta, the shelf narrows considerably, becoming non-existent in some places. The outer shelf edge is relatively well defined in many areas by a number of elongated ridges and escarpments at an average depth of approximately 120 m. In some areas, however, the shelf/slope transition is smooth, gradual, and rounded in nature. Western Gulf shelf gradients along transects A and B (Figures 52 and 54) are 0.08^{o} or 1.4 m/km and 0.03^{o} or 0.59 m/km, respectively.

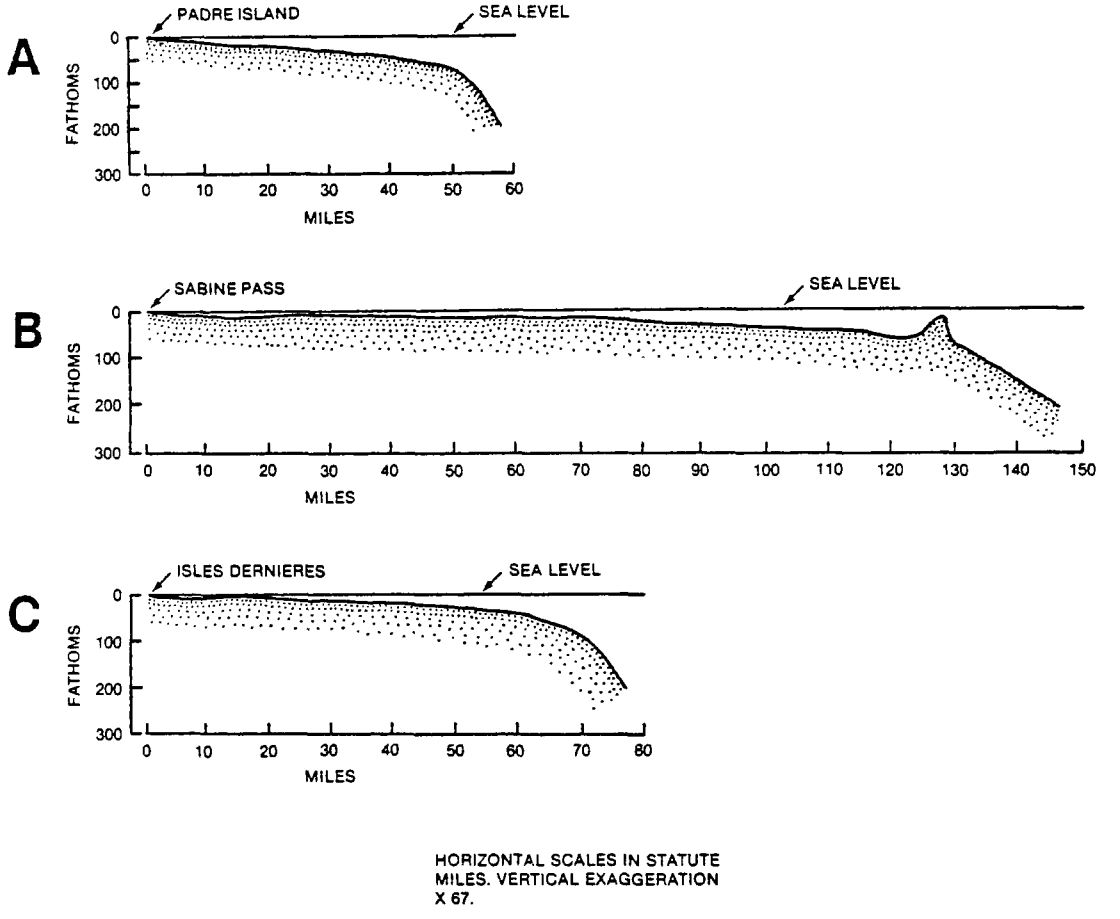
A series of widely spaced shelf banks (e.g., the West Flower Garden) rise above relatively smooth bottom reef structures predominantly at depths of 16, 60, and 90 m. Those with relief greater than 4-6 m are believed to have been caused by underlying salt domes, while others with less relief are considered remnants of earlier shoreline deposits. Recent (Holocene) sediments on the shelf are generally non-calcareous silty-clays, particularly near the Mississippi Delta and off the central Texas coast. However, in offshore areas between east-central Texas and western Louisiana, the surface lithology shows great variation, being mostly sandy and containing much shell material (Shepard 1963).

The upper continental slope extends in a west-southwest direction, with little indication of widening due to Mississippi Delta sedimentation. The slope extends approximately 240 km beyond the shelf off the Louisiana-Texas boundary and is extremely irregular in relief due to the intrusive nature of the underlying salt deposits, erosion associated with lowered sea levels in the past, and probably some submarine slumping. The average upper slope gradient between depths of 180 and 360 m is 1.1^{o} or 18.9 m/km.

The continental slope ends at between 1,800 and 2,000 m (5,900 and 6,560 ft) at the Sigsbee Escarpment which drops another 1,000 m (3,280 ft). Beyond the escarpment is the continental rise leading to the abyssal plain which reaches depths of 3,600 m (11,810 ft). The plain is a remarkably flat, oval shaped basin having bottom gradients of only 1/8000 (Ewing et al., 1962). Although the eastern portion of the abyssal plain is known to be partially covered by Mississippi Cove sediments (reddish-brown foraminiferal lutite overlying beds of grey silty clay), less is known regarding the characteristics of sediments in the extreme western portion of the plain. The clustered Sigsbee Knolls, which rise 100-200 m (328-656 ft) above the plain, have sediments consisting of foraminiferal oozes due to deposition of planktonic debris.

Circulation Patterns--

The large scale circulation pattern in the Gulf of Mexico is dominated by two current systems; the strong well-defined clockwise Loop Current in the east, and an elongated less permanent clockwise circulation cell located over the deeper areas of the central and western Gulf. The Loop Current enters the eastern Gulf through the Yucatan Straits, exiting through the Straits of Florida (Leipper 1970; Maul 1977). The horizontal distribution of temperature in the main thermocline is well correlated with the dynamic topography of the sea surface (Nowlin 1972). Loop current seasonality was examined by Leipper (1970) on the basis of temperature data, resulting in definition of a "spring intrusion" to describe growth of the loop into the



REFERENCE: Curray, 1960.

Figure 54. Profiles from the shoreline to the upper continental slope.

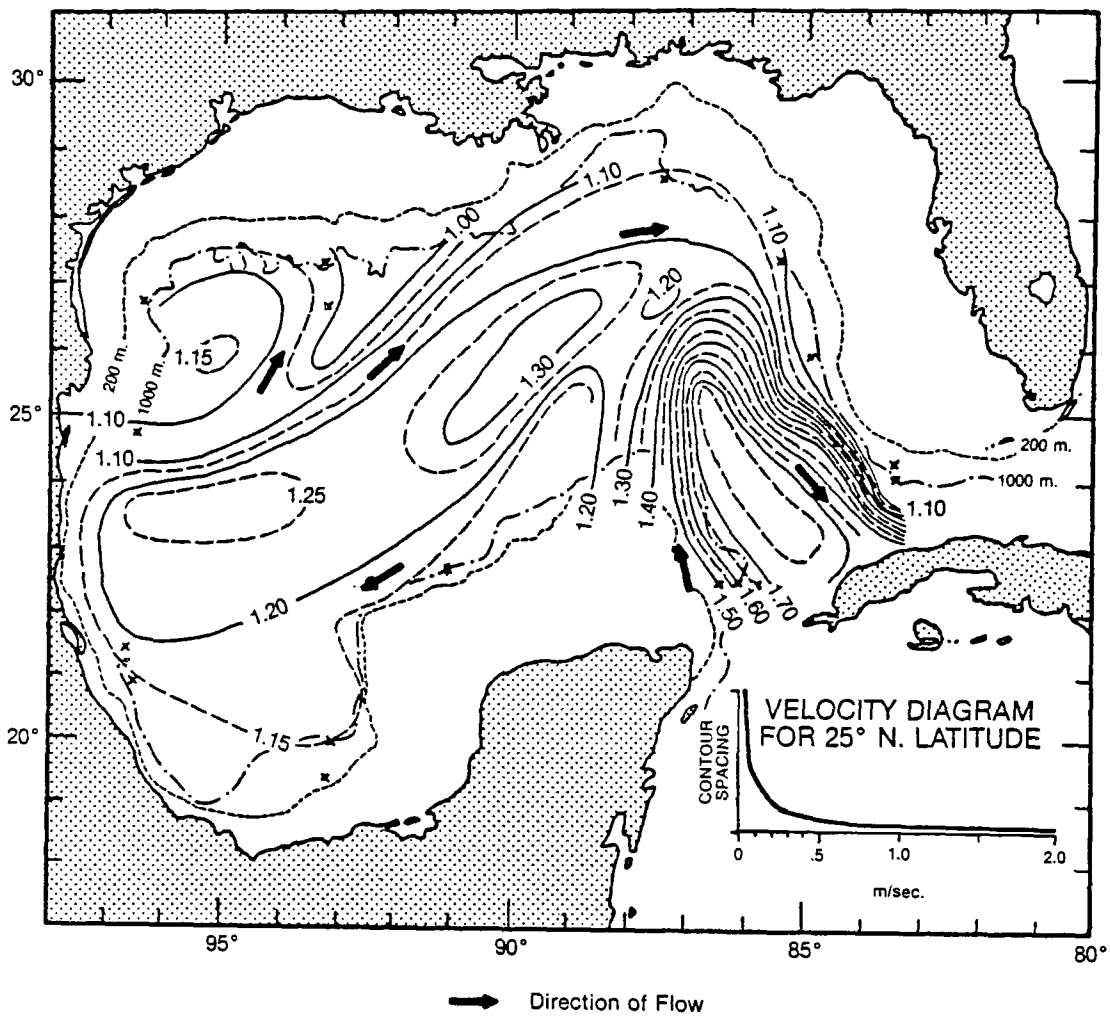
Gulf, and "fall spreading" to describe the subsequent westward movement of the loop or of a detached eddy. The velocity in the core of such a detached eddy was observed in 1965 to be 113 cm/sec, which was comparable to that in the East Gulf Loop Current itself. One month later, after passage of a hurricane, the eddy was considerably modified in shape, and core velocities had decreased to 73 cm/sec (Leipper et al., 1972).

An analysis of 1958-1964 data indicates that the western Gulf is dominated, in the wintertime at least, by a weak clockwise gyre, apparently driven in part by separated portions of the Loop Current and partly by surface winds. The gyre, whose major axis is oriented in a northeast-southwest direction, consists of a broad, rather weak southwestward flow on the southern flank, and a somewhat more narrow and stronger flow in the deep water portion of the northern Gulf. Velocities in the core of the northeastward-flowing current have been computed to be some 50 cm/sec (Figure 55), whereas downstream core flows appear to decrease to approximately 30 cm/sec.

In addition to the clockwise western Gulf gyre, there may be a narrow westward counterclockwise flow just above the continental slope, separated from the gyre by a strong shear zone. A north-flowing western boundary current may also exist as noted by Sturges and Blaha (1976), evidenced in modeling experiments (Ichiye et al., 1978), and shown by the trajectory of tracers released off the coast of Mexico (Vasquez 1975).

Isotherm depths reported by Sturges and Horton (1981) suggest that the flow approaches the coast at 22-23^{o} N and remains near the western boundary all the way to the continental shelf in the north. Winter satellite photographs indicate departure of this flow from the coast at approximately 28^{o} N near the mouth of the Rio Grande River.

Several hypotheses have been offered for the irregularity and driving mechanism of the clockwise gyre in the western Gulf. Some researchers suggest that the gyre is the result of forcing by the wind stress curl rather than by pinched-off eddies, which would explain stronger winter and summer currents in phase with wind forcing. Others feel the gyre is always present as in the Atlantic and Pacific basins. Maul (1977) in studying the annual Loop Current penetration cycle confirmed Leipper's (1970) proposition that there is an annual cycle of growth and decay, but that year-to-year variability in the pattern is significant. An eddy separation from the Loop Current appears to have occurred each year during the 1972 to 1976 period examined. Molinari et al. (1978) confirmed the Leipper cycle on the basis of computed monthly sea surface dynamic topographies. A permanent counterclockwise flow on the Texas Shelf was found to join the eastward transport of the northern limb of the clockwise gyre in the western Gulf. Behringer et al. (1977) found that Loop Current penetration into the Gulf increases during the winter and spring periods, reaching a maximum in early summer. At that time, a large eddy separates from the loop. Deviations from this pattern were also noted, however, (i.e., year-round persistence of the clockwise gyre, and strongest periods during summer and winter). Molinari (1980) has concluded that the typical Loop Current cycle of spring intrusion, summer eddy breakoff and fall spreading may not be typical, and that such events may occur during any season.



REFERENCE: Nowlin, 1972.

Figure 55. Dynamic topography of sea surface relative to the 1,000-db surface, Hidalgo 62-H-3, x's indicate some extrapolation. Contour interval, 0.05 dynamic meters.

The western Gulf of Mexico is a difficult area to describe, owing to the paucity of observations and to the complexity of the pertinent dynamics. The presence of two important driving mechanisms seems apparent; the eddies propagating to the west, and the wind field. Elliot (1979) concludes that the eddies take approximately a year to drift from their eastern formation region to the western side of the Gulf. He also feels that the western gyre is half driven by the introduction of one new large eddy per year, and half driven by the wind stress. However, what happens when an eddy moves into the region, its path and decay characteristics, are not yet well known.

Characteristics of Representative Areas

Two general locations are considered as representative of potential nodule processing waste disposal sites; a midshelf site and a deepwater site. In addition, conditions at an upper-slope site are also described because of the site's historical use for chemical waste disposal (Atlas et al., 1980). Shallow nearshore waters and a gentle bottom slope effectively preclude disposal of nodule processing wastes through a nearshore outfall pipe.

Oceanographic data from Texas A & M western Gulf synoptic oceanographic surveys in February and March, 1962, serve to define selected parameters in each area. Stations 120, 122, and 92 shown in Figure 53 are considered representative of mid-shelf, upper-slope, and deep basin areas, respectively. In synthesizing the physical oceanographic nature of each area, many technical documents were reviewed in addition to the Texas A & M transect data (Table 52). Nevertheless, the data set available for compiling general area characteristics was found to be limited (e.g., seasonally or for a particular parameter) not only for the Gulf of Mexico areas, but for west coast and Hawaiian areas as well.

Mid-Shelf--

The temperature, salinity, density and dissolved oxygen characteristics of a mid-shelf disposal site in the north-western Gulf of Mexico are presented in Figure 56. Nearshore surface salinities are typically low due to intrusion of freshwater from continental drainage (Nowlin 1972). Salinity increases with depth and with distance offshore. Due to significant mixing, temperatures are relatively uniform with depth. This temperature-salinity combination results in a typical March density gradient of 1.0 sigma-t units in the upper 30 m. Dissolved oxygen levels are relatively uniform with depth, decreasing from 6.5 to 5.8 ml/l.

Current measurements on the shelf indicate that they are typically aligned alongshore, are highly seasonal, and exhibit layering of contrasting flow in late spring and during summer (Armstrong 1980). Mean surface currents are downcoast to the southwest throughout the year, with an onshore component in summer. Mid-depth to bottom flows are directed upcoast and offshore (east and southeast, respectively) from May to August, and downcoast the remainder of the year. Deeper eastward currents do occur during some winter periods. Mean current speeds decrease with depth, being

TABLE 52. REFERENCES CONSULTED IN SYNTHESIZING THE PHYSICAL OCEANOGRAPHIC CHARACTERISTICS OF WESTERN GULF OF MEXICO DISPOSAL AREAS

Anderson et al., 1979

Atlas et al., 1980

Atlas et al., 1981

Behringer et al., 1977

Curray 1960

Dietrich 1939

Ewing et al., 1962

Ichiye et al., 1978

Ichiye et al., 1981

Leipper 1970

Leipper et al., 1972

Maul 1977

McLellan and Nowlin 1963

Meyer and Warsh 1981

Molinari 1980

Mungall and Horne 1978

Nowlin 1971

Nowlin 1972

Okubo and Ebbesmeyer 1976

Shepard 1963

Sturges and Blaha 1976

Sturges and Horton 1981

U.S. Naval Oceanographic Office 1972

Vasquez 1975

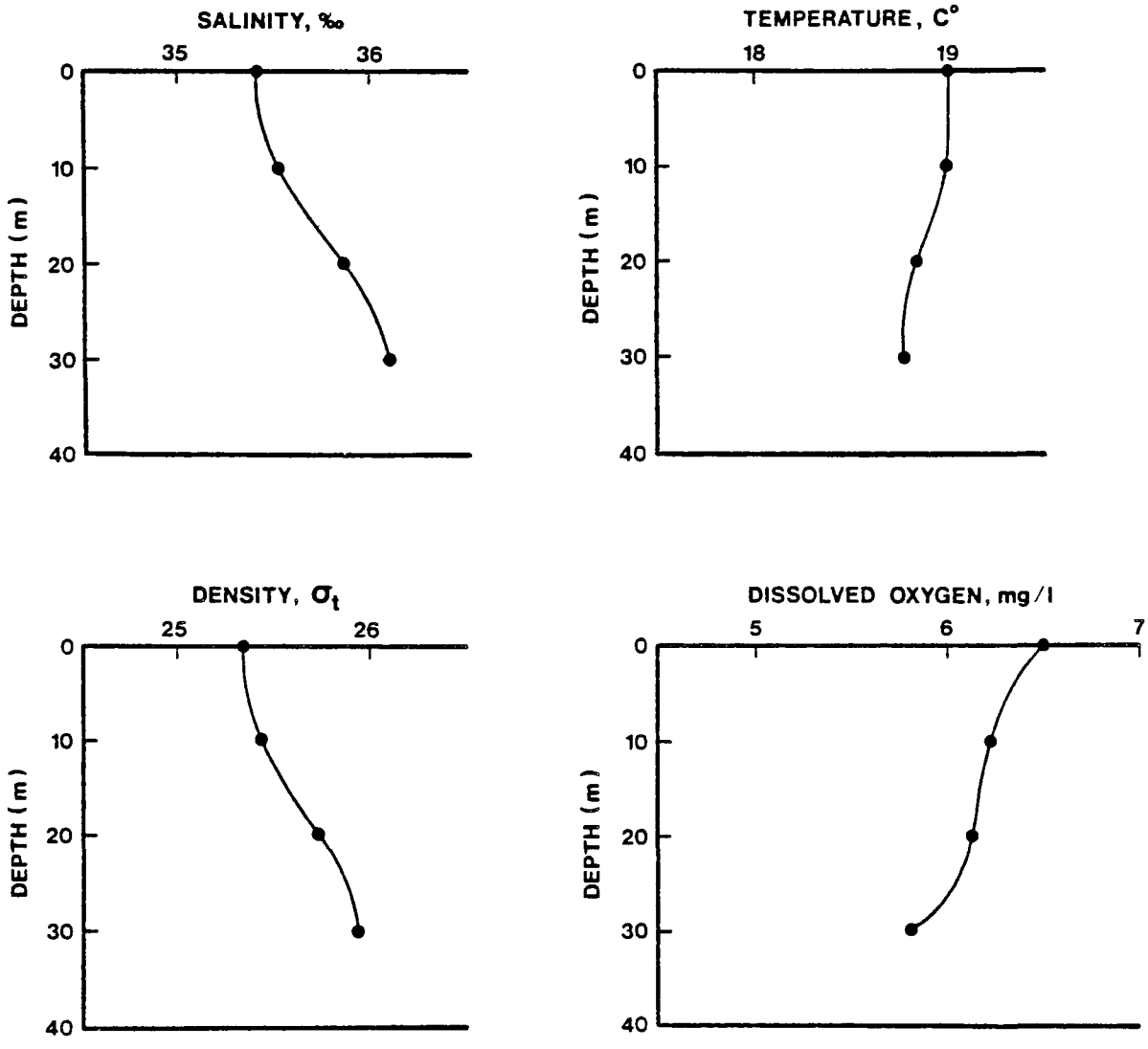


Figure 56. Characteristics of a Western Gulf of Mexico mid-shelf disposal site.

approximately 15 cm/sec near the surface and decreasing to 10 cm/sec near the bottom. Seasonally, speeds are lowest in summer and highest in the fall and spring. Flow variability is principally due to wind shifts and tidal currents.

Upper-Slope--

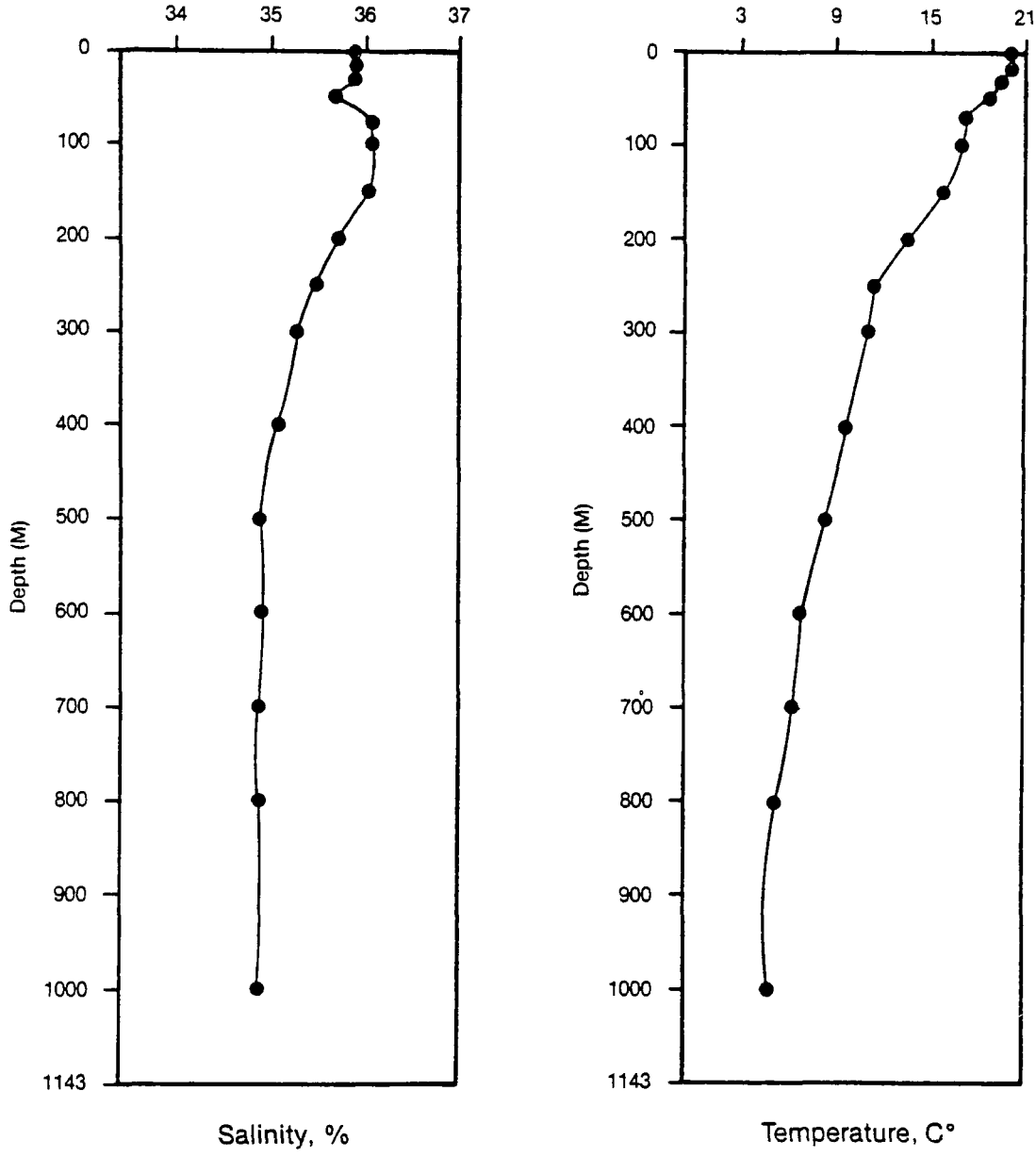
Further offshore, the salinity is relatively constant at 35.9 ppt in the upper 50 m (164 ft), increasing somewhat between 100 and 200 m to 36.1 ppt, and thereafter decreasing gradually with depth to approximately 35 ppt (Figure 57). The March temperature profile indicates a gradual reduction in temperature from approximately 20° C near the surface to 4° C at 1,000 m (3,280 ft). The resultant density profile (Figure 58) consists of a small positive density gradient to the 50 m (164 ft) point, a sharp density increase between 50 and 120 m (164 to 492 ft), tapering off to a relatively small increase with depth thereafter. Surface dissolved oxygen concentrations of 6.5 to 7.0 mg/l decrease to a minimum of approximately 3.5 mg/l at between 250 and 400 m (820 and 1,312 ft), and increase to 5.0 mg/l at 1,000 m (3,281 ft). Geostrophic flow is predicted to generally be eastward, varying from 25 cm/sec near the surface to less than 5 cm/sec below 350 m (1,148 ft), as shown in Figure 59. At the industrial-chemical waste disposal site A (water depths of 900-1,400 m), absolute near-surface currents on the order of 26 cm/sec or less have been measured (Mungall and Horne 1978).

Deep Basin--

Beyond the slope, over the abyssal plain, surface water salinities commence at 36.1 ppt, increase slightly to a maximum of 36.35 ppt at 125 m (410 ft) and decrease sharply thereafter, reaching a minimum of 34.89 ppt at 580 m (1,902 ft). At greater depths, the salinity asymptotically approaches 34.97 ppt (Figure 60). Temperature decreases rather slowly from 22.3° C at the surface to 20.5° C at 125 m (410 ft). At this depth however, a pronounced gradient occurs, with temperature decreasing 15° C in the next 800 m (2,624 ft). Beyond this depth the temperature remains relatively constant at 4.2° C. The associated density profile (Figure 61) indicates a uniform surface density of 25 sigma-t units in the upper mixed layer [in this case down to 25 m (82 ft)]. A relatively sharp pycnocline occurs beyond this point, with sigma-t values increasing another 2.75 units by the 1,000 m (3,281 ft) depth. Thereafter, the density remains relatively constant at 27.75 sigma-t units.

Dissolved oxygen concentrations of 6.1-6.9 mg/l in the upper 100 m (328 ft) decrease sharply to a characteristic minimum of 3.83 mg/l at approximately 250 m (820 ft). Beyond this depth, dissolved oxygen concentration increases, at first relatively slowly to 4.9 mg/l at 775 m (2,542 ft), then quickly to 5.91 at 70 m (3,182 ft), and thereafter again slowly to a maximum value of 4.83 mg/l at 2,920 m (9,579 ft).

Calculated geostrophic flows for a deep-basin area (Figure 62) indicate westward surface currents of up to 35 cm/sec, decreasing to no current at approximately 350 m (1,148 ft). Beyond this depth, very low flows are



DATA FROM: National Oceanic Data Center

Figure 57. Temperature and salinity profiles characteristic of the western Gulf of Mexico upper slope, Hidalgo Cruise 62-H-3, March, 1972.

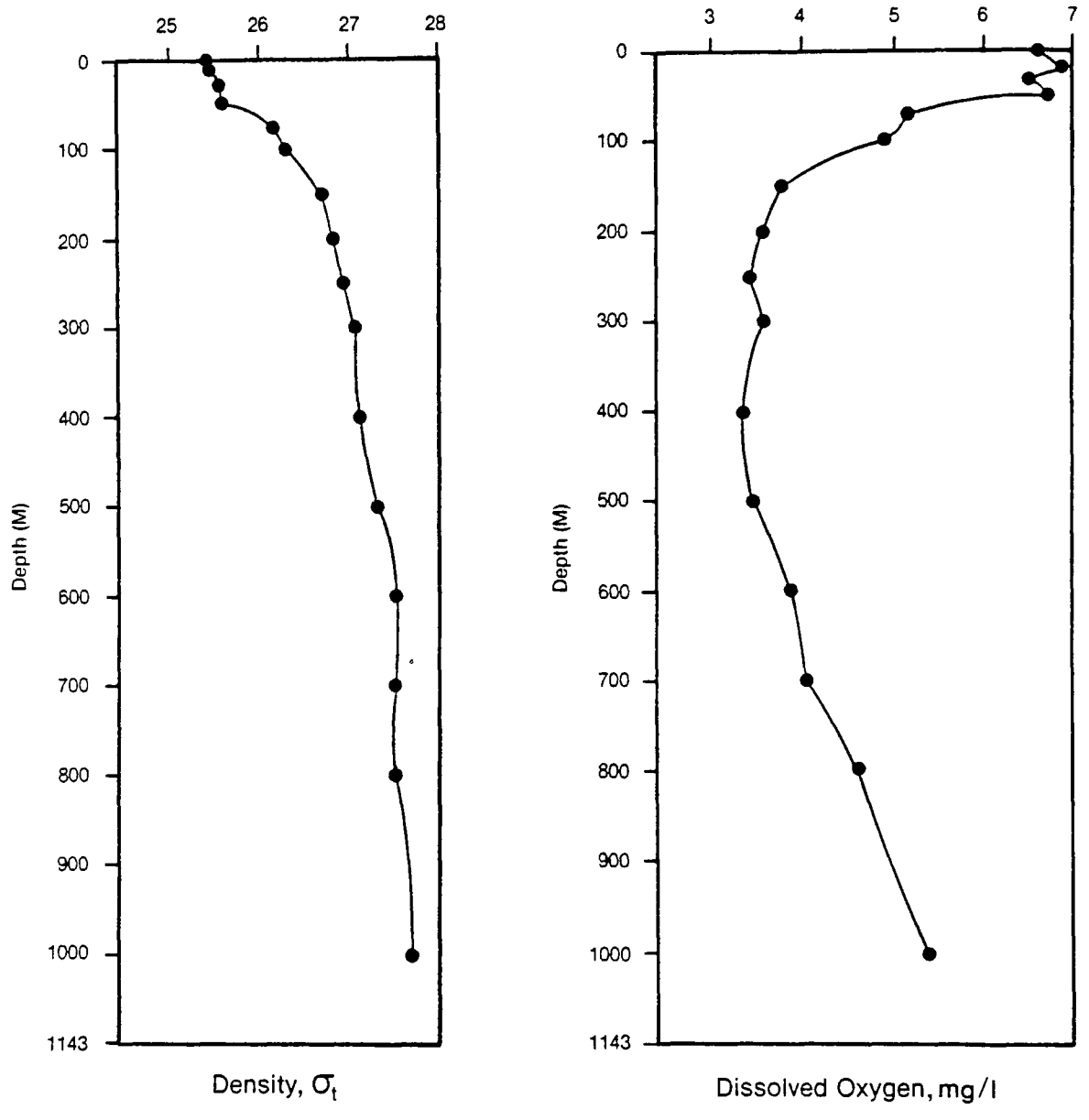


Figure 58. Density and dissolved oxygen profiles characteristic of the western Gulf of Mexico upper slope, Hidalgo Cruise 62-H-3, March, 1972.

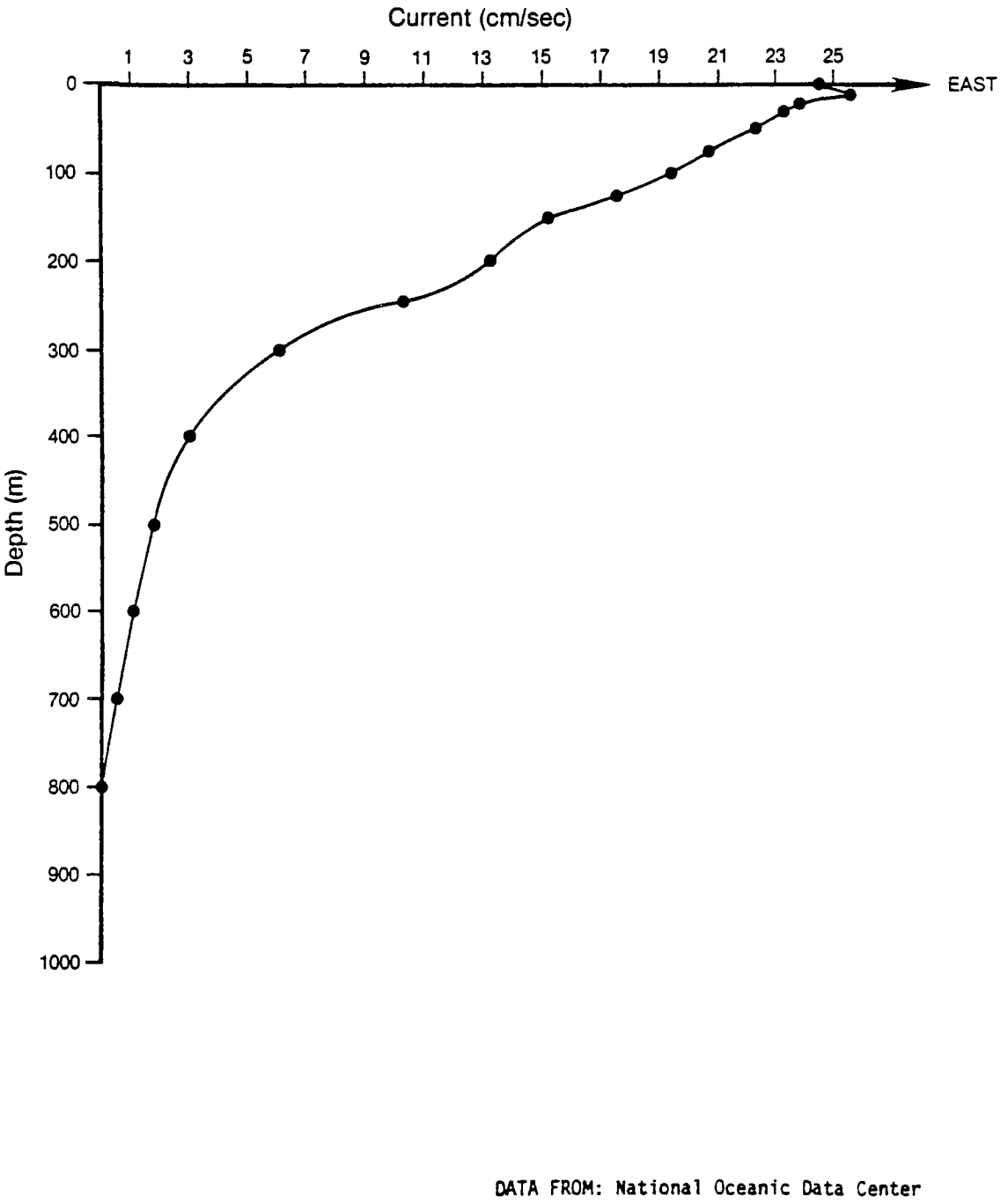
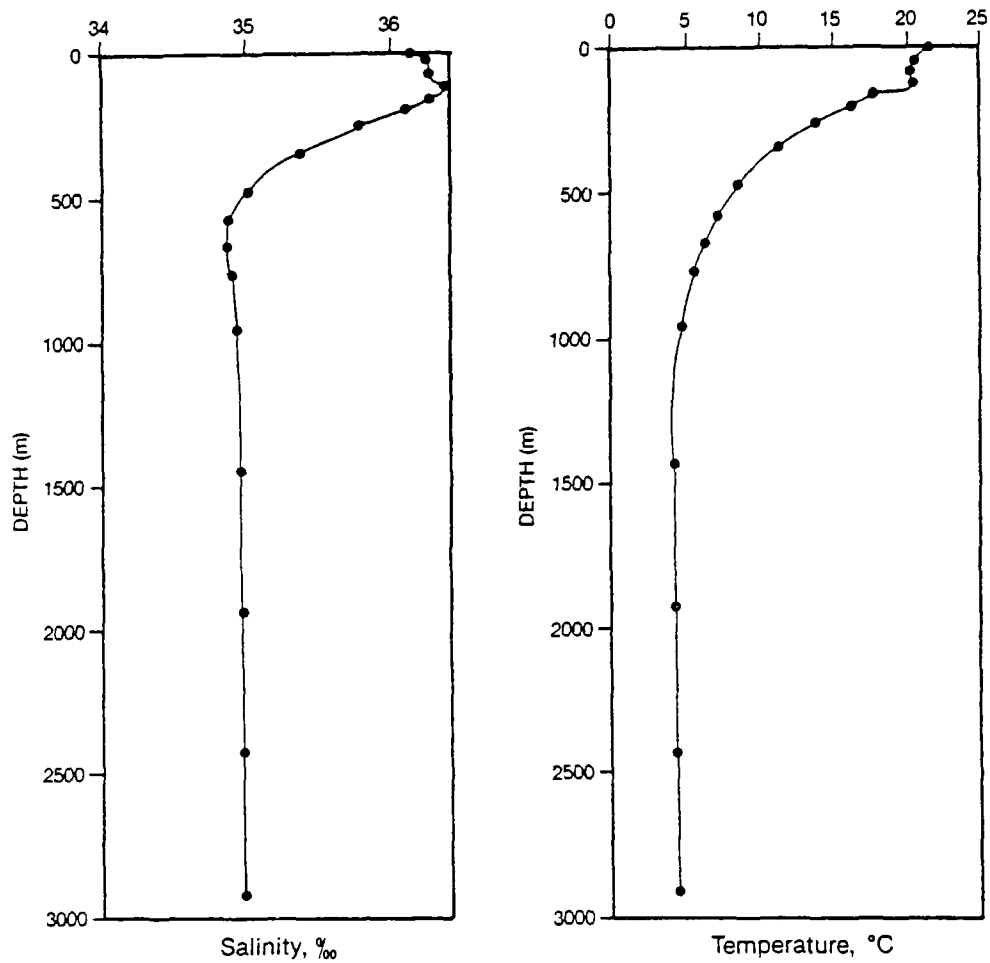


Figure 59. Geostrophic flow profile for an upper-slope area between Stations 122 and 123, Hidalgo Cruise 62-H-3, March, 1972.



DATA FROM: National Oceanic Data Center

Figure 60. Salinity and temperature profiles for a deepwater area in the northwestern Gulf of Mexico, Hidalgo Cruise 62-H-3, March, 1972.

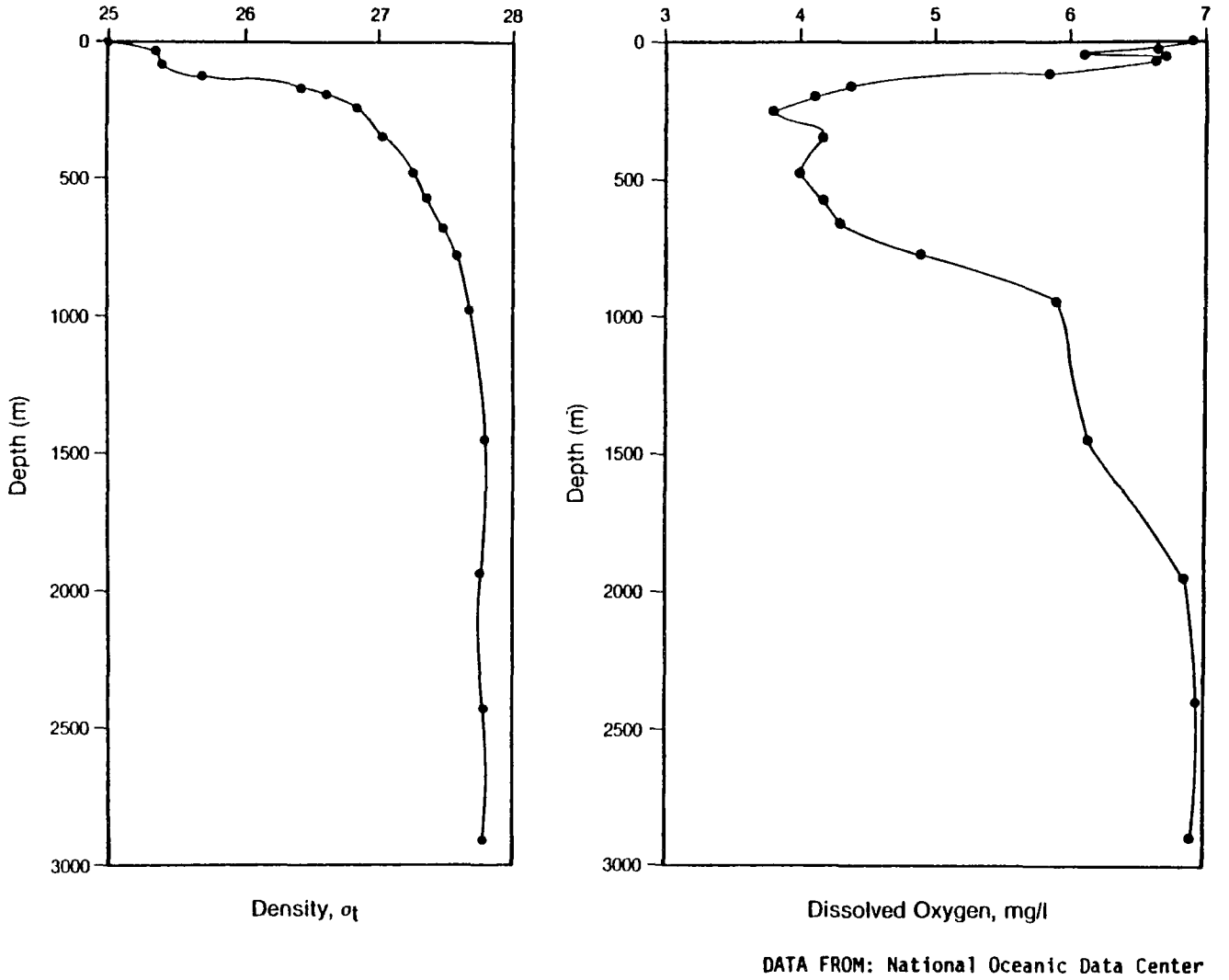


Figure 61. Density and dissolved oxygen profiles for a deep-basin area in the northwestern Gulf of Mexico, Hidalgo Cruise 62-H-3, March, 1972.

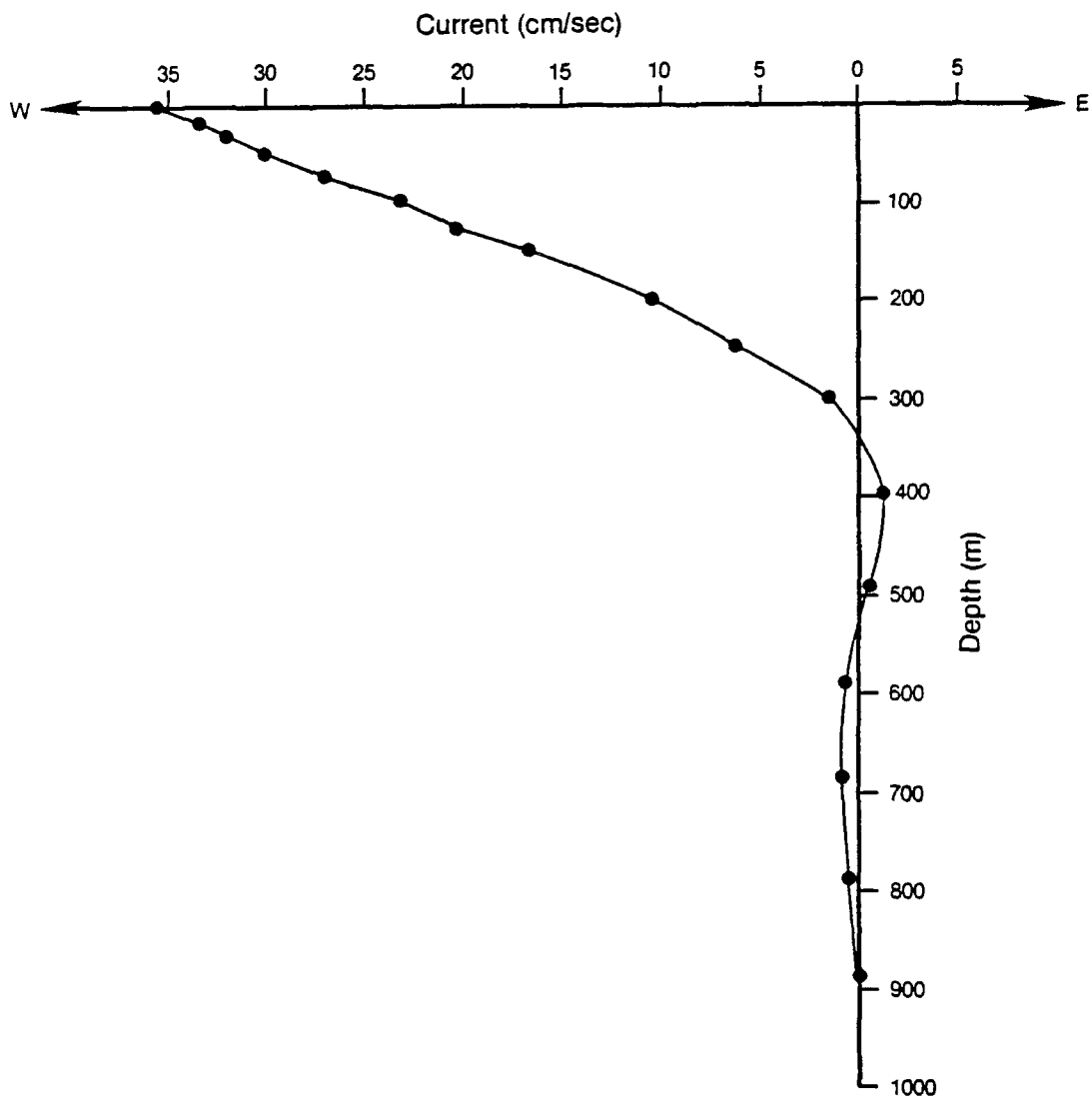


Figure 62. Geostrophic flow profile for a deep-basin area between Stations 91 and 92, Hidalgo Cruise 62-H-3, March, 1972.

indicated, eastward at up to 1.2 cm/sec down to 550 m (1,804 ft), and thereafter again westward at greater depths, but at less than 1 cm/sec.

Biological Characteristics

Open Ocean Environments of the Gulf of Mexico--

In open ocean environments of the Gulf of Mexico, far removed from effects of proximity to land, virtually all primary production is performed by phytoplankton. Due to its dependence on sunlight, phytoplankton production is limited to the upper (< 100 m usually) sunlit layers of the gulf. All other life in these environments is dependent on the fixation of carbon by phytoplankton, and hence production by the phytoplankton is essential to all higher trophic levels. Phytoplankton production in the Gulf of Mexico is primarily limited by the availability of nutrients (especially nitrogen as nitrate or ammonium), which are typically in very low concentrations in the upper 100 m. Nutrients are supplied to the phytoplankton either by upward transport from deeper, nutrient-rich water, or by excretion of animal wastes. As a consequence of the vertical stratification of the water column, the supply of nutrients from deeper waters is slow. Regeneration of nutrients by animals is important, but due to losses from the upper layers (e.g., the sinking of fecal pellets), it cannot completely supply the required nutrients. Since nutrients are in short supply, phytoplankton production in the western Gulf of Mexico is low [290 mg C m^{-2} day^{-1}; El-Sayed and Turner (1974)], and consequently, production at all higher trophic levels is also low, relative to coastal and nearshore areas.

One result of the supply of nutrients from deeper waters is that phytoplankton biomass is often greater deep in the euphotic zone than at shallower depths. Hobson and Lorenzen (1972) reported, for instance, that a subsurface maximum in chlorophyll a concentration (a commonly-used measure of phytoplankton standing stock) was typically found at depths between 50 and 90 m in the Gulf of Mexico. During times when the subsurface chlorophyll maximum was well developed, the top of the pycnocline was often at less than 100 m depth. When the top of the pycnocline was depressed below about 100 m, no subsurface chlorophyll maximum was observed. Hobson and Lorenzen (1972) suggest that these results indicate that the depth of the chlorophyll maximum is influenced by the depth of the pycnocline, and that this association is probably caused by the distribution of nutrients near pycnoclines. This is supported by the data of El-Sayed and Turner (1974), who found that at more than 90 percent of the stations occupied in the Gulf of Mexico and the Caribbean, maximum chlorophyll a concentrations coincided with the depth of the nitrate nutricline. The depths of development of the chlorophyll maximum do not appear to be related to subsurface light intensities (Hobson and Lorenzen 1972).

Hobson and Lorenzen (1972) reported that the phytoplankton in the Gulf of Mexico was dominated numerically by coccolithophores and diatoms, and that numbers of cells decreased with depth even in the presence of subsurface chlorophyll maxima. Thus, it is likely that the cells within these maxima have increased their chlorophyll content, perhaps as a

mechanism of adapting to the lower light intensities. Other authors (e.g., Hulburt and Corwin 1972) have also noted the dominance of the Gulf of Mexico phytoplankton by coccolithophores, notably Coccolithus huxleyi. The fact that phytoplankton of the open Gulf of Mexico were predominantly small was verified by El-Sayed and Turner (1974), who reported that nanoplankton (cells < 20 um in diameter) contributed 83 percent of the total chlorophyll and 84 percent of the primary productivity in these waters. Hulburt and Corwin (1972) noted, however, that phytoplankton were more abundant over the continental shelves of the Gulf, and that diatoms were the dominant phytoplankton near shore. They suggested that the nutrient-poor water offshore "can support only the coccolithophorid type of flora." Diatoms are also the dominant phytoplankton near the Mississippi River delta (Simmons and Thomas 1962).

Oceanic phytoplankton are primarily consumed by zooplankton, many of which filter these small cells from the seawater. Since body-size of the grazer is often smaller when the food is predominantly small, oceanic zooplankton are typically small relative to those in coastal and nearshore areas. This is especially true in the Gulf of Mexico, where, as indicated above, small coccolithophores are the dominant phytoplankton. Iverson and Hopkins (1981) reported, for instance, that microzooplankton, collected in the central Gulf of Mexico by filtering the contents of water bottles through a 30-um gauze, averaged 10 times the number and one-third the biomass of the larger zooplankton sampled with a 162-um net. Near the surface, small calanoid copepods predominate, while at intermediate depths, larger calanoid copepods and euphausiids are abundant (Iverson and Hopkins 1981). While many zooplankton species inhabit the euphotic zone, others perform diel vertical migrations which bring them into the euphotic zone only at night. Iverson and Hopkins (1981) reported, for instance, that increases in zooplankton biomass in the upper 50 m at night and in the 300-600 m zone in the day were likely the result of such migrations. Zooplankton occur at all depths throughout the water column in the Gulf of Mexico, but those occurring below about 200 m are almost exclusively carnivores and/or detritivores.

All animals larger than zooplankton which inhabit the water column are classified as nekton. This group includes not only fishes, but squid, shrimp, whales, dolphins, etc. Common fishes occurring near the surface in Gulf of Mexico waters include flying fishes, white (Tetrapturus albidus) and blue (Makaira nigricans) marlins, dolphins (Coryphaena hippurus), sailfish (Istiophorus platypterus), spearfish (Tetrapturus pfluegeri), and yellowfin (Thunnus albacares) and bluefin (T. thynnus) tunas. Marine mammals of the Gulf of Mexico include various whale and dolphin species. The larger nekton species are generally strong swimmers which range over large areas of the oceans and are not restricted to a single geographic area. Because primary production is low in the open waters of the Gulf of Mexico, and because these larger species of nekton are a number of trophic levels removed from the primary producers, they are quite rare considering the total expanse of the Gulf of Mexico. Nevertheless, certain species (e.g., tunas) are known to school, and consequently they may be abundant in a given area for a short period of time.

Many small nektonic species in the Gulf of Mexico inhabit mesopelagic depths (100-1,000 m), and many of these perform diel vertical migrations into the epipelagic zone (< 100 m) (cf. Hopkins and Baird 1975, 1977). While these species are widespread, individuals of these species are not as wide-ranging as those of the larger, epipelagic species.

With the notable exception of flying fishes, which attach their eggs to floating objects, most pelagic fish species lay and fertilize their eggs in the sea itself. The eggs and larvae, collectively referred to as ichthyoplankton, are carried about by the currents. The larvae are typically very small, and dependent on plankton for food.

Benthic animals, including both organisms living in and on the sea floor and demersal organisms swimming just above the sea floor, are entirely dependent on the production of organic matter in the overlying waters. Organic matter is transported to the benthos in the deep Gulf of Mexico by sinking carcasses, fecal material, exoskeletons, and detritus, and by the vertical migrations of some nektonic species. Since the supply of organic matter is inversely related to the distance from the surface, and since primary production in the Gulf of Mexico is low, deep benthic life there is sparse by comparison to benthic communities in shallow, nearshore areas (Rowe and Menzel 1971). Rowe and Menzel (1971) found that the infaunal biomass (expressed in terms of wet weight, dry weight, animal numbers, and organic carbon) in the Gulf of Mexico decreased exponentially with increasing depth. Animal abundance and biomass are quite low on the Sigsbee Abyssal Plain, about one-tenth the values observed at comparable depths on the Atlantic Continental rise (Thistle and Lewis 1981). The Sigsbee Abyssal Plain, with depths in excess of 3,700 m, has been formed with sediments from the Mississippi River. During the last glacial period (Wisconsin stage), sediment accumulated on the plain at the rate of about 60 cm/1,000 yr. In the past 10,000 yr (since the end of the last glacial period) sediment has accumulated more slowly (about 8 cm/1,000 yr) (Gross 1977).

Thistle and Lewis (1981) indicate that the quantitative structure, energetics, and physical and biological control mechanisms of benthic communities in the deep Gulf of Mexico are largely unknown. It seems likely, however, that the benthic organisms in the deep Gulf of Mexico are similar to those in the other deep oceans of the world. Hence, these organisms are likely to be either large, mobile scavengers able to locate and utilize large organic "windfalls" such as carcasses, or very small (less than a few millimeters in length) and not very mobile organisms living on or in the sediments.

Outer Continental Shelf Environments of the Western Gulf of Mexico--

The productivity of the nearshore waters of the western Gulf of Mexico is influenced by the discharge of water both from the Mississippi River and from the Texas rivers. Near the mouth of the Mississippi, phytoplankton photosynthesis may be depressed by high turbidity, but at greater distances offshore (to 80 km), enhancement of phytoplankton production (as evidenced by elevated chlorophyll concentrations) apparently occurs (Riley 1938). The south Texas shelf can be divided into several zones, based on the source of

freshwater runoff (Kamykowski and Van Baalen 1979). The nearshore zone (to 26 km from shore) is influenced solely by runoff from the Texas rivers, while an offshore zone (59-70 km from shore) is influenced solely by Mississippi River water. Between these zones (26-59 km from shore), two mixing zones occur: an inner zone of primarily Texas river water, and an outer zone of primarily Mississippi River water. Beyond 59 km from shore, increases in surface chlorophyll appear to be correlated with decreases in salinity. Inshore, phytoplankton biomass undergoes a strong seasonal cycle, but the magnitude of the seasonal changes decreases with distance from shore.

Whereas the open waters of the Gulf of Mexico are dominated by nanoplankton, especially coccolithophores, the shelf waters are dominated by netplankton, notably diatoms (cf. Hulburt and Corwin 1972). Changes in the abundance of netplankton are largely responsible for the seasonal cycles in phytoplankton abundance nearshore (Kamykowski and Van Baalen 1979).

It has been suggested (Iverson and Hopkins 1981) that the Mexican Current (a western boundary current in the Gulf of Mexico analogous to the Gulf Stream but smaller in size) may enhance phytoplankton productivity along its western edge by cross-stream transport of nutrient-rich water into the euphotic zone. This supposition requires further study for verification, however.

Zooplankton collected over the Texas continental shelf with 233-um mesh nets were dominated by copepods (Park 1975, 1976; as cited by Iverson and Hopkins 1981). The dominant species varied with distance from shore; calanoid copepods (e.g., Paracalanus, Clausocalanus, and Acartia) were abundant nearshore, while cyclopoid copepods (e.g., Farranula, Oithona, Oncaea) contributed significantly over the outer shelf. Other abundant groups included ostracods, mollusks, chaetognaths, and larvaceans. Zooplankton abundance and biomass decreased, and species diversity increased, with increasing distance from shore. As for phytoplankton, zooplankton abundances had the greatest seasonal variations nearshore, and these variations decreased with distance from the shore. Radiolarians were important components of the microzooplankton over the Texas shelf (Casey 1976, as cited by Iverson and Hopkins 1981).

Some pelagic fishes of the open Gulf of Mexico are also common in waters over the continental shelf (e.g., dolphin); other abundant pelagic fishes may be more or less confined to coastal waters [e.g., Spanish (Scomberomorus maculatus) and king (S. cavalla) mackerels, bluefish (Pomatomus saltatrix), little tunny (Euthynnus alletteratus); (cf. Gulf of Mexico and South Atlantic Fishery Management Councils 1981). Some marine mammals [notably bottlenose dolphins (Tursiops truncatus)] are largely confined to coastal waters in the Gulf of Mexico.

Due to the relatively shallow water column over the continental shelf, there is essentially no mesopelagic fauna there.

Benthic communities on the continental shelf of the western Gulf of Mexico are generally separated into three distinct communities, whose

boundaries are delineated by type of substrate, water depth, and distance from shore. The soft-bottom communities are separated into white-shrimp (Penaeus setiferus) grounds (shore to approximately 22 m depth) and brown-shrimp (P. aztecus) grounds (22 m to at least 90 m depth, and perhaps farther offshore) (Hildebrand 1954). Each has its own characteristic invertebrate and fish faunas. Nearshore disposal of manganese nodule processing wastes is not considered to be a viable option along the Gulf coast, and therefore the discussion of soft-bottom benthic communities which follows will be limited to the brown-shrimp grounds of the outer shelf. Along the seaward margin of the continental shelf of the western Gulf of Mexico are found a series of hard-bottom banks or reefs, which have a fauna distinct from the surrounding soft-bottom communities (Bright et al., 1981).

Due in part to the commercial importance of the brown shrimp, considerable attention has been given to studying the benthic macrofauna of the brown-shrimp grounds. Included are studies of both the epibenthic macroinvertebrates (cf. Hildebrand 1954) and the demersal fishes (cf. Chittenden and McEachran 1976). While these studies have concentrated on waters less than 110 m depth, little work has been done on the benthic communities between 110 m and the edge of the continental shelf (about 182 m). Chittenden and McEachran (1976) contend, however, that since only a narrow portion of the shelf lies between 110-182 m depth, the area may only represent a transition zone between the brown-shrimp grounds and the communities of the upper continental slope. Although the epibentic macroinvertebrates of the brown-shrimp grounds are reasonably well-known, little work has been done on the benthic infauna, especially the meiofauna (Thistle and Lewis 1981).

Hildebrand (1954) reported that the dominant invertebrates of the brown-shrimp grounds included the brown shrimp, a crab (Callinectes danae), a bivalve (Pitar cordata), a conch (Busycon contrarium), and a starfish (Astropecten antillensis). He also listed the characteristic demersal fishes as being a flounder (Syacium gunterii) and the butterfish (Poronotus triacanthus). Hildebrand's (1954) study was confined to the inshore portion of the brown-shrimp grounds, however, and since species diversity tends to increase with depth across the shelf (Chittenden and Moore 1977), it is not surprising that other demersal fish species are more abundant farther offshore. Chittenden and Moore (1977) report, for instance, that the three most abundant demersal fishes at 110 m depth were the longspine porgy (Stenotomus caprinus), the wenchman (Pristipomoides aquilonaris), and the Mexican searobin (Prionotus paralatus).

Fishes characteristic of the brown-shrimp grounds are less likely to be dependent on the estuaries for spawning and/or nursery purposes than are the fishes characteristic of the white-shrimp grounds inshore (Chittenden and McEachran 1976). The brown-shrimp grounds represent a more stable environment, less subject to temperature or salinity variations, than the white-shrimp grounds, and consequently it is not surprising that species diversity is higher on the brown-shrimp grounds. Seasonal variations in abundance are also less pronounced on the brown-shrimp grounds.

The type of substrate obviously plays a large role in determining the type of fauna found in a given area. Williams (1958) found that shrimp actively select the type of substrate they are associated with; white and brown shrimps are found on the terrigenous muds common along the Texas and Louisiana coasts, while pink shrimp (Penaeus duorarum) occur over calcareous substrates (e.g., on the Campeche Bank north of the Yucatan Peninsula). The fact that shrimps select the type of substrate they are associated with may be of critical importance when considering possible implications of the disposal of manganese nodule processing wastes on the shelf. Chittenden and McEachran (1976) suggest that the fish characteristic of each area may also be influenced by substrate type.

As mentioned above, hard-bottom communities exist on a series of banks occurring on the seaward half of the continental shelf in the western Gulf of Mexico. Bright (1977) has grouped these banks into three categories based on their biota and depth of origin. The first group includes banks originating in 50-60 m of water and cresting at depths of less than 25 m. The biota of these banks is dominated by fire coral (Millepora alcicornis) and various sponges. Banks representative of this group include Stetson and Sonnier Banks south of Louisiana (Bright et al., 1981). The second group includes a number of banks which do not rise as close to the surface as banks of the other two groups. The biota of these banks includes antipatharian black corals (Cirripathes spp.), encrusting coralline algae, and gorgonians. Banks representative of this group include the South Texas Banks off the southern Texas coast (Bright et al., 1981). The third group includes banks originating at depths of 100-200 m, and is typified by the East and West Flower Garden Banks south of Louisiana. These two banks bear the most complete and complex coral communities on the northwestern Gulf of Mexico continental shelf (Bright et al., 1981). They are, however, climatologically near the limits of existence for many of the resident species, and at least partially isolated from the gene pool. Bright et al. (1981) suggest that because of this geographical separation, they are susceptible to collapse should the existing populations be destroyed. These banks are of particular research interest because the biotic zonation at the Flower Gardens has been described as one of the most extensive of all Gulf of Mexico banks (Bright et al., 1981). Potential threats to these reefs already include increased oil and gas drilling in the area, their close proximity to major shipping lanes, and increased recreational use. The possible disposal of manganese nodule processing wastes in this area would likely pose another threat to their continued existence.

The topographic relief of the aforementioned reefs and banks is important habitat for various tropical reef fishes. These include snappers (Lutjanidae), groupers and sea basses (Serranidae), tilefishes (Branchiostegidae), jacks (Carangidae), triggerfishes (Ballistidae), wrasses (Labridae), grunts (Pomadasyidae), and porgies (Sparidae). Chittenden and McEachran (1976) suggest that as for the corals, the northwestern Gulf of Mexico is a near-marginal environment for many of these fishes, and that species least tolerant of lowered winter temperatures may be absent from the northern Gulf.

Nearshore Environments of the Western Gulf of Mexico--

As mentioned above, nearshore disposal of manganese nodule processing wastes is not considered to be a viable option along the Gulf Coast. Consequently, nearshore environments of this area will not be discussed herein.

Western Gulf of Mexico Fisheries--

Fisheries considered in this section occur in the western half of the Gulf of Mexico, which lies off the coasts of Louisiana and Texas. The gulf's continental shelf is the primary fishing area. The waters of the north central gulf which include fishing areas for shrimp (Penaeus spp.), menhaden (Brevoortia patronus), and bottomfish species may be considered "among the most productive fishing grounds in the world" (Thompson and Arnold 1971). Gulf fisheries currently account for approximately 25 to 37 percent by weight of the total U.S. landings (Pequegnat et al., 1978). Estuaries are an integral part of the life cycles of many of the economically important fish species in this region. It is estimated that more than 90 percent of the U.S. gulf commercial catch is made up of species that spend part or all of their lives in estuarine areas (Thompson and Arnold 1971). Moreover, nearly all of the gulf coast catch, including most of the menhaden, is made within a few miles of the coast (Pequegnat et al., 1978). Among the important commercial fishes, only groupers and red snappers (Lutjanus campechanus) are caught beyond the 12-mi limit; combined they constitute only about 1 percent of the volume and 2 percent of the value of the total gulf catch (Pequegnat et al., 1978).

In 1980, Texas and Louisiana commercial landings totaled 684,833 mt, valued at $331.9 million (Resource Statistics Division 1981). Landings from the two states represented 77 percent of the entire gulf catch and accounted for 72 percent of the total gulf landing value during 1980.

Approximately 75 percent of the gulf fish catch is used for fishmeal, oil, or other processed products (Thompson and Arnold 1971). The most valuable gulf fishery is for the various shrimp species (Thompson and Arnold 1971). The gulf shrimp fisheries account for 67 percent of the catch by weight and 83 percent of the ex-vessel value of U.S. shrimp landings (GMFMC 1980a).

Fishing Areas--Brown shrimp (Penaeus aztecus) fishing grounds are located along the Texas and Louisiana coasts. The fishery occurs in depths to 91 m, but is generally conducted in waters of less than 55 m (GMFMC 1980a). The annual catch of brown shrimp for the entire gulf during 1959-1975 averaged 27,397 mt (GMFMC 1980a).

Fishing areas for white shrimp (Penaeus setiferus) occur primarily along the Louisiana coast and in the Campeche Bank area off the Yucatan Peninsula. This is a shallow water fishery generally conducted at depths less than 27 m. The largest U.S. catches occur in the area west of the Mississippi River to Freeport, Texas (GMFMC 1980a). Annual landings of gulf white shrimp during 1959-1975 averaged 14,878 mt (GMFMC 1980a).

Minor fisheries for royal red shrimp (Hymenopenaeus robustus) and seabobs (Xiphopenaeus kroyeri) also occur in the western gulf. The deepwater royal red shrimp are harvested at depths of 183 to 549 m in the area southeast of the Mississippi River Delta (GMFMC 1980a). During 1959-1975, annual gulf landings of royal red shrimp averaged 376 mt (GMFMC 1980a).

Seabobs are caught incidentally to other shrimp fisheries in waters shallower than 13 m primarily off the Louisiana coast (GMFMC 1980a). Annual gulf landings of seabobs during 1959-1975 averaged 635 mt (GMFMC 1980a).

The average annual ex-vessel value of the gulf shrimp fisheries during 1970-1977 was $183.5 million (GMFMC 1980a). Texas accounts for 42 percent of the average shrimp catch value, followed by Louisiana at 36 percent (GMFMC 1980a). Brown shrimp is the most valuable species, accounting for 56 percent of the average shrimp catch value during 1968-1977, followed by white shrimp which contributed 30 percent (GMFMC 1980a).

The densest concentrations of groundfish occur in the inner shelf areas of the gulf (depths less than 64 m) over silty-clay substrates (GMFMC 1981). The principal fishing grounds for species utilized in the production of fish meal, oil and other processed products occur east of the Mississippi delta (GMFMC 1981). Atlantic croaker (Micropogon undulatus) is the target species for this fishery, accounting for 69 percent by weight of the catch (GMFMC 1981).

The commercial groundfish food fishery is centered near Southwest Pass, Louisiana, in water depths of 9 to 36 m (GMFMC 1981). The important species include Atlantic croaker, spot (Leiostomus xanthurus), sand seatrout (Cynoscion arenarius), and silver seatrout (C. nothus) (GMFMC 1981). Although not target species, Atlantic cutlassfish (Trichiurus lepturus) and sea catfish (Arius felis) are also abundant in trawl landings.

Total annual landings of groundfishes are approximately 56,000 mt, of which 50,000 mt are utilized for petfood and 6,000 mt for human consumption (GMFMC 1981).

Gulf of Mexico menhaden support the largest domestic fishery in terms of quantity of landings. Although three menhaden species occur in the gulf, a single species, (Brevoortia patronus) comprises over 99 percent of the menhaden catch (Nicholson 1978). The fishery for fishmeal and oil is centered between Empire and Intracoastal City, Louisiana (Nicholson 1978). Between 85 and 90 percent of the purse seine sets are made within 24 km of shore in this area (Nicholson 1978). Over 95 percent of the menhaden catch is comprised of 1- and 2-year old fish.

The Gulf menhaden catch during 1979-1980 averaged 740,724 mt with an average value of over $71 million (Resource Statistics Division 1981). During 1970-1973, over 80 percent of the menhaden catch was made in Louisiana, while Texas landings accounted for approximately 4 percent (Nicholson 1978).

The reef fisheries of the Gulf of Mexico target on demersal snappers (lutjanids, 15 spp.), groupers (serranids, 15 spp.), and seabasses (Centropristis spp.) (GMFMC 1980b). The red snapper (Lutjanus campechanus) is the primary target species along with other Lutjanus spp. in the western gulf. Directed reef fisheries for groupers and the yellowtail snapper (Ocyurus chrysurus) are confined to Florida waters (GMFMC 1980b). The hook and line reef fisheries are conducted in waters overlying the continental shelf (< 183 m depth) (GMFMC 1980b). Productive fishing areas are associated with reefs or reef-like hard bottoms. Overall, the reef fisheries are of lesser importance in the western gulf than in the eastern gulf, where over 87 percent of the reef fish landings occur (GMFMC 1980b). During 1970-1976, gulf commercial reef fish landings have ranged between 7,496 mt (1973) and 8,532 mt (1970), with an average value of $8,013,000 (GMFMC 1980b).

The reef fish stocks in many gulf areas may already be severely depleted due to overexploitation. The Gulf of Mexico Fishery Management Council has designated particular areas as stressed in terms of resource abundance. In the western gulf, the region extending from the Louisiana-Texas state line to the 95° meridian out to the 30 m depth contour is considered a stressed area by the council (GMFMC 1980b).

There is great potential for expanding and/or developing other fisheries in the Gulf of Mexico, High seas pelagic species which could support domestic fisheries include tunas and tuna-like fishes (scombrids), flying fishes (exocoetids), sharks (carcharhinids) and billfishes (Xiphias gladius, istiophorids). Iwamoto (1965) reported that commercially exploitable stocks of four species of tuna [skipjack (Euthynnus pelamis), yellowfin (Thunnus albacares), blackfin (T. atlanticus), bluefin (T. thynnus)] are found in the northern gulf area, especially in waters overlying the continental slope between the 183-m and 1,830-m depth contours. In the northern gulf, sharks and billfishes are abundant in the Mississippi Delta area (Bullis et al., 1971). Coastal pelagic schooling fish such as anchovies (Anchoa spp.) are also abundant but underutilized in the delta region. Gulf shelf bottomfishes (e.g., sciaenids, demersal sharks) and shellfish (e.g., lobsters, crabs, clams) are also abundant and could support major fisheries. At present, the commercial fishery potential of the continental slope of the northern Gulf of Mexico is not being exploited in any systematic way (Pequegnat et al., 1976). Exploratory bottom longlining operations in this area (Nelson and Carpenter 1968) have revealed commercial quantities of fishes [notably tilefish (Lopholatilus chamaeleonticeps) and yellowedge grouper (Epinephelus flavolimbatus)] at depths of 183 to 365 m over the continental slope, especially off the Texas coast.

In summary, the major western Gulf of Mexico fisheries are conducted in relatively nearshore shelf waters. The most valuable domestic fishery for shrimp occurs in the coastal regions of Texas, Louisiana, and Mississippi. The largest U.S. fishery for menhaden is also conducted primarily in the nearshore areas of Louisiana. Therefore, selection of a site for the disposal of manganese nodule processing wastes should include consideration

of potential impacts on these highly productive fishing grounds. Due to the potential importance of currently unexploited fish stocks over the continental slope, the potential impacts of waste disposal there should also be evaluated.

Fishery Biology--The general life cycles of the important gulf shrimp species are similar. Adult brown shrimp spawn during spring through early summer in water depths of less than 18 m. Year-round spawning takes place at depths of 46 to 110 m (GMFMC 1980a). White shrimp typically spawn repeatedly during spring through fall at depths ranging from 7 to 31 m (GMFMC 1980a). Brown and white shrimp larvae are pelagic and are concentrated off the Texas coast. Brown shrimp larvae are abundant during August to November in water depths of 27 m and are also found in large concentrations at depths ranging from 48 to 82 m during September to November (GMFMC 1980a). White shrimp larvae are found in shallower areas (14 m) offshore of Texas during May to August.

It has been suggested that brown shrimp postlarvae burrow into offshore substrates to overwinter prior to entering estuaries (GMFMC 1980a).

Estuaries serve as important nursery areas for brown and white shrimp. Their food consists of detritus, algae, and microfauna (GMFMC 1980a). Juveniles enter the coastal estuaries during spring through early fall. Brown shrimp adults migrate from the estuaries into the gulf fishing grounds from May through November (GMFMC 1980a). The adult white shrimp migration period is somewhat later, occurring during September through November (GMFMC 1980a).

Royal red shrimp and seabobs are not estuarine dependent. The life cycles of these species occur entirely within the offshore waters of the gulf. Royal red shrimp spawn during the winter and spring months and seabobs reproduce during July through December (GMFMC 1980a).

Adult shrimps are opportunistic omnivores and subsist on a variety of plant and animal material. Brown shrimp, white shrimp, and seabobs prefer substrates consisting of soft mud or peat with large amounts of decaying organic matter or vegetation (GMFMC 1980a). Royal red shrimp have no apparent substrate preferences, and are found on sand, silty sand, or calcareous sediments (GMFMC 1980a). Shrimps, once offshore, do not generally display extensive migrations, although some onshore-offshore movements have been documented (GMFMC 1980a).

Many of the groundfish species harvested in the western Gulf of Mexico share common life history characteristics. Spawning occurs in the gulf and early developmental stages inhabit the estuaries (GMFMC 1981). During late juvenile stages, there is an offshore migration. Adults predominate in nearshore coastal areas of the gulf. Highest densities of groundfishes occur over shallow, silty clay regions (GMFMC 1981). Water temperatures influence migratory patterns; adults move shoreward during the summer and retreat offshore during winter months (GMFMC 1981).

Rapid growth and high natural mortality rates are characteristic of most groundfish species (GMFMC 1981). A variety of benthic organisms are preyed upon by groundfishes.

During fall and winter, adult menhaden move offshore to overwinter in inner and mid-shelf areas. It is believed that spawning occurs during this period (Gallaway and Strawn 1974). During the following fall and winter, larvae enter estuaries where they feed on phytoplankton and detritus (Gallaway and Strawn 1974). Adults return to nearshore areas in the spring and are abundant in near surface waters until fall (Gallaway and Strawn 1974).

Similar to juveniles, adult menhaden are also planktivores, feeding primarily on phytoplankton.

Little specific life history information is available for reef fishes. For red snapper, the major species in the fishery, spawning occurs on the gulf shelf during June to October (GMFMC 1980b). Adult red snapper are found in areas associated with coral reefs or limestone outcroppings (GMFMC 1980b). During the winter, adults congregate at depths of 30 to 65 m. An inshore movement occurs during the summer to depths of 20 to 30 m (GMFMC 1980b). Extensive migrations have not been demonstrated for red snapper; older, larger fish tend to be distributed in deepwater areas to the edge of the continental shelf (GMFMC 1980b).

Shrimp grounds are nursery areas for juvenile croakers, which occur in depths of 10 to 35 m over sand or mud substrates (GMFMC 1980b). Juveniles primarily forage on shrimp. Adult croakers are presumed to be bottom feeders taking a variety of fishes and squid.

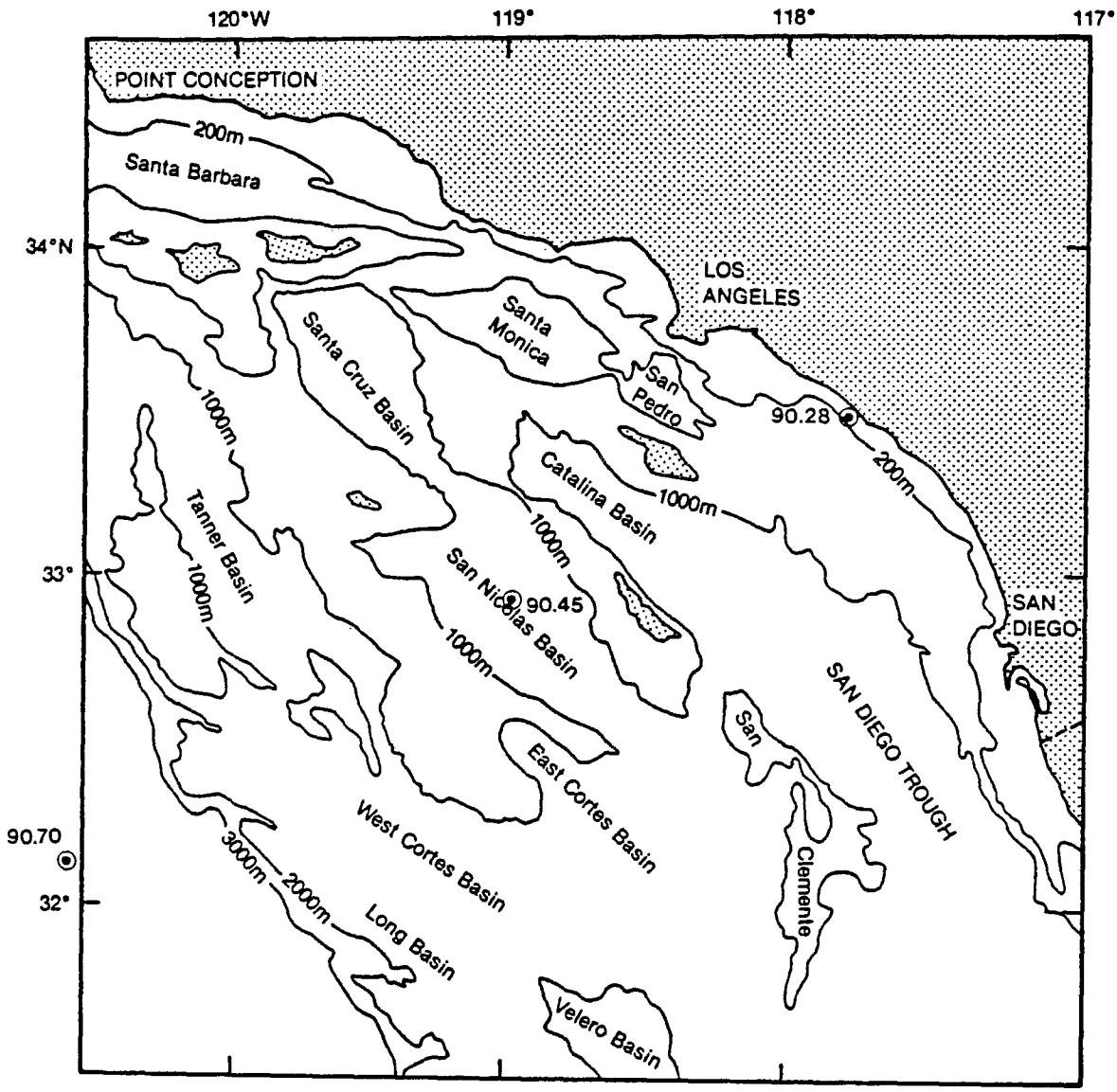
Summary--Common characteristics of the species of economic importance in the western Gulf of Mexico include shelf spawning, pelagic larvae, and estuarine nursery areas. Due in part to the commercial importance of the gulf fisheries and their almost total dependence on coastal and estuarine waters, nearshore disposal of manganese wastes is not contemplated for the gulf area. However, it is important that the shelf spawning areas and the distribution of pelagic larvae be considered in selecting an offshore waste disposal site in the gulf.

The productive habitats of the commercial species must also be considered prior to selecting a disposal method and location. Special consideration should be given to shrimp and groundfish fishing areas as well as regions including coral reefs or limestone outcroppings, which are important to reef fishes.

SOUTHERN CALIFORNIA BIGHT

Physical Characteristics

The southern California Bight, which extends from the California-Mexico boundary northward to Point Conception (Figure 63) is morphologically classed as a continental borderland. The profile of this type of



REFERENCE: Uchupi and Emery, 1963.

Figure 63. The southern California Bight.

continental margin is much more irregular than the marginal plateau, shelf-rise and marginal depression types of margins which also exist along the western coast of North America (Figure 64). The southern California continental margin consists of a very narrow shelf down to approximately the 100 m (328 ft) depth, a limited basin slope, a relatively wide borderland having a series of basins and interbasin ridges, and a true continental slope which extends to the deep-sea floor. Within the borderland there are more than 20 basins extending as deep as 3,000 m (9,842 ft) separated by submarine ridges, banks, and islands which reach elevations of 500 m (1,640 ft) above sea level (Uchupi and Emery 1963). The basins contain thick sediment fills whereas the higher areas consist of sedimentary, igneous, and metamorphic rocks. Shelves around the islands and along the mainland coast resemble typical continental shelves except for being much narrower. A number of submarine canyons cut across the shelf providing pathways for offshore transport of coastal sediments. The seaward boundary of the borderland province is distinguishable by a continental slope followed by an 8 to 20 km (4.3 to 10.8 nmi) wide ridge at depths of 400 to 1,600 m (1,312 to 5,249 ft). Beyond the ridge the topography deepens abruptly, dropping to the ocean basin at 3,400 to 3,800 m (1.8 to 2.1 nmi).

Bathymetry--

Continental Shelf--The Bight continental shelf ranges in width from about 1 to 23 km (0.54 to 12.4 nmi), averaging 6.5 km (3.5 nmi) and extends down to a depth of approximately 200 m (656 ft). Maximum widths of greater than 12 km (6.5 nmi) occur at four places; the U.S.-Mexican border, San Pedro Bay, Santa Monica Bay, and east of Santa Barbara (Figure 63). Although each area is at the mouth of a river, the added width cannot be attributed to delta formation since rocky bottom prevails at each site. Irregular rocky bottom, present at many places on the mainland shelf, is even more common on the island shelves, and is most abundant on the flat bank tops. In addition to these rocky areas, the shelves and bank tops have a series of step-like terraces similar to those on adjacent land areas (Emery 1960).

The southern California coast has been dynamically active throughout its history. Seismic activity and sea level changes have changed the position and shape of the coastal area significantly. Upland erosion has contributed vast quantities of sediments to the coastal waters with ultimate deposition in the deep basins. The detrital material is afforded passageway to the deeper areas via numerous canyons incising the mainland shelf. Major submarine canyons in the southern California Bight include Scripps, La Jolla, San Gabriel, Redondo, Santa Monica, Dume, Mugu, and Hueneme. Of all the sediments of the mainland shelf, those composed of detrital fragments are by far the most common, and an estimated 80 percent of the shelf surface is covered by such sand-sized sediments.

Continental Slope--Off southern California the continental slope descends from an outer deep ridge of the borderlands to a depth of about 3,400 to 3,800 m (1.8 to 2.1 nmi) (Uchupi and Emery 1963). Much of the slope is continuous from the crest of the ridge down to the continental rise. However, in some areas it is discontinuous, with breaks marked by

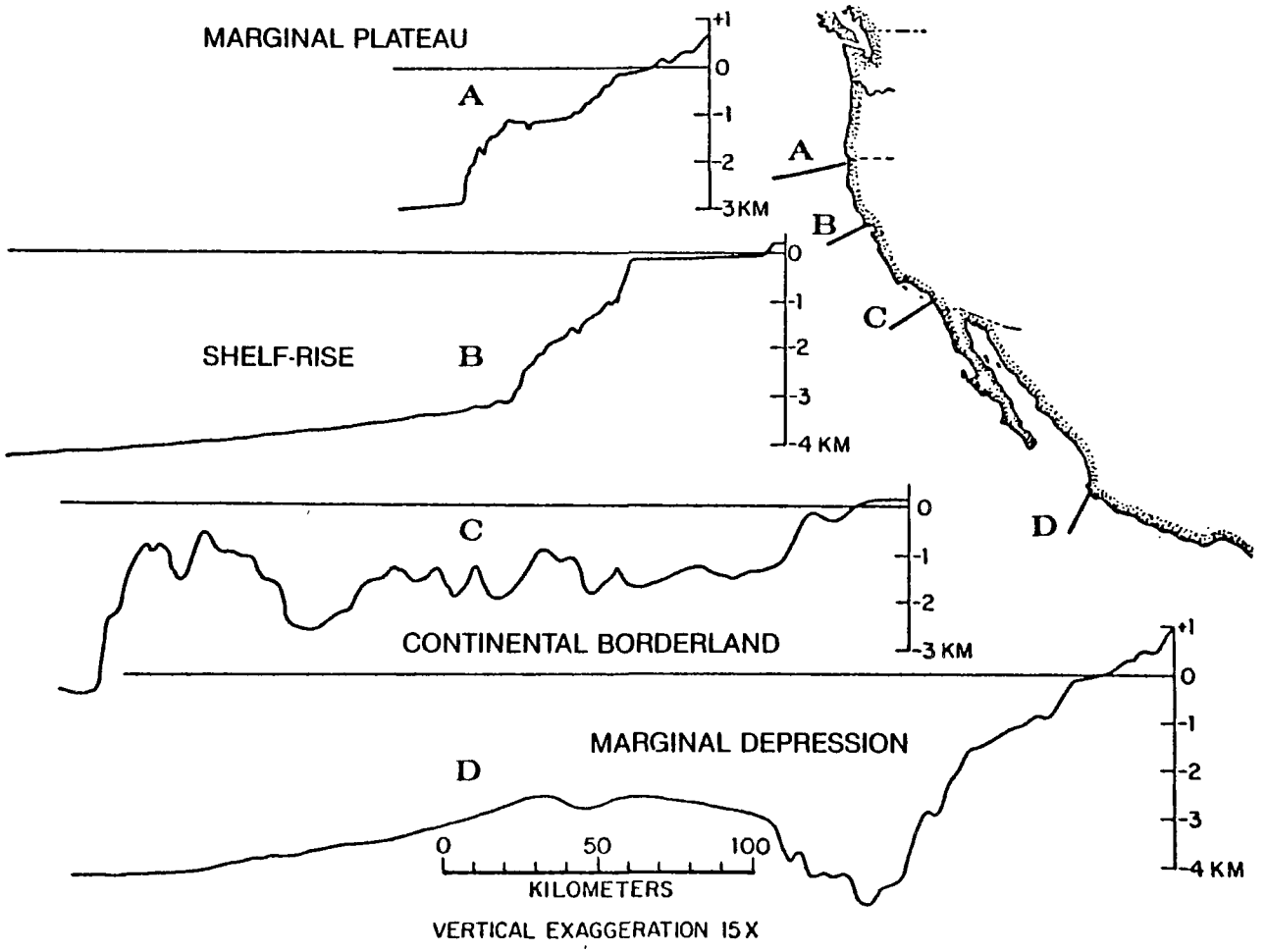


Figure 64. Profiles illustrating morphological types of continental margins off of western North America.

spur-like ridges which are 50 to 100 m (164 to 328 ft) high. The continental slope in this region has an average width of about 10 km (5.4 nmi) and its gradient ranges from 10^{o} to 17^{o}, averaging about 12^{o}. The slope has a northwest trend and is in line with slopes in regions to the north and south. Submarine canyons have not been recognized on the slope although several gaps and offsets are present.

Continental Rise--The rise off southern California is poorly developed or missing, and its position at the slope's base is occupied by a shallow marginal trench. Where present, the rise is only a few tens of kilometers wide and is very irregular. In this region the surface of the rise is broken by three seamounts, only the largest of which (San Juan) has been surveyed and named. It is 33 km (17.8 nmi) long, 3,000 m (9,842 ft) high, and oriented in a northeasterly direction. Deep-sea channels are also present on the continental rise but are not common.

Abyssal Sea Floor--The topography of the abyssal sea floor off California is of diastrophic origin (volcanic, faulting, and folding) except where sediments have blanketed it (Emery 1960). South of Point Conception, bottom smoothness ceases and the topography is highly irregular due to sediment from the land being intercepted by the basins of the continental borderland. Numerous seamounts are also present on the abyssal floor. One of these, San Juan Seamount (near 33^{o}N, 121^{o}W), has the appearance of a volcano; however, others have flat tops. Since erosion is virtually nonexistent on the abyssal floor, the flat tops suggest planing off during a lower relative stand of the sea.

Circulation Patterns--

In the north Pacific Ocean, strong westerly winds at high latitudes move the water eastward, and the strong and constant trade winds farther south push the water westward. Both the winds and the water in the north Pacific Ocean go through a large clockwise circulation pattern called the North Pacific Gyre. The northern limb of the Gyre feeds the southward flow along the west coast of the United States. Beneath this flow and concentrated over the continental slope is a northward flow. These two currents essentially form the California Current System.

There is some confusion in nomenclature used for the currents comprising the California Current System. Following Hickey's (1979a) convention, the California Current refers to the southward flow, the California Undercurrent refers to the northward flow at intermediate depths over the continental slope, and the Davidson Current refers to the northward surface flow that occurs north of Point Conception during the fall and winter. The Southern California Countercurrent refers to the northward flow which is found south of Point Conception, inshore of the Channel Islands in the California Bight. Thus, the California Current System is comprised of the southward California Current and the northward flowing California Undercurrent, Davidson Current, and the Southern California Countercurrent.

California Current--The title "California Current" applies to all southward flows in the North Pacific Gyre adjacent to the west coast of the

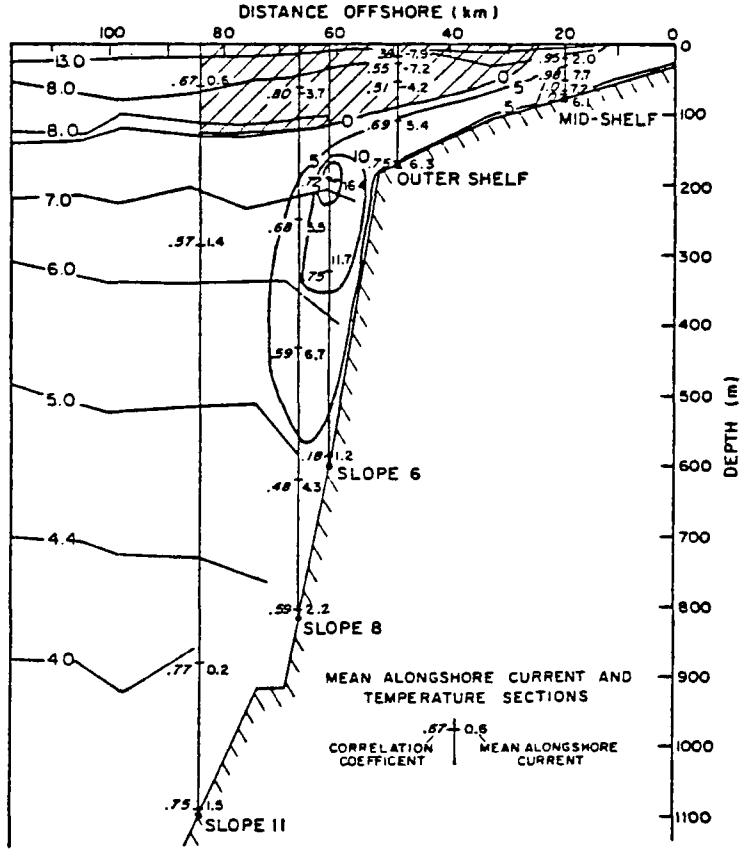
United States (Reid et al., 1968). It is a broad [500 to 1,000 km (270 to 540 nmi)], weak (5 to 10 cm/sec), southflowing eastern boundary current extending from Washington to Baja California. Reid (1965) states that it has become common to arbitrarily define the western boundary of the California Current at a distance of 1,000 km (540 nmi) from shore. The water carried south by the California Current is cooler than the waters farther offshore and is also characterized by its low salinity, high oxygen, and high phosphate.

At most latitudes, there exist two regions of strong southward flow. The nearshore region is most fully developed in spring and early summer south of Cape Blanco. The offshore region is most fully developed in late summer or fall. Its mean annual location appears to be about 430 km (232 nmi) from the coast off Cape Mendocino and 270 km (146 nmi) off Point Conception. South of Point Conception, the offshore region of southward flow moves somewhat closer to the coast so that off Cape San Lazaro, Mexico, the nearshore and offshore regions of southward flow are not usually distinct (based on available data). From Cape Mendocino southward, a second offshore region of strong southward flow occurs year-round. The region moves closer to shore toward the south, being 850 km (459 nmi) offshore at Cape Mendocino and 500 km (270 nmi) off Cape San Lazaro.

California Undercurrent--The California Undercurrent flows northward below the California Current, at intermediate depths beneath the pynocline and seaward of the continental shelf. It is much narrower [approximately 50 km (27 nmi) in width] than the overlying southward-flowing California Current. The Undercurrent is sometimes referred to as the California Countercurrent, which should not be confused with the Southern California Counter Current discussed in the following section. The Undercurrent, which is believed to have the Equatorial Pacific water mass as its source, is characterized by high temperature, salinity, and phosphate concentrations, but is low in dissolved oxygen.

The observations of the California Undercurrent have been made all along the coast through development of dynamic topographies and by direct current measurements (Hickey 1979a). Reid and Schwartzlose (1962) first presented the evidence that the northward flow might have a relatively narrow, high speed core. Drogue measurements along lines at 30^{o}N and 36^{o}N have indicated a northward flow with widths of 30 to 70 km (16 to 38 nmi), and maximum speeds of 15 to 20 cm/sec. The measurements of Wooster and Jones (1970) indicated an undercurrent jet in August, 1966, off northern Baja California. The jet at between 200 and 500 m (656 and 1,640 ft) had a width of about 20 km (10.8 nmi), a thickness of 300 m (984 ft), and an average speed of 30 cm/sec. A similar jet (Figure 65) was observed with direct current measurements off Washington during July-September (Hickey 1979a). The width over the slope was 20 km (10.8 nmi), the thickness was about 200 m (656 ft), and the maximum current speed at the core was 16 cm/sec.

Southern California Counter Current--Flow in the region from Point Conception to San Diego has been described in terms of the Southern California Eddy (Schwartzlose 1963), or Countercurrent (Sverdrup and Fleming



REFERENCE: Hickey, 1979a.

Figure 65. Current meter data averaged from July 21 to August 28, velocity units are in cm/sec. Regions of southward flow are shaded.

1941). Generally, the flow is referred to as a countercurrent only when northward flow extends north around Point Conception (Reid 1965). When the mainstream of the California Current approaches the coast, some of the water turns southward and some northward, so that an "eddy" is formed north of Point Conception. The southernmost tip of the eddy can reach as far south as San Diego. The seasonal and spatial variations in the flow have been intensively investigated through dynamic topography development (Wyllie 1966) and by current measurements (Schwartzlose 1963). Dynamic height data indicate that northward flow is found in the upper half of the California Bight except during April, and in the lower half of the Bight except from January to May. The northward flow is fed by the mainstream of the California Current which turns eastward near 32°N. The axis of the eddy usually occurs several hundred kilometers offshore, roughly in line with the coastline north of Point Conception.

Northward flow in the Bight is sometimes continuous with the Davidson Current, particularly during winter months when the term countercurrent rather than eddy is commonly used to describe it. However, the relative infrequency with which drift bottles released in the Bight are retrieved north of Point Conception suggests that the northward flow usually contributes the majority of its volume to recirculation in the California Current. Drift bottle data also suggest that a wind-driven coastal current occurs inshore of the northward flow that forms the eddy.

Representative Areas

The physical oceanographic characteristics of three southern California Bight disposal areas are presented in the following section; a shelf/canyon area, a borderland basin area, and finally a deep ocean basin area. The information presented represents a synthesis of data obtained by review of a large number of references (Table 53).

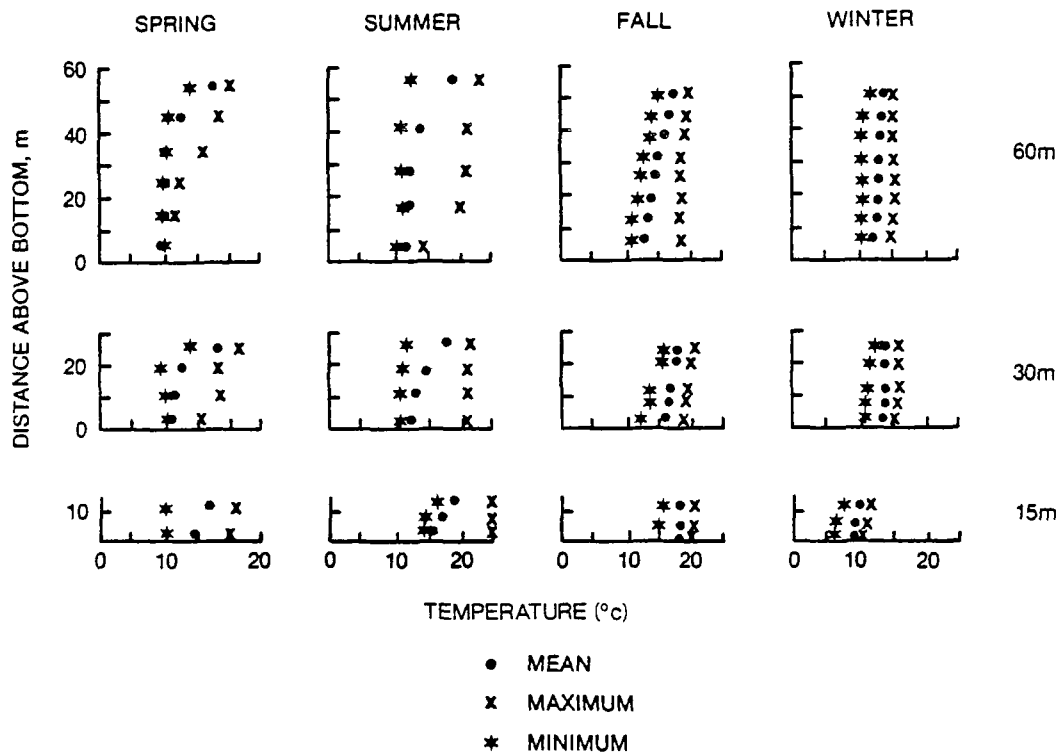
Shelf/Canyon--

Shelf temperature profiles determine the local density structure much more than salinity, and change markedly from season to season (Figure 66). In summer there is a shallow warm layer which rarely exceeds 5 m (16 ft) in thickness, followed by a 20 m (66 ft) thermocline having a gradient of 0.25°C per meter, and an isothermal (10°C) bottom layer. In the winter, the difference between the mean surface and bottom temperatures is significantly reduced to 2.3°C, being only slightly colder at the bottom. Below 20 m (66 ft), the normal winter cooling is reversed, a common feature on the west coast shelf (Huyer 1977). The average shelf temperature is 15°C during the summer and 13.6°C during the winter.

Horizontal currents on the Southern California continental shelf are variable, having root mean square changes in a few hours to 10 days which typically exceed the seasonally averaged mean values. Typical speeds observed on the nearshore shelf are from 7 to 10 cm/sec, but can vary between no current and 50 cm/sec (Hendricks 1975). During spring and summer, when the water column is thermally stratified, surface and bottom currents may be opposed, whereas during fall and winter, the water column is less stratified and the flow structure is more unidirectional (Figure 67).

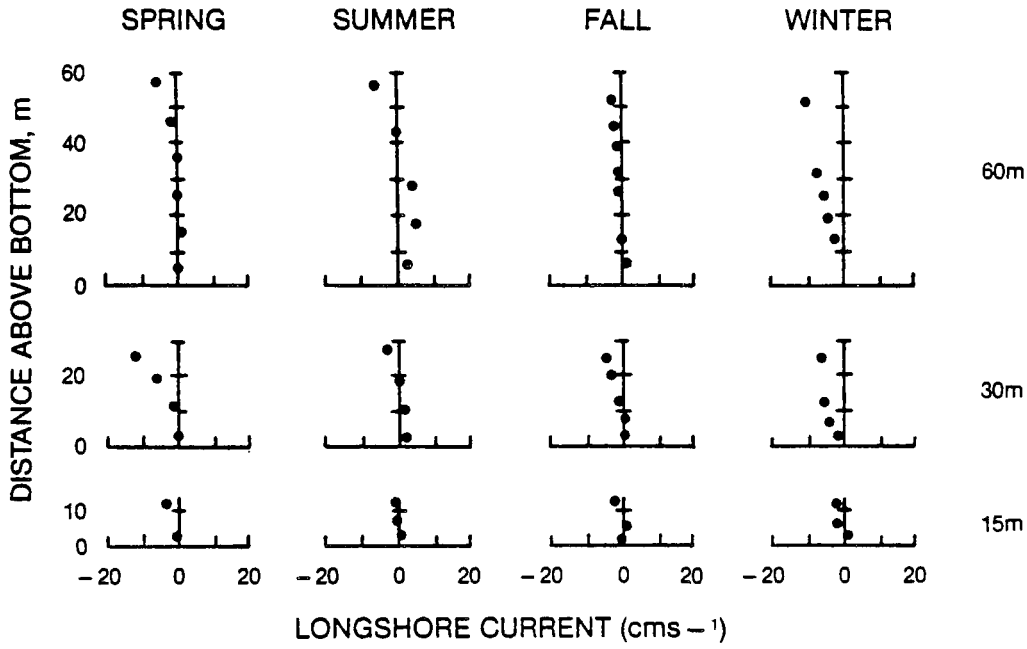
TABLE 53. REFERENCES REVIEWED TO COMPILE PHYSICAL OCEANOGRAPHIC INFORMATION ON CHARACTERISTIC DISPOSAL AREAS IN THE SOUTHERN CALIFORNIA BIGHT

Dodimead et al., 1963
Wyllie 1966
Uchupi and Emergy 1963
Emery 1960
Hickey 1979a
Reid et al., 1968
Reid 1965
Reid and Schwartzlose 1962
Wooster and Jones 1970
Hickey 1979b
Sverdrup and Fleming 1941
Schwartzlose 1963
Huyer 1977
Winant and Bratkovich 1981
Hendricks 1975
Hendricks 1980
Wyllie and Lynn 1971



REFERENCE: Winant and Bratkovich, 1981.

Figure 66. Mean, maximum, and minimum temperatures at each depth and during each deployment on the southern California Shelf.



REFERENCE: Winant and Bratkovich, 1981.

Figure 67. Distribution of mean longshore currents on the southern California Shelf. A positive value corresponds to a current to the north.

Mean surface currents in all seasons sweep to the south. At their weakest during the fall they still exceed 2 cm/sec. Although the current structure has been found to be similar in 60, 30, and 15 m (197, 98, and 49 ft) of water, the amplitude of mean currents is substantially reduced at shallower stations.

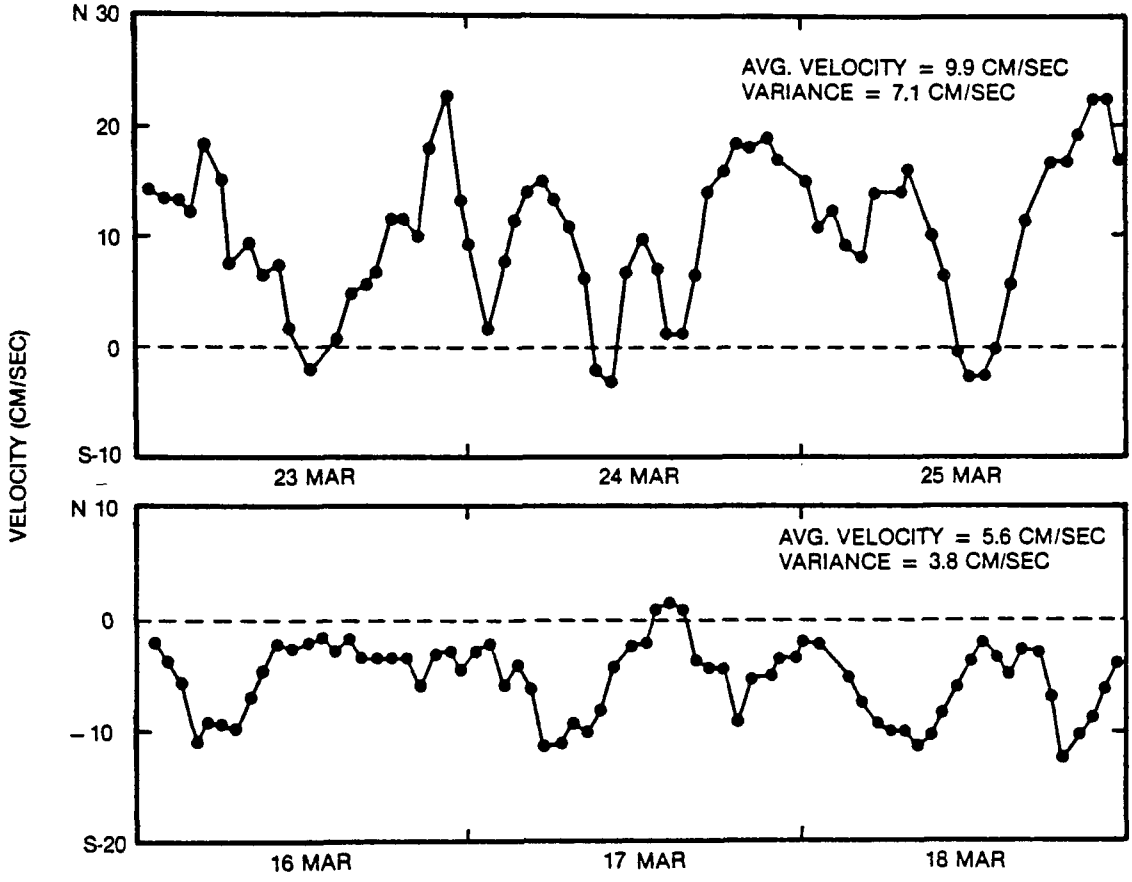
The largest vertical shear in mean longshore velocities occurs during the summer. During this season the near-surface currents [measured 4 m (13 ft) beneath the surface in 60 m (197 ft) of water] have been oriented downcoast (southward) with a velocity of 6.2 cm/sec, whereas 28 m (92 ft) deeper the mean current was reversed, with an upcoast velocity of 4.1 cm/sec. The velocity difference over the entire water column is reduced to 5 cm/sec at the 30 m (98 ft) location, and to 1 cm/sec at the 15 m (49 ft) location. Cross-shelf current measurements averaged over a relatively short period of deployment were within error of zero for each instrumented location. The observations are thus unable to resolve any mean cross-shelf circulation patterns associated with upwellings and downwellings. The temporal variability in along-shore currents can be significant, however. Hendricks (1975) reports amplitude changes of greater than 20 cm/sec within a day, and significant differences in average 3-day velocities within a week's time (Figure 68). Median speeds at the 41 m (135 ft) depth have been measured at 10.7 cm/sec in Santa Monica Bay and 9.4 cm/sec off the Palos Verdes peninsula (Hendricks 1980). Figure 69 presents a measured velocity distribution for shelf, canyon, and slope stations in the California Bight.

Canyon flows are expected to differ from those of the nearby shelf due to the channeling effect of the canyon walls. Higher axial current speeds occur near the heads of submarine canyons at a more frequent interval than at other bottom sites. Persistent down canyon flows have been measured (average 5.5 cm/sec) for as much as 22 days. About 5 percent of the time, speeds have exceeded 27 cm/sec, which is sufficiently strong to resuspend organically enriched sediments. It should be noted that upcanyon movement can occur as well. Although a downcanyon speed of 3.8 cm/sec was observed at the 384 m (1,260 ft) depth of the Santa Monica Canyon one year, during another, net movement was upcanyon at 3.3 cm/sec at the 168 m (550 ft) depth. Periodic turbidity currents are known to flush accumulated bottom material down canyon axes and into basin or outer shelf areas.

Background dissolved oxygen (DO) levels at a shelf disposal site will be similar to that at the shoreward CalCOFI line 9 station (90.28) located in approximately 200 m (656 ft) of water (see Figure 70). Surface values remain fairly constant near 8.6 mg/l during the spring months, decreasing to 7.9 mg/l in the winter. At 100 m (328 ft), however, the dissolved oxygen values are much lower, ranging from an April minimum of 2.5 to 3.0 ml/l to a high in December of 4.0 ml/l. At 200 m (656 ft), dissolved oxygen concentrations below 2.0 ml/l have been recorded between February and August.

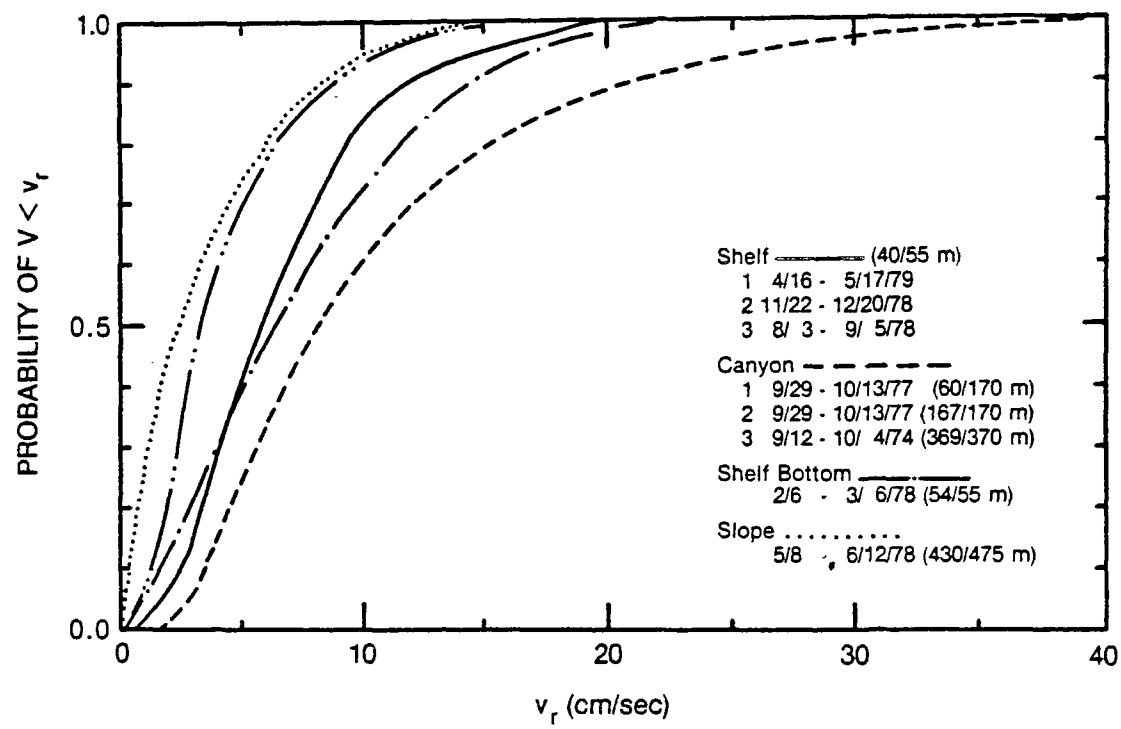
Borderland Basin--

CalCOFI Station 90.45 which is in 900 m (2,953 ft) of water is representative of basin disposal locations within the California Bight.



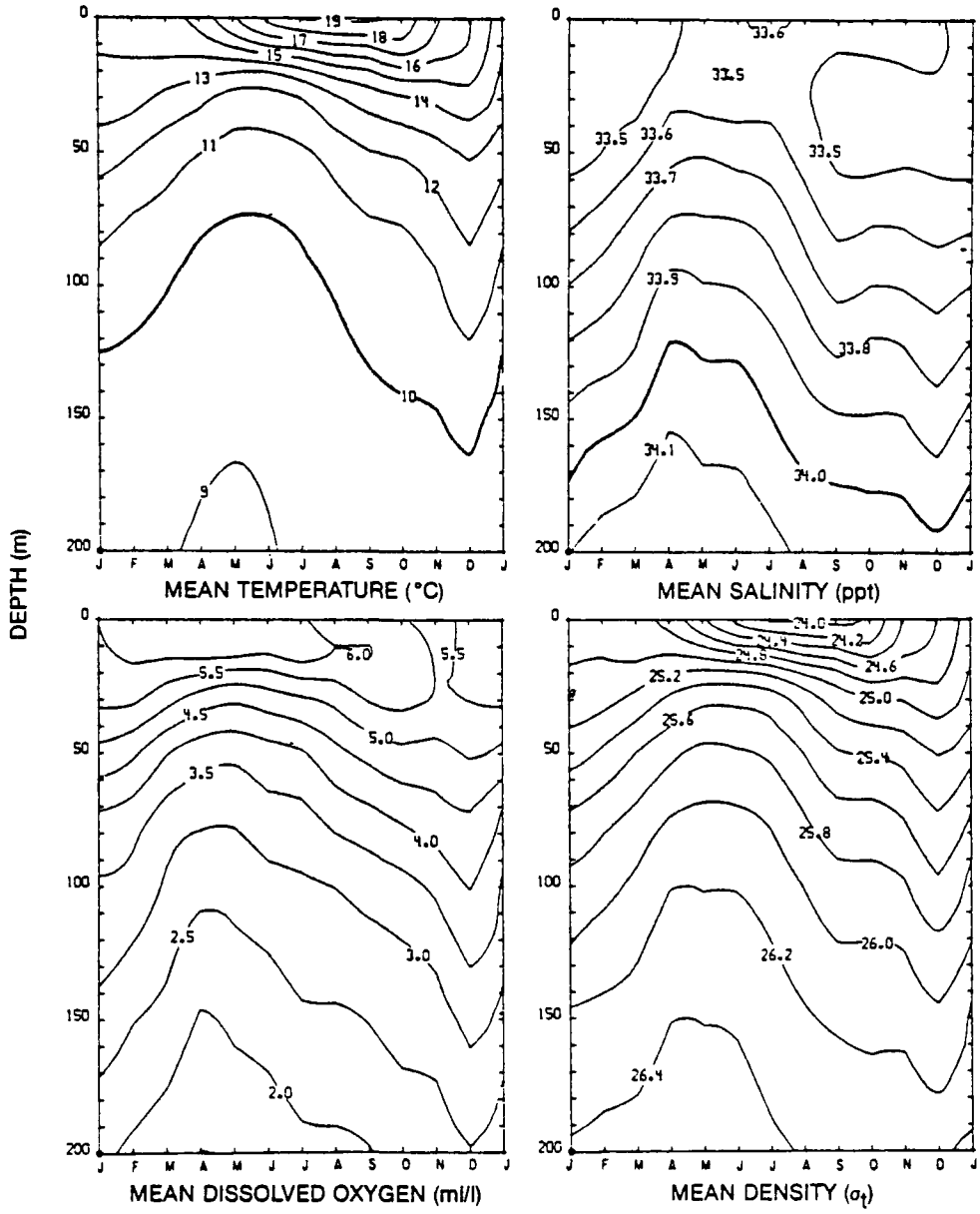
REFERENCE: Hendricks, 1980.

Figure 68. Alongshore current at 40-m depth (55-m water depth) off Point Loma, March, 1975, showing considerably different flow conditions only a week apart.



REFERENCE: Hendricks, 1980.

Figure 69. Distribution of current speeds - southern California canyon, slope, and near-bottom.



NOTE: 1ml/l = 1.428 mg/1

REFERENCE: CALCOFI Atlas No. 25

Figure 70. Annual temperature, salinity, dissolved oxygen, and density distributions in the upper 200 m at CalCOFI Station 90.28.

Annual variations in the mean temperature, salinity, density, and dissolved oxygen expected at such a site are presented in Figure 71.

Surface temperatures typically range from 19°C in August to as low as 14.5°C in January. A pronounced spring thermocline forms at 10 to 20 m (33 to 66 ft) as at shelf stations, and tends to persist through October. The salinity distribution in contrast is relatively uniform in the upper 50 m (164 ft), increasing somewhat beyond the 100 m (328 ft) depth. The characteristic density profile exhibits a strong density gradient associated with ambient temperature, following the same pattern as temperature but in reverse magnitude. A very strong density gradient forms in the spring, becomes maximum [sigma-t difference is 1.0 from 10 to 30 m (33 to 98 ft) depths] in the summer and dissipates in the fall. Dissolved oxygen values are a maximum near the surface (7.8 mg/l), decrease with depth, and are relatively constant in the upper 50 m (164 ft) throughout the year. At 100 m (328 ft) and greater depths, a relatively pronounced DO minimum occurs during June, gradually returning to maximum values in December and January. Concentrations below 2.1 mg/l have been recorded at depths beyond 300 m (984 ft) as indicated in Figure 72.

Dynamic topography contours for surface geostrophic flows relative to flows at 500 m (1,640 ft) (Wyllie 1966) for a mid-Bight location such as Station 90.45 indicate south to southeast flows for February through June, with northerly flows from July to January. Flows at a 200 m (656 ft) depth relative to those at 500 m (1,640 ft) appear to be northward throughout the year except during March and April, when calculated flows become very low. Although monthly mean charts serve only as a guideline, the trend of the southward-flowing California Current moving inshore during April-May and eliminating the Southern California Counter Current at the surface is evident, and may happen briefly even at the 200 m (656 ft) level. Outside of this period, however, flows can be expected to be northward. Dynamic topography charts indicate approximate current speeds of from 0 to 10 cm/sec at the surface, and less than 5 cm/sec at 200 m (656 ft).

Deep Ocean--

The typical physical oceanographic conditions which exist at deep-ocean areas off the California Bight are presented in Figure 73 for CalCOFI Station 90.70. Surface temperatures vary from 17°C between August and October to a low of 14.5°C between January and June. At 100 m (328 ft) the temperature variation is slight, remaining at approximately 10.5°C. Although a thermocline is present, it is far less pronounced than for nearshore stations. Surface salinity concentrations vary little, remaining at 33.4 ppt. An increase of 0.1 ppt is apparent at depths of 100 to 200 m (328 to 656 ft) in October and November. The density profiles appear to follow the water temperature pattern in the upper 50 m (164 ft), and seem to be dependent primarily on salinity variations in waters beyond this depth. The maximum density gradient occurs in September and October. Seasonal density variation at depths below 50 m (164 ft) is small, amounting to approximately 0.2 sigma-t units or less. Dissolved oxygen in the surface waters remains seasonally constant at 7.8 mg/l and decreases approximately 2.9 mg/l per 100 m (328 ft) of depth from 50 to 200 m (164 to 656 ft).

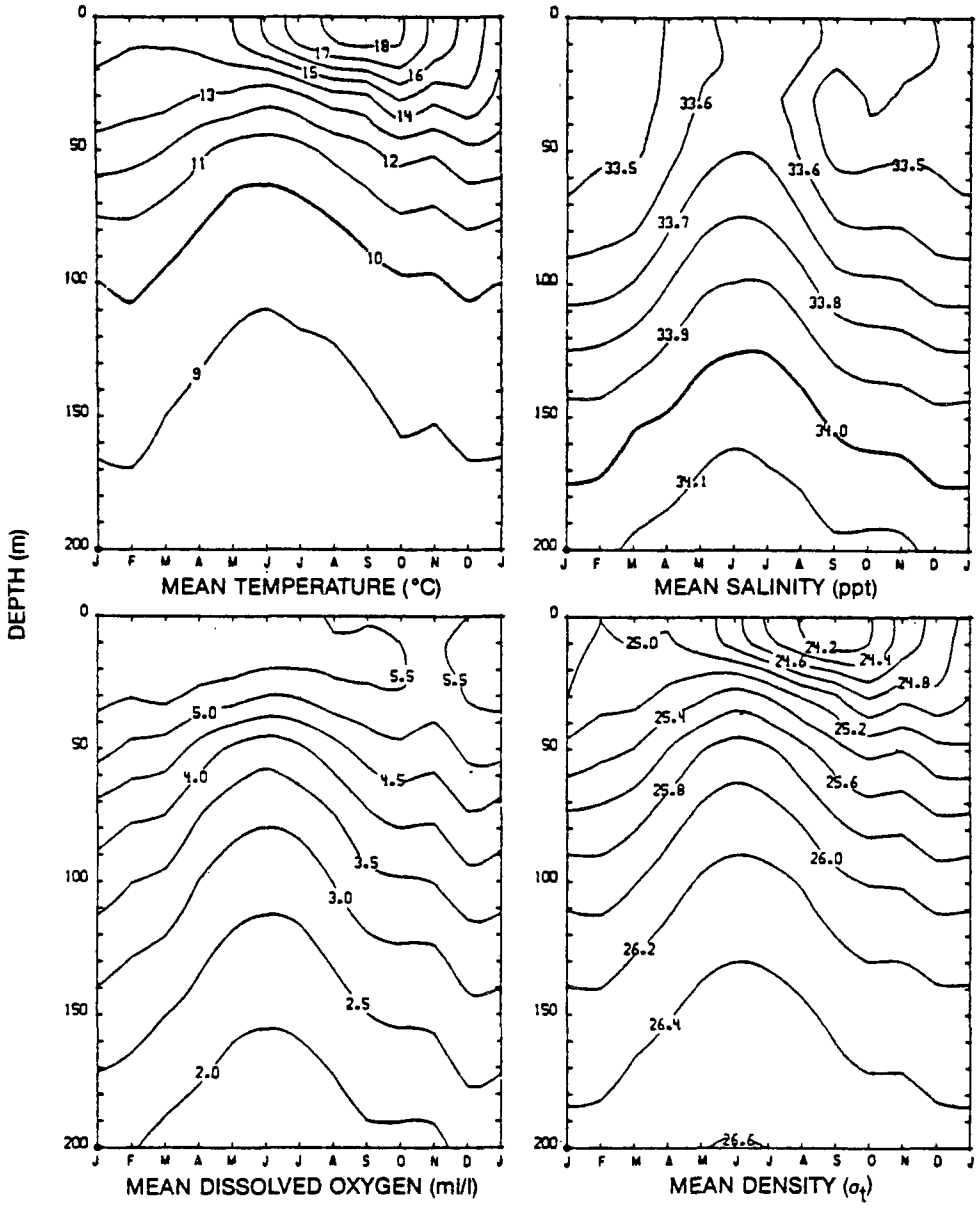


Figure 71. Annual temperature, salinity, dissolved oxygen, and density distributions in the upper 200 m at CalCOFI Station 90.45.

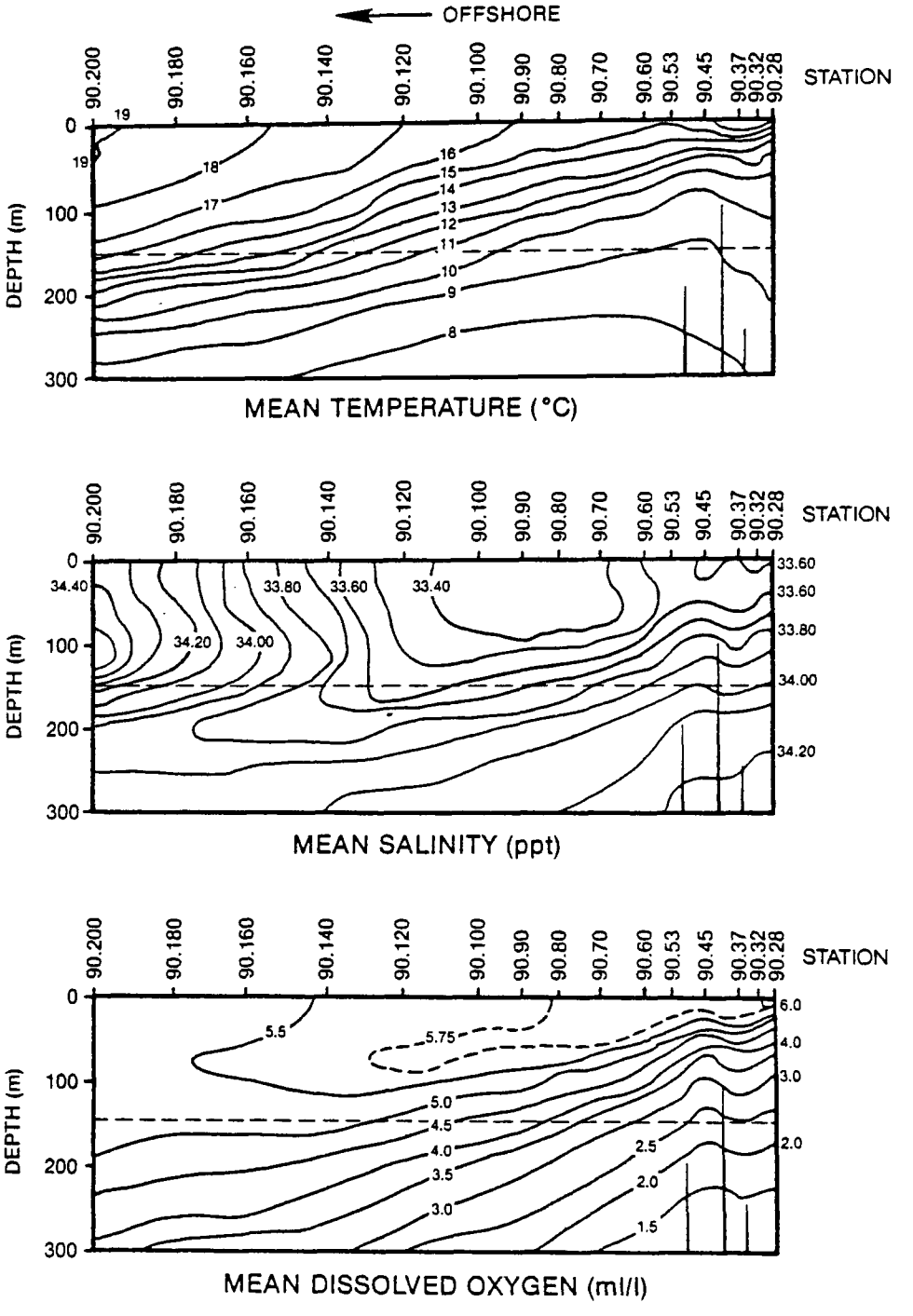
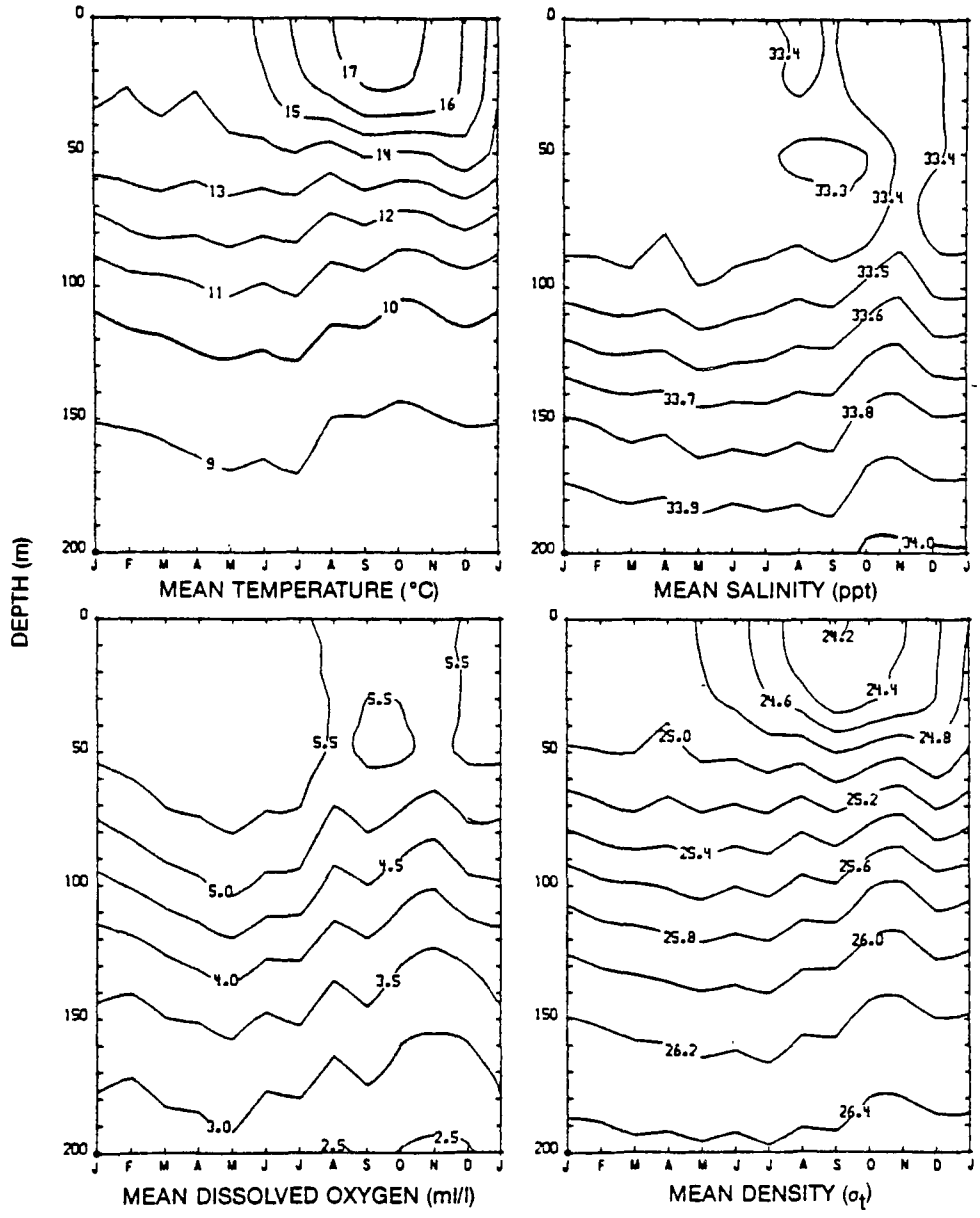


Figure 72. Representative Line 90 vertical sections for temperature, salinity, and dissolved oxygen.



NOTE: 1ml/l = 1.428 mg/l

REFERENCE: CALCOFI Atlas No. 25

Figure 73. Annual temperature, salinity, dissolved oxygen, and density distributions in the upper 200 m at CalCOFI Station 90.70.

There is evidence of slight maxima in May and minima in November. However, the annual range at a given depth is approximately only 1.4 mg/l beyond 75 m (246 ft) deep. At 200 m (656 ft), a value of 3.6 mg/l has been reported. As indicated in Figure 21, values as low as 2.1 mg/l occur at depths beyond 300 m (984 ft). Calculated geostrophic flows at the surface relative to a 500 m (1,640 ft) depth appear to be between 2 and 15 cm/year to the southwest throughout the year. Maximum currents probably occur in the June/July and November/December periods (Wyllie 1966). At 200 m (656 ft) relative to 500 m (1,640 ft) currents, the flows appear to be much weaker, being between 0 and 3 to 4 cm/sec. For much of the year (e.g., August to December) the flow pattern appears to be poorly defined.

Biological Characteristics

Open Ocean Environments off Southern California--

In open ocean environments beyond the continental slope offshore from southern California, virtually all primary production is performed by phytoplankton. Due to its dependence on sunlight, phytoplankton production is limited to the upper (< 100 m) sunlit layers of the ocean in this region. All other life in these environments is dependent on the fixation of carbon by phytoplankton, and hence production by the phytoplankton is essential to all higher trophic levels.

Phytoplankton production in waters of the California Current is apparently not nutrient limited, in spite of strong thermal stratification of the water column and low nitrate concentrations within the euphotic zone (Malone 1971). Nanoplankton (phytoplankton with cells < 22 um in diameter) accounted for 75 to 99 percent of the observed productivity and standing stock in waters of the California Current, and this fraction was remarkably stable geographically (Malone 1971).

In summer, a subsurface chlorophyll maximum is typically found near the base of the euphotic zone, at approximately 100 m depth (Malone 1971). This maximum is primarily due to increases in the nanoplankton fraction, while chlorophyll contained within the netplankton fraction (cells > 22 um in diameter) was relatively uniformly distributed with depth within the euphotic zone (Malone 1971). The position of the subsurface chlorophyll maximum was generally closely associated with the nitrate nutricline, and the shoaling of the chlorophyll maximum at stations nearer the California coast paralleled the upward trend of the isotherms and nitrate isopleths (Malone 1971).

In winter, the subsurface chlorophyll maximum is still present, but at considerably shallower depth (approximately 30 m; cf. Malone 1971). The depths of this maximum was again closely associated with the nitrate nutricline.

The fact that phytoplankton production in California Current waters does not appear to be nutrient limited is likely related to the predominance of nanoplankton over netplankton. Nanoplankton typically have lower half-saturation constants for nitrate uptake (MacIssac and Dugdale 1969;

Eppley et al., 1969), and are therefore able to photosynthesize at higher rates under low nitrate concentrations than can netplankton. In addition, it seems likely that animals grazing on nanoplankton are smaller (e.g., protozoans; cf. Beers and Stewart 1969) than those grazing on netplankton. As a consequence of the short generation times of these small grazers, the coupling between primary productivity and grazing would be much closer for nanoplankton-based food chains than for netplankton-based food chains, and there would be less opportunity for unrestricted growth followed by nutrient limitation (Malone 1971). Overall phytoplankton production is low in the offshore waters of the California Current relative to that in nearshore waters over the continental shelf and the continental slope, where phytoplankton production is enhanced in spring and summer by coastal upwelling (Malone 1971).

Malone (1971) described the nanoplankton fraction of the phytoplankton as being dominated by flagellates, and cited the more detailed observations of Reid et al. (1970) which indicated that the nanoplankton were likely composed primarily of naked dinoflagellates, "monads," and coccolithophores. The netplankton fraction, although a relatively minor portion of the phytoplankton community, was composed almost exclusively of diatoms (Malone 1971).

Zooplankton inhabiting oceanic waters off southern California include species having a variety of faunistic affinities. Investigations of zooplankton communities in the California Current off Baja California (Longhurst 1967) revealed that species characteristic of Pacific Transitional Water, Central Pacific Water, and Tropical Surface Water were all present on occasion. The species characteristic of Pacific Transitional Water are obviously transported into the area by the southward flow of the California Current, while the tropical species are sometimes advected by occasional northward movements of tropical water masses. The Central Pacific Water species are those inhabiting oceanic waters beyond the California Current. Small calanoid copepods (e.g., Paracalanus sp., Pseudocalanus sp.) and cyclopoid copepods (e.g., Oithona similis) are abundant near the surface in oceanic waters off southern California. Arthur (1977) found that the small calanoid copepod, Mecynocera clausii, could be used as an indicator of offshore water masses in this area, as it was not found inshore. Copepod nauplii are particularly abundant in the California Current, and concentrations of these nauplii are important for the successful feeding of many larval fishes (Arthur 1977).

While small calanoid copepods predominate in the euphotic zone, deeper layers are inhabited by larger copepods, euphausiids, and other zooplankton species, some of which perform diel vertical migrations which bring them into the euphotic zone only at night. Zooplankton occur at all depths throughout the water column in the region offshore of southern California, but those occurring below about 200 m are almost exclusively carnivores and/or detritivores.

Common epipelagic fishes of the California Current include sardines (Sardinops sagax), anchovies (Engraulis mordax), jack mackerel (Trachurus symmetricus), sauries (Cololabis saira), and albacore (Thunnus alalunga).

Marine mammals of this area include various whale and porpoise species (cf. Dailey 1974). The larger nekton species are generally strong swimmers which range over large areas of the oceans and are not restricted to a single geographic area. Because these large species of nekton are a number of trophic levels removed from the primary producers, they are quite rare considering the total expanse of the oceans. Nevertheless, certain species (e.g., whales, porpoises, albacore) are known to school, and consequently they may be abundant in a given area for a short period of time.

A number of small nektonic species in the California Current region inhabit mesopelagic depths (100-1,000 m) and some of these perform diel vertical migrations into the epipelagic zone (< 100 m) [cf. Wisner 1976]. While these species are widespread, individuals of these species are not as wide-ranging as those of the larger, epipelagic species.

Most pelagic fish species in waters offshore of southern California lay and fertilize their eggs in the sea itself. The eggs and larvae, collectively referred to as ichthyoplankton, are carried about by the currents. The larvae are typically very small, and dependent on plankton for food (Arthur 1976). The spawning strategies of many of these fishes are dependent on surface drift conditions, and food limitation during critical larval stages of these fishes may regulate their reproductive success (Parrish et al., 1981).

While little specific information is available on deep benthic communities off southern California, it seems likely that the benthic organisms there are similar to those in the other deep oceans of the world. The discussion of benthic animals presented in the Gulf of Mexico section is applicable to southern California.

Oceanic Environments of the Continental Borderland off Southern California--

The complex topography of the sea floor off southern California renders this area relatively unique and has important implications for the biological communities inhabiting the area. The basins, ridges, banks, and islands of the continental borderland encompass attributes of both the deepwater environments farther offshore and the nearshore environments inshore of the borderland.

The standing stock of phytoplankton, as indicated by chlorophyll a, exhibits a typical onshore-offshore gradient in the southern California Bight. Eppley et al. (1978) reported that average concentrations of chlorophyll a within the euphotic zone were generally < 1 mg m^{-3}, except at stations within 3 km of the coast, where concentrations sometimes exceeded 10 mg m^{-3}. These gradients were persistent and not seasonal when based on stocks per m^3, but the gradients were not so apparent when stocks were expressed per m^2. The latter fact is expected because the depth of the euphotic zone increases as one moves offshore (Eppley et al., 1978). Phytoplankton production is apparently limited, except during periods of coastal upwelling, by the availability of fixed nitrogen, primarily as nitrate. The abundance of phytoplankton was inversely related to the depth of the nitrate nutricline (i.e., phytoplankton was most abundant when the

nitrate nutricline was shallowest; Eppley et al., 1978). The depth of the subsurface chlorophyll maximum was closely associated with the depth of the nutricline, and not with a given light level (Eppley et al., 1978). In the offshore waters (> 100 m depth), the depth of the nutricline is influenced by variations in wind speed and direction, with maximum wind-induced upwelling during June (Eppley et al., 1978).

Small flagellates are the dominant phytoplankton in this area, although dinoflagellates and diatoms are also abundant (Reid et al., 1978). Diatoms may become more abundant during periods of coastal upwelling (Malone 1971).

As for the zooplankton farther offshore, the zooplankton inhabiting waters over the continental borderland of southern California represent a transitional fauna which may include representatives of subarctic Pacific waters to the north, Central Pacific waters to the west, and Equatorial Pacific waters to the south, as well as species endemic to the area (Seapy 1974). Abundant calanoid copepods include Calanus pacificus (= helgolandicus), Rhincalanus nasutus, and Labidocera trispinosa (McGinnis 1971), while Oithona similis is the dominant cyclopoid copepod. While many zooplankton species inhabit the euphotic zone, others perform limited (< 200 m) diel vertical migrations which bring them into the euphotic zone only at night. Zooplankton occur at all depths throughout the water column in this area, but those occurring below 200 m are almost exclusively carnivores and/or detritivores.

The epipelagic fishes common to the California Current are also abundant over the continental borderland. Included are sardines, anchovies, jack mackerel, sauries, and albacore. Notable among the marine mammals frequenting the area are the California gray whales (Eschrichtius robustus), which annually migrate between feeding grounds in the Bering Sea and breeding grounds off Baja California.

The deep basins of the California borderland have a resident mesopelagic fish fauna (Ebeling et al., 1971). Many of the mesopelagic fishes make diel vertical migrations into the epipelagic zone where they feed on zooplankton (Anderson 1967).

The California borderland represents a variety of benthic habitats because of the large variations in depth and distance from shore. Shallow-water subtidal habitats may be found as far as 180 km from shore (e.g., Cortes and Tanner Banks; cf. Lewbel et al., 1981), while relatively deep basins (depths in excess of 800 m) may be found within 5 km of shore (e.g., Santa Monica and San Pedro Basins; cf. Jackson et al., 1979).

Shallow-water benthic communities of the California borderland share many species with the shallow-water benthic communities nearshore, to be described below. Lewbel et al. (1981) reported, for instance that the benthic fauna of Cortes and Tanner Banks could be subdivided into two communities: a shallow (< 25 m) community dominated by the southern sea palm (Eisenia arborea), and a deeper (> 30 m) community characterized by encrusting red coralline algae (Lithophyllum proboscideum). Relative species abundances differed from those at comparable depths near the

mainland, however, and there were species notably absent (e.g., the giant kelp, Macrocystis pyrifera).

The benthic infauna on the sea floor of the California borderland exhibit depth-related trends to be expected in any marine benthic habitat. Benthic infaunal abundance, biomass, and number of species all decrease with increasing depth (Mearns et al., 1979). One complicating factor, however, is that the dissolved oxygen concentration in the deep basins may be depressed (< 0.3 mg/l) due to reduced water exchange and organic matter decay in the basins (Jackson et al., 1979). The benthic fauna in these basins is consequently depauperate relative to the fauna at similar depths where oxygen concentrations are higher (Mearns et al., 1979). Invertebrates present include polychaetes, arthropods, echinoderms, mollusks, and coelenterates (Mearns et al., 1979). Basins on the outer shelf have distinctly different faunas than those of the nearshore basins (Hartman and Barnard 1958, 1960). Their faunas are more similar to the continental slope and shallow bottom faunas of the North Pacific (SCCWRP 1973).

Within the basins of the continental borderland is found a diverse demersal fish fauna. Common representatives include longspine thornyhead (Sebastolobus altivelis), California rattail (Nezumia stelgidolepis), shortspine thornyhead (Sebastolobus alascanus), sablefish (Anoplopoma fimbria) and brown cat sharks (Apisturus brunneus) (Mearns et al., 1979). The peak biomass of bottom fishes occurs between 200 and 400 m, while fish diversity remains relatively unchanged from 20 to 610 m (Mearns et al., 1979).

Nearshore Environments of Southern California--

The coastline of southern California includes both rocky headlands and sandy beaches, but relatively few estuarine embayments (e.g., San Diego Bay, Newport Bay). Only the open ocean environments (exclusive of the embayments) will be discussed below. Each represents a unique habitat for marine organisms.

Nearshore phytoplankton communities exhibit a continuation of those trends noted above for phytoplankton further offshore (e.g., onshore-offshore gradients of phytoplankton standing stock and primary productivity, with the highest values of each occurring nearshore). Whereas average concentrations of chlorophyll a within the euphotic zone are typically low offshore (< 1 mg m^{-3}), within 3 km of the coast concentrations sometimes exceed 10 mg m^{-3} (Eppley et al., 1978). Although the depth of the euphotic zone increases with increasing distance offshore (Eppley et al., 1978), integrated primary productivity is still highest near shore [Institute of Marine Resources (1971) and Thomas (1972) report values of 2,460 mg C m^{-2} day^{-1} and 1,972 mg C m^{-2} day^{-1} for nearshore stations over Scripps Canyon and off Camp Pendleton, respectively]. Eppley et al. (1978) demonstrated that the increase in phytoplankton stocks with approach to the shore at depths < 100 m is consistent with Riley's (1967) model which attributes this effect to the increases in vertical eddy diffusivity associated with increased tidal action nearshore.

As in waters farther offshore, phytoplankton production nearshore is apparently limited, except during periods of coastal upwelling, by the availability of fixed nitrogen, primarily as nitrate (Eppley et al., 1978). Phytoplankton production nearshore may be enhanced by tidal action, internal waves (cf. Kamykowski 1973), and coastal upwelling (Eppley et al., 1978).

There is typically a subsurface chlorophyll maximum at depths corresponding to 3-30 percent of surface irradiance, except during periods of strong upwelling (Reid et al., 1978). The subsurface chlorophyll maximum layer is typically found in the thermocline and in the upper portion of the nutricline (Reid et al., 1978). Phytoplankton species within the chlorophyll maximum layer change more abruptly with distance offshore than alongshore, and give the impression of elongate bands of phytoplankton oriented parallel to shore (Reid et al., 1978).

As for the zooplankton farther offshore, the zooplankton inhabiting neritic waters of southern California represent a transitional fauna which may include representatives of Subarctic Pacific waters to the north, Central Pacific waters to the west, and Equatorial Pacific waters to the south, as well as species endemic to the area (Seapy 1974). While many zooplankton species inhabit the euphotic zone, others perform diel vertical migrations which bring them into the euphotic zone only at night. Koslow and Ota (1981) have shown how the presence of nearshore submarine canyons serves to concentrate migratory zooplankton species descending into them.

Abundant pelagic fishes of the southern California nearshore zone include the aforementioned anchovies, sardines, and jack mackerel. The spawning of many of the pelagic fishes of this area is closely linked to the prevailing current regimes (Parrish et al., 1981). Food limitation during critical larval stages may regulate reproductive success. Lasker (1975, 1978) has shown that successful feeding of early anchovy larvae is dependent on concentrations of phytoplankton within chlorophyll maximum layers. Such concentrations persist only in the absence of storm-driven turbulence or strong upwelling. Sardines and jack mackerel spawn during the period of maximum upwelling, and their larvae feed almost exclusively on the early stages of copepods (Arthur 1976). The abundance of copepods is largely dependent on upwelling-related meteorological conditions prior to and during the spawning periods, because upwelling causes increases in primary productivity and results in copepod reproduction (Parrish et al., 1981). Hence, conditions favoring larval survival are quite different for anchovies than for sardines or jack mackerel. Similar relationships are likely to exist for other pelagic species of the southern California nearshore zone.

Certain marine mammals [notably sea otters (*Enhydra lutris*] were once common in nearshore southern California waters, but now are quite rare (Dailey 1974). Resident populations of some pinnipeds [e.g., California sea lion (*Zalophus californianus*), Stellar sea lion (*Eumetopias jubatus*), northern elephant seal (*Mirounga angustirostris*)] are found on some of the offshore islands (Dailey 1974). The California gray whale is the only baleen whale commonly observed within several kilometers of the southern California coast. Several porpoise and dolphin species are abundant in the area and may enter nearshore waters (Dailey 1974).

Rocky shorelines of southern California provide hard substrate for the attachment of benthic algae and many sessile animal species. In certain areas where benthic algae are particularly abundant (e.g., kelp beds), a significant portion of the community primary production may be attributed to these benthic macrophytes. The communities inhabiting these rocky shorelines are complex assemblages of organisms which include representatives of many of those types common on rocky shorelines worldwide [e.g., starfish, limpets, chitons, barnacles, sea urchins, sea anemones, brown and red algae, etc.; cf. Bright (1974)]. In certain areas where there is adequate rocky subtidal habitat, kelp [notably giant kelp (Macrocystis pyrifera)] grows in large quantities and is harvested commercially (cf. Wilson et al., 1978).

Shallow sandy subtidal and sandy intertidal areas of southern California are inhabitated primarily by organisms which burrow into the substrate for protection from wave action and sediment scour (Bright 1974). Sand-bottom areas are subject to considerable seasonal and year-to-year variation, and hence the abundance of organisms at any given location undergoes substantial fluctuations.

A relatively unique feature of nearshore environments in southern California is the presence of submarine canyons which extend from the coastline to deep basins and troughs offshore (SCCWRP 1973). These submarine canyons serve as conduits for the transport of sedimentary material into the deeper waters offshore, and may be considered for the disposal of manganese nodule processing wastes. These canyons contain a unique and varied fauna. Hartman (1963) found that 30-60 percent of the species found in one canyon were not found in adjacent canyons, indicating some degree of isolation (Fay 1972). The indigenous fauna in these canyons must be adapted to widely varying environmental conditions (e.g., shoreward movement of upwelling waters, seaward transport of sedimentary material) which can change quite rapidly (SCCWRP 1973). In general, the diversity and abundance of animals decrease with depth within the canyons, and the benthic biomass there is intermediate between that on the shelf and in the deeper basins of the continental borderland.

Southern California Fisheries--

The fisheries considered in this section occur in the Southern California Bight, an area of about 41,000 to 51,000 km^2, which is bounded to the north by Point Conception and to the south by Point Descanso, Mexico (Mais 1974). Major commercial fisheries conducted in the bight focus on pelagic species such as tuna (Thunnus spp., Euthynnus spp.) and schooling fishes [e.g., northern anchovy (Engraulis mordax), jack mackerel (Trachurus symmetricus)] which are caught with purse seines, gill nets, and hook-and-line gear. The continental shelf is extremely narrow, ranging from 1 to 23 km in width, with the wider areas found in the northern portion of the bight. Because of the limited shelf area and some regulatory limitations, trawl fisheries are not as important in Southern California as in areas to the north (Leet and Cramer 1971).

The main fishing ports in Southern California are Santa Barbara, San Pedro, and San Diego (Leet and Cramer 1971). The latter two areas were the leading U.S. ports in terms of landing values in 1980; $121.9 million for San Pedro, $110.6 million for San Diego. Combined landings at San Pedro and San Diego exceeded 262 million kg in 1980 (National Marine Fisheries Service 1981).

Fishing Areas--The tuna fisheries are the most important in Southern California. The main species which support the tuna industry are yellowfin (Thunnus albacares) and skipjack (Euthynnus pelamis), which are taken off the coasts of Central and South America (Frey 1971). The local fisheries for albacore (Thunnus alalunga) and bluefin (Thunnus thynnus) depend upon these species migrating into the bight.

The albacore fishery is generally conducted 80 to 124 km offshore, beginning in June by trollers and bait boats (Browning 1980). Albacore arrive when offshore water temperatures range between 15.5 and 20^{o} C, and then they continue northward up the coast following the warm water (Frey 1971). Poor year-class strength drastically affects the fishery because 1 and 2 year old fish are the primary age classes taken in the fishery.

Bluefin tuna occurring in the bight are landed by the local purse seine fleet, which also participates in the oil and meal reduction fishery. Bluefin tuna are taken between Baja California and Point Conception during July and August (Frey 1971). The highseas fleet accounts for about 95 percent of the catch of this species.

Pacific bonito (Sarda chiliensis) are primarily taken incidental to the troll and purse seine fisheries for tuna. Bonito's chief importance in Southern California is to the recreational fishery (Frey 1971).

The oil and meal reduction fishery targets primarily on northern anchovy and to a lesser extent on jack mackerel, Pacific mackerel (Scomber japonicus), bonito, bluefin tuna, and squid (Loligo spp.) (PFMC 1978a). The Pacific sardine (Sardinops sagax) and Pacific mackerel were the traditional species supporting the fishery, but these stocks are now extremely depleted (MacCall et al., 1976). Recently, there are indications that Pacific mackerel abundance may be increasing (Klingbeil et al., 1980).

The central anchovy subpopulation is the most abundant of the three west coast stocks. The bulk of the population occurs in the Southern California Bight (PFMC 1978a). The oil and meal reduction fishery is centered in the channel region extending from Santa Barbara - Santa Cruz Island to Santa Catalina Island - Dana Point, an area of approximately 6,800 km^{2} (PFMC 1978a).

The Southern California reduction fishing fleet consists of approximately 25 vessels fishing in the Catalina and Santa Barbara channels (PFMC 1978a). In addition to the reduction fishery, a small live bait industry also harvests anchovies in Southern California. The average annual value of these two fisheries during 1970-1975 amounted to $3.3 million, of which 98 percent was attributed to the reduction fishery (PFMC 1978a).

Over 90 percent of the catch of jack mackerel, the second major species supporting the reduction fishery, is taken in the vicinity of Santa Catalina and San Clemente Islands and on Cortes Bank (Mais 1974).

The market squid (Loligo opalescens) is the major squid species taken in Southern California. The fishery occurs within 4.8 km of shore along the mainland coast and around the channel islands (PFMC 1978b). This fishery begins in December and continues until the squid move northward in spring. Typically, fishermen search the edge of kelp beds for schools of spawning squid. The fishery occurs in depths ranging from 35 to 55 m (PFMC 1978b). Two types of methods are used to harvest squid; purse seines in deeper water areas and a light attraction technique in waters of 24 to 33 m. Average annual landings in California during 1970-1977 were 10,237,580 kg (PFMC 1978b). A large portion of this total was caught in Monterey Bay, however, and not in Southern California. California accounts for 76 percent of the nation's squid catch, which had an average exvessel value during 1970-1976 of $1.4 million (PFMC 1978b). Squid are the most important underutilized species in Southern California, although effort is increasing in the fishery (Mais 1974). Fifty vessels fished squid in 1970, but by 1974, 126 boats participated in the fishery (PFMC 1978b).

The groundfish species of Southern California are of secondary importance in comparison to pelagic fishes. Regulations and the narrow shelf area of the bight confine trawling to the Santa Barbara Channel (Frey 1971). Depending on the target species, trawls are fished from 4.8 km offshore to depths of 457 m (PFMC 1980). Rockfishes (Sebastes spp.) and flatfish such as California halibut (Paralichthys californicus), English sole (Parophrys vetulus), petrale sole (Eopsetta jordani) and rex sole (Glyptocephalus zachirus) are the major species exploited (Frey 1971; PFMC 1980). Minor quantities of lingcod (Ophiodon elongatus) and sablefish (Anoplopoma fimbria) are also taken by trawls. Trawl landings during 1975-1979 averaged 2,696 mt in the International North Pacific Fisheries Commission Conception statistical area which includes the bight (PFMC 1980). California groundfish landings in 1976 were valued at over $11 million (PFMC 1980).

In areas south of Oxnard, trammel nets are usually fished close to shore in shallow water. The primary catch is California halibut, with incidental catches of petrale sole, rex sole, and various rockfishes (Frey 1971).

The rockfish fishery in Southern California is primarily conducted with gill nets and hook-and-line gear (Frey 1971; PFMC 1980). Bocaccio (Sebastes paucispinis), chilipepper (S. goodei), olive rockfish (S. serranoides), and yellowtail rockfish (S. flavidus) are the main species taken (PFMC 1980). Olive rockfish school at depths ranging from 15 to 46 m and are harvested in the vicinity of kelp beds south of Point Conception and also around offshore islands such as Santa Barbara and San Nicolas (Frey 1971).

A pot fishery for sablefish has been rapidly developing since 1978 in Southern California. Landings during 1975-1977 were less than 1,000 mt but by 1979 over 4,000 mt were landed (PFMC 1980).

Miscellaneous fisheries conducted in the bight include those for swordfish (Xiphias gladius), California barracuda (Sphyraena argentea), white seabass (Atractoscion nobilis), white croaker (Genyonemus lineatus), and surfperches (embiotocids). The latter four are generally more important to recreational fisheries than to the commercial industry.

The specialized harpoon swordfish fishery is centered in the channel islands Basin between Point Conception and San Diego (Frey 1971). Major fishing areas are associated with islands, banks, mouths of submarine canyons, and at steep submarine ridges. There is also a small-scale longline fishery for swordfish conducted at the edge of the continental shelf between Cedros Island and Cape San Lucas, Baja California (Frey 1971).

California barracuda are taken with hook-and-line troll gear and gill nets. The fishery occurs primarily during May and June in the vicinity of San Pedro, Santa Barbara, and San Diego in relatively shallow (36 m) shelf waters (Frey 1971). Currently, stocks of barracuda appear to be depleted (MacCall et al., 1976).

White seabass are also fished using gillnets and hook-and-line gear in the coastal waters of the bight (Frey 1971). This is a small fishery with approximately 15 vessels participating (PFMC 1980). MacCall et al. (1976) reported that the stock was already moderately to highly exploited.

The white croaker fishery employs small round nets to harvest this schooling species in inshore areas ranging in depth from 3 to 30 m (Frey 1971).

The two important shellfisheries in Southern California are for spiny lobster (Panulirus interruptus) and abalone (Haliotis spp.). All rocky coastal areas from Point Conception to the U.S.-Mexican border, as well as the islands and banks of the bight, are important fishing areas for lobster (Frey 1971). Most pots are set at depths of less than 18 m; however, in some areas pots are set at depths to 64 m (Frey 1971). In 1969, a total of nearly 140,000 kg of lobster was landed with a value of $300,000 (Frey 1971).

The abalone fishery is centered in the vicinity of kelp beds near the Channel Islands and Santa Barbara. Red (Haliotis rufescens), pink (H. corrugata), white (H. sorenseni), and green (H. fulgens) abalone make up the commercial catch. The fishery is conducted by divers at depths ranging from 8 to 24 m and at times extending to 55 m (Frey 1971).

Squid may support expanded fisheries in the future in Southern California (Mais 1974). Both nearshore and offshore areas appear to be equally productive for this resource. Also, there is potential for growth in the reduction fishery for anchovies and jack mackerel if other markets become established (PFMC 1978a). Similarly, expansion may occur in the groundfish fisheries if markets and processing facilities are developed for currently underutilized species such as sharks, skates, and rays.

In summary, the most important fisheries in the Southern California Bight are for pelagic species such as tuna and those exploited by the reduction fishery. Groundfish fisheries are generally of less importance because of the limited extent of the continental shelf and some regulatory limitations. It may not be desirable to dispose of manganese nodule wastes in the area of existing trawling grounds off Santa Barbara. The highly mobile nature of the pelagic species and the wide areas over which the fisheries are conducted make it extremely difficult to predict potential impacts which may be associated with waste disposal.

Fish Biology--Albacore and bluefin tuna are seasonal migrants into the bight whose abundance is influenced by water temperatures and the availability of forage species (Frey 1971). The fishery exploits immature fish, primarily 1 and 2 year olds. In the bight, these tunas feed on pelagic organisms such as anchovies, squid, and euphausiids.

Northern anchovies spawn during late winter in the upper water layers south of San Pedro when water temperatures of 10 to 23.3^{o} C occur (PFMC 1978a; Hart 1973). Their pelagic eggs hatch within 2 to 4 days (Hart 1973). Both eggs and larvae have been encountered as far as 480 km offshore; however, greatest densities generally occur inshore (Hart 1973; PFMC 1978a). Anchovy year class strength is directly associated with larval habitat conditions. Favorable conditions for larvae include dense plankton blooms of edible and nutritious organisms (PFMC 1978a). Plankton production relies on upwelling, the timing and extent of which is influenced by wind patterns. Severe storms which interfere with upwelling conditions are sufficient to cause poor larval survival.

In the Southern California Bight, anchovies are widely distributed from shore to 157 km. Greatest abundance is usually within 37 km of shore over deepwater (> 183 m) basins (PFMC 1978a). Adult fish have been found to depths of 300 m. The most common schooling behavior for anchovies is the formation of small, very low density aggregations in near-surface waters during the day (PFMC 1978a). At night, the schools disperse widely throughout the surface layer. Longshore anchovy migrations between southern and central California have been documented, and onshore-offshore movements are common. Adults tend to remain farthest offshore (PFMC 1978a). Anchovies have been described as "indiscriminate filter feeders," taking both zooplankton and phytoplankton (Frey 1971). Small fishes may also provide a portion of the diet.

Jack mackerel spawning populations occur offshore between Point Conception and Cape San Quintin with peak spawning during March to July (Frey 1971). Females may spawn more than once during the season (Frey 1971). Their pelagic eggs hatch in 4 to 5 days. Jack mackerel eggs are among the most abundant fish eggs collected in Southern California plankton surveys (Frey 1971). Small juveniles are widely distributed from 9 to 111 km offshore where near-surface schooling occurs over deepwater basins (Mais 1974). Adult jack mackerels school at depths ranging from 9 to 73 m (Mais 1974). Commercial concentrations are found only in very specific locations with particular types of habitat. Preferred habitats include relatively shallow (9 to 55 m) rocky banks, rocky perimeters of offshore islands, and

rocky coastal areas associated with kelp beds (Mais 1974). Jack mackerel are known to conduct onshore-offshore migrations. Juveniles move inshore from the offshore spawning regions, and the adults return to oceanic areas as they mature (Frey 1971). Coastal migrations between California and Baja California also occur (Frey 1971). Prey items include copepods, pteropods, euphausiids, juvenile squid, and anchovies (Frey 1971).

Pacific bonito are a pelagic schooling species inhabiting the waters of the continental shelf, primarily between Point Conception and Magdalena Bay in Baja California (Frey 1971). Pelagic eggs, spawned during January to May, hatch in 3 days (Frey 1971). Little information is available concerning the migratory patterns of this species. Bonito feed on pelagic species including sardines, anchovies, and squid (Hart 1973).

In January and February, spawning squid congregate in semi-protected bays over sand bottoms in Southern California (PFMC 1978b). Fall spawning is also known to occur during some years. Egg capsules are attached to the substrate and hatching occurs within 3 to 4 weeks (PFMC 1978b). Squid feed on small fishes, shrimp, and other squid (Frey 1971). Little information is available on migratory patterns of squid. General offshore movements occur, followed by inshore spawning migrations. Squid of all sizes are found throughout the year in nearshore waters, however (PFMC 1978b).

The biological aspects of groundfish species are discussed in the section characterizing the Pacific Northwest fisheries. Only the species which are of particular importance in the Southern California fisheries will be considered here.

California halibut spawn during February to July in waters ranging in depth from 5 to 18 m (Frey 1971). Demersal eggs are produced but larval and post-larval stages are pelagic prior to undergoing metamorphosis and settling on the bottom. Northern anchovies are the primary forage species although octopus, white croaker, and queenfish (Seriphus politus) are also taken (Frey 1971). Based on tagging studies, juvenile halibut do not undertake extensive migrations although adults may; onshore-offshore movements are known to occur (Frey 1971).

English sole spawn during October to May in the Santa Barbara Channel and in Santa Monica Bay (Frey 1971). Both eggs and larvae are pelagic. Important nursery areas for English sole include protected inshore locations such as embayments and estuaries. Benthic food items predominate in the diet and include segmented worms, clams, and small starfish (Frey 1971). English sole display extensive migrations in California coastal waters (Frey 1971).

Petrale sole spawn in deepwater (274 to 366 m) basins during the winter months (Frey 1971). Pelagic eggs are produced. Important food items include euphausiids, shrimp, anchovies, and other small fishes (Frey 1971).

The four principal rockfish species in Southern California are bocaccio, chilipepper, olive, and yellowtail. These are ovoviviparous species which produce pelagic larvae. Spawning periods for these species

include the months of November through March. Leet and Cramer (1971) indicate that rockfish larvae are among the most abundant fish larvae in the California current, exceeded only in quantity by northern anchovy and Pacific hake (Merluccius productus) larvae. Bocaccio larvae have been encountered in the upper surface waters as far as 483 km offshore (Frey 1971). Kelp beds in Southern California are critical habitat areas for juvenile bocaccio, olive rockfish, and yellowtail rockfish (PFMC 1980).

Rockfishes feed on various organisms, including euphausiids, cephalopods, crabs, and small fishes (Frey 1971). Preferred habitats of chilipepper and bocaccio are hard, rocky bottoms in depths of 183 to 305 m (Frey 1971). Olive rockfish inhabit shallower areas to 146 m depth on kelp beds and rocky reefs (Frey 1971).

Although there is not a directed fishery on hake in the Southern California Bight, the region is vitally important to the biology of the species. As previously discussed, a hake fishery is developing off the Pacific Northwest coast.

During the winter, mature hake congregate for spawning in depths of 183 to 503 m over the California continental slope (Frey 1971). The main spawning area is between Point Reyes, California, and Magdalena Bay, Baja California (Frey 1971). The pelagic eggs and larvae of hake are widely distributed and have been found 644 km offshore (Hart 1973; Frey 1971). Juvenile hake occur in shelf waters, while adults inhabit both shelf and slope regions. Over the slope and shelf at depths of 36 to 201 m, hake schools consist of long, narrow bands oriented parallel to depth contours, from 61 m to 19 km in length and with a width of 0.3 to 3 km (Frey 1971). Most schools range in thickness from 5 to 18 m (Frey 1971). Generally, schools remain just above the bottom during daylight hours, and during the summer rise through the water column and disperse at night (Frey 1971). These schools may persist for several days or only for a few hours. Hake feed on various pelagic fishes and zooplankton (Frey 1971). Adult hake undertake extensive migrations during the spring and summer into the northeastern Pacific, with movements directed towards shore and into shallower water. Southward migrations from the Pacific Northwest regions occur during late fall and winter, with hake moving into the deeper slope waters for spawning (Frey 1971).

Little specific biological information is available for swordfish, a wide-ranging pelagic species. Adults are seasonal migrants into the Southern California Bight. Evidence indicates that swordfish spend considerable time feeding at depths of 305 m or more (Frey 1971). In the bight, swordfish feed on northern anchovies, hake, jack mackerel, rockfishes, and squid.

California barracuda spawn during May to July in Southern California and may spawn more than once during the season (Frey 1971). Pelagic eggs are produced. Barracuda school relatively close to shore and migrate northward along the coast and offshore islands during the summer, and then reverse direction during the fall (Hart 1973). This species feeds on pelagic fishes such as northern anchovies and Pacific sardines.

Peak spawning occurs during May and June in nearshore areas for white seabass. Apparently, very specific sites such as off Long Point on the Palos Verdes Peninsula in Southern California are utilized for spawning (Frey 1971). Little information is available concerning the developmental biology of white seabass. The species is primarily a piscivore and also preys on crabs and squid (Frey 1971).

White croakers spawns in the spring in the nearshore area. White croakers often swim in loose schools at or near sandy substrates at depths ranging from 3 to 30 m (Frey 1971). Prey items include fishes, squid, shrimps, and a number of benthic invertebrates (Hart 1973; Frey 1971). White croakers which inhabit areas of sewage outfalls in Southern California have developed physiological abnormalities, including oral papillomas, exopthalmia (bulging eyes), and deformed skeletons (Frey 1971).

Lobsters mate during January to April and berried females occur in shallow (< 9 m) inshore waters (Frey 1971). Eggs hatch in approximately 10 weeks. The phyllosoma larvae undergo 12 molt stages to the final puerulus stage; i.e., the stage at which the larvae resemble adults (Frey 1971). Specific spawning areas have not been documented but are believed to be throughout the range of the adults (i.e., rocky coastal regions). Food items include snails, sea urchins, sponges, and rock scallops (Frey 1971). Female lobsters move inshore in March and April, followed by the males in May. Both sexes apparently migrate offshore in October (Frey 1971).

Abalone begin spawning in spring and continue through summer and fall. Spawning is triggered by rising water temperatures and chemical stimuli may also play a role (Frey 1971). Pelagic larvae are produced which feed on phytoplankton. After 1 to 2 weeks, the larvae settle in rocky areas and begin grazing on diatoms and coralline algae (Frey 1971). As abalone mature, larger macrophytes are included in the diet. The kelps, Nereocystis luetkeana and Macrocystis spp., are the main foods of adult abalone (Frey 1971).

Summary--Pelagic fishes support the major fisheries of the Southern California Bight. Because of their wide-ranging habits and distribution in the water column it is difficult to predict the potential impacts which may be associated with manganese nodule processing waste disposal. The water column effects of the wastes will probably be the most significant consideration for pelagic species. For example, it will be important to evaluate the potential toxicity of the waste material, the residence time of the wastes in the water column, their particle size, and other characteristics. Increasing water turbidity may interfere with the schooling behavior of important fish species (e.g., northern anchovies, jack mackerel, bonito). Turbidity could also alter plankton production, which could result in poor survival of northern anchovy larvae and thus alter population abundance.

The pelagic eggs and larvae of other pelagic species, as well as those of groundfishes (e.g., English sole, petrale sole), may also be vulnerable to the water column effects of reject wastes. Hake are of particular

concern in this regard since the main slope spawning area is located at the seaward boundary of the bight.

The demersal eggs of squid and California halibut may be susceptible to the depositional effects of the waste materials. Adults may also be affected if the wastes contain potentially toxic substances. Both Dover sole (Microstomus pacificus) and white croaker which inhabit sewage outfall areas in Southern California have developed physiological abnormalities which may be related to sediment contamination.

Waste disposal impacts on critical habitats should also be considered. For example, rocky substrates associated with kelp beds are important for jack mackerel, rockfishes, and abalone.

In summary, it is difficult to predict the magnitude of waste disposal impacts on the fishery resources of the Southern California Bight. However, potential disposal sites should be evaluated in terms of biological importance to the species which support the fisheries of the region.

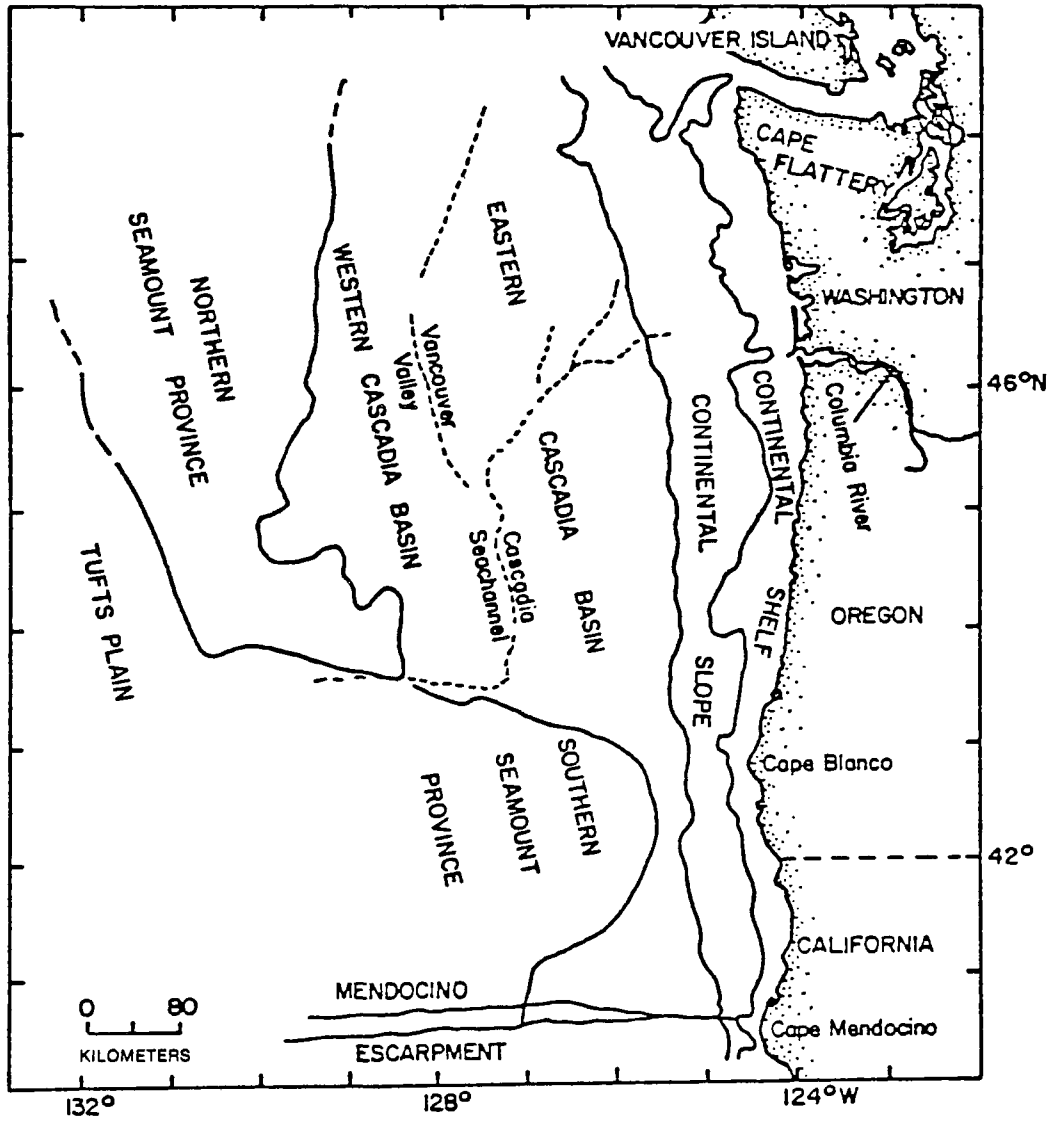
PACIFIC NORTHWEST REGION

Physical Characteristics

Bathymetry--

The northwest offshore region described in this section extends from Cape Mendocino in northern California to Cape Flattery in Washington (Figure 74). Major physiographic provinces include a continental terrace consisting of the shelf and slope, the Cascadia Basin, and "a province of irregular topography on the western flank of the basin" (McManus 1964). The Cascadia Basin can be further divided into eastern and western portions on the basis of the Vancouver Valley and southern trend of the Cascadia Seachannel (Gross 1965). A major bathymetric feature, the Mendocino Ridge-Gorda Escarpment strikes east-west into the continental margin and separates it from northern California. The major fracture zone marks a regional seafloor change, to the south of which floor depths are several hundred meters deeper than to the north.

Continental Shelf--The continental shelf in this northwestern region is generally narrower, steeper, and has greater depths than average values for other continental shelves of the world (Shepard 1963). From Cape Mendocino northward, the shelf tends to widen, from 30 km (16 nmi) on the average in California to 40 km (22 nmi) off Oregon and 50 km (27 nmi) off Washington. Widest regions of the shelf of approximately 65 km (35 nmi) occur in the Heceta Bank area off of central Oregon and at the mouth of the Columbia River. The narrowest segment which is less than 10 km (5.4 nmi) wide, occurs off Cape Mendocino. The outer shelf edge occurs at approximately 145 m (475 ft) off Washington and increases in depth going southward to 165 m (541 ft) off central Oregon and 185 m (607 ft) off northern California. The shelf break is most pronounced off central Oregon near Heceta Bank (Figure 75) and least evident to the north and south of this point. At least six submarine canyons transverse the seaward edge of the shelf. Shelf gradients



REFERENCE: McManus, 1964; Gross, 1965.

Figure 74. Physiographic provinces off northwest Pacific coast.

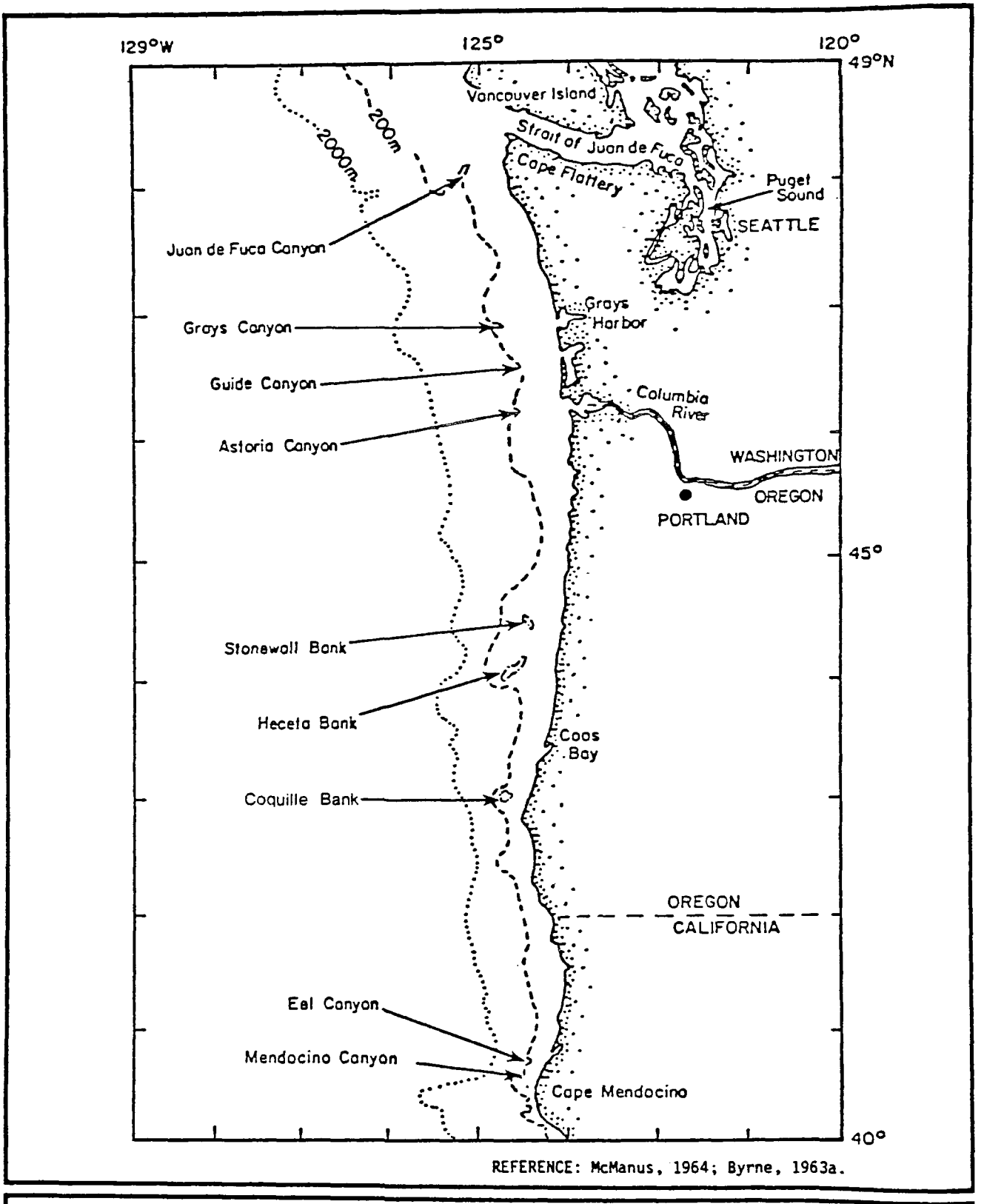


Figure 75. Relative positions of major submarine banks and canyons off Northwest coast.

range from 0.13 to 0.72° averaging less than 0.5° and are generally uniform out to the shelf break.

Surface sediments of the nearshore zone are primarily sands consisting of detrital quartz and feldspar. The sand zone extends from the shoreline out to about 90 m (295 ft) off the northern and central Oregon coast (Byrne 1962), but forms a narrow belt along the southern Oregon coast at depths of less than 50 m (164 ft). Off the Washington coast, the sand zone extends to depths of 50 m (164 ft) or more. Seaward of this zone, bottom sediments consist of patches of mixed sand and mud, modern mud, and exposures of bare rock. The onshore-offshore movement of sand is greatest during the winter when longshore transport is to the north.

A major portion of the outer shelf is covered by unconsolidated sediment, with rock outcrops projecting above the shelf floor in several places. Such outcrops occur primarily near the shelf edge where a number of individual banks exist at approximately the 145 m (476 ft) contour (Byrne 1963a, b). The three major shoals occurring on the Oregon continental shelf are the Stonewall, Heceta, and Coquille, with 60-73 m (197-239 ft) reliefs. Published chart notations indicate a hard brown clay at Heceta, although Byrne (1962) indicates that this is probably based on the collection of shale or mudstone. Rocks collected at Stonewall are dense light-gray fossiliferous mudstone and dense gray siltstone or fine sandstone. The lithology of Coquille has yet to be defined.

Continental Slope--The relatively narrow northern California-Southern Oregon continental shelf is bordered by a topographically complex slope which extends from the 145-185 m (476-607 ft) break to the deep sea floor at approximately 1,800 m (5,905 ft) in the south and 1,400 m (4,593 ft) in the north. The slope width varies from approximately 45 to 55 km (24-30 nmi) in the south to between 60 and 80 km (32-43 nmi) in the north. The slope is convex in shape off southern Oregon, whereas the central and northern Oregon slope contains an outer terrace zone or continental borderland, which disappears further to the north near Vancouver Island (Figure 76). This seaward borderland is approximately 50 km (27 nmi) wide with narrow north to northwest ridges and has a distinct marginal ridge. The interior ridges are from 10 to 75 km (5.4-40 nmi) long and have reliefs of up to 1,150 m (3,773 ft) (McManus and McGary 1967). The average slope gradients are typically somewhat less than 2°, but range from 1.8°-2.0° in the south to 1.2°-1.5° in the north. Seaward of banks, declinations can be much greater, however. For example, south of the Heceta Bank the slope gradient is as great as 40° at the onset of the escarpment, tapering off to first 16° and then again increasing to as much as 30° farther offshore.

Off both Oregon and Washington, the slope is broken by normal faulting parallel to the shoreline, resulting in a number of structural benches and basins similar to those associated with the side slopes of deep trenches (Menard 1964). As the terrace widens to the north of the Gorda Escarpment (Figure 77), a step develops at about 900 m (2,953 ft). Seaward of the step, a marginal ridge drops to the deep-sea floor. Cascade Bench, which is one of the largest on the slope, occurs between the 400 and 600 m depth (1,312-1,968 ft), and another prominent bench occurs near the California border at depths of 500 to 700 m (1,640-2,297 ft).

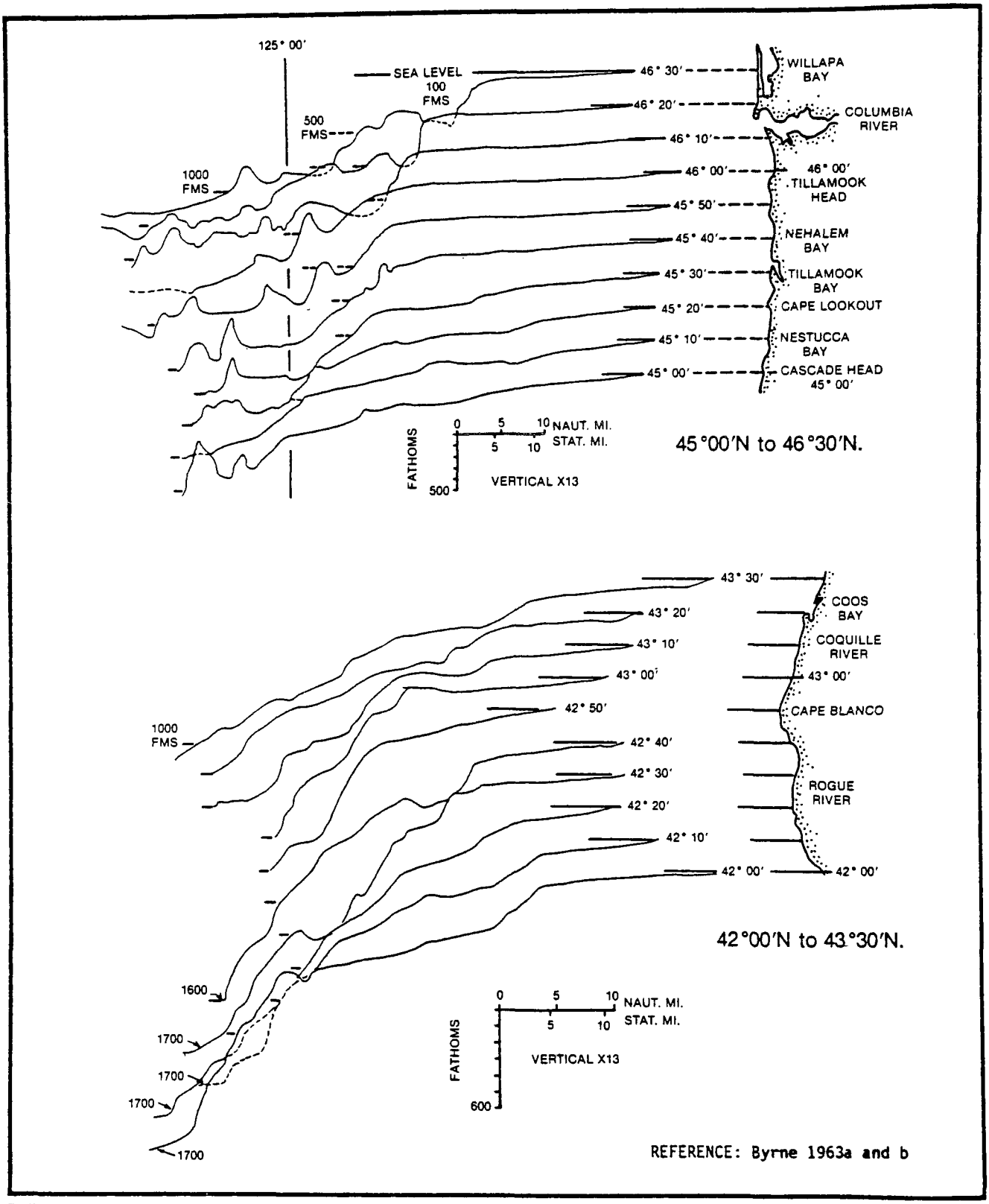
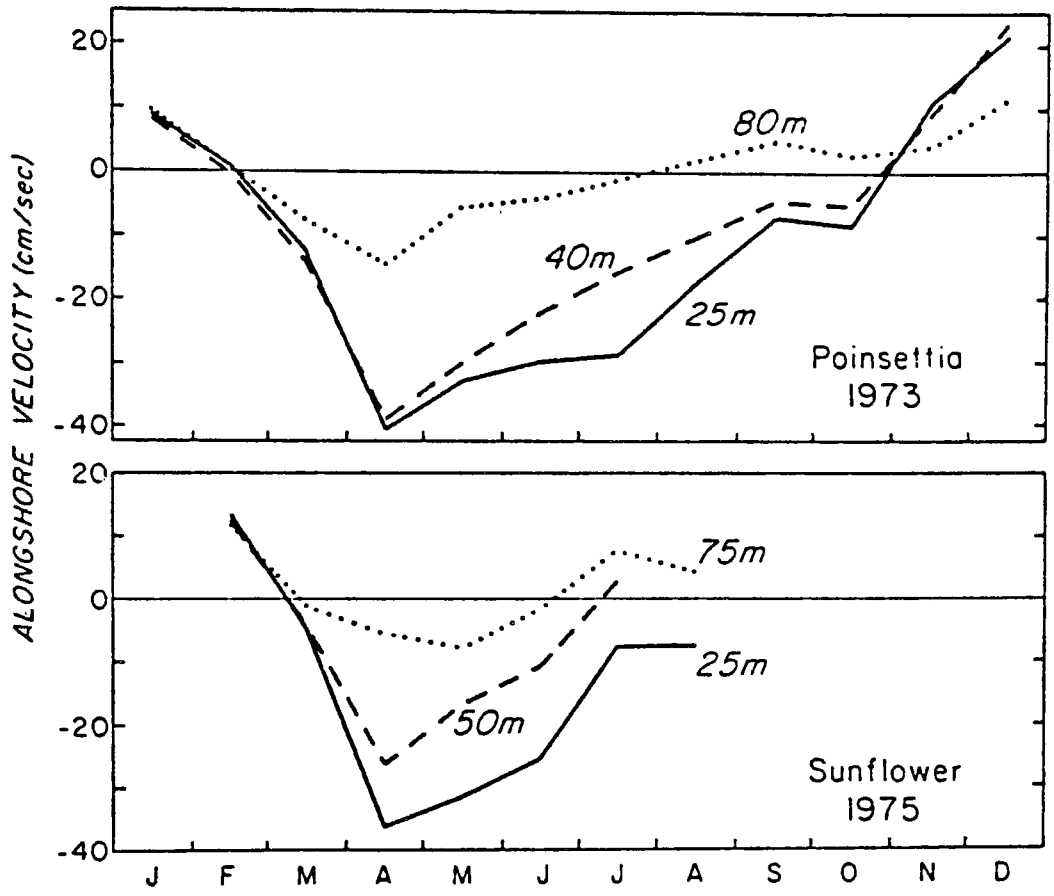


Figure 76. Continental margin (shelf and slope) profiles of the Oregon and Washington coastlines.



REFERENCE: Huyer and Smith, 1978.

Figure 77. Monthly mean values of the alongshore component of the currents off the Oregon coast.

Large submarine canyons notch the upper-slope and extend down to the borderland. For example, the Astoria Canyon (Figure 75) meanders through the ridge topography, commencing about 18 km (9.7 nmi) west of the Columbia River mouth at the 182 m (597 ft) depth. The canyon extends 31 km (16.7 nmi) down to a 1,000 m (3,280 ft) depth, turning to the southwest and continuing 24 km (13 nmi) to a depth of 1,500 m (4,921 ft). Thereafter the canyon splits; the northwestern arm leads to the mouth of the Willapa Canyon, while the west-southwest arm continues to the head of the Astoria Fan. The Fan, whose apex is located at the 1,830 m (6,004 ft) depth, extends 140 km (75.5 nmi) to the west and 230 km (124 nmi) to the south of this point.

Continental Rise--Mendocino and Gorda Escarpments are major bathymetric features that strike east-west into the continental margin. A 300 km (162 nmi) long segment of the oceanic rise, Gorda Ridge with its crestal mountains and median valley, lies just north of the Mendocino Escarpment. The northern limit of Gorda Ridge is formed by Blanco Fracture Zone, a 20 to 75 km (10.8-40.5 nmi) wide system of ridges and troughs that have an average relief of about 900 m (2,952 ft), although depths exceed 5,100 m (16,732 ft) in some troughs, and relief exceeds 2,750 m (9,022 ft) (Dehlinger et al., 1970). The rough topography of the 460 km long zone (248 nmi) acts as a barrier to turbidity current dispersal, reflected in the existence of the deep-sea fans and plains in Cascadia Gap. Therefore, much of the sediment of Tufts Abyssal Plain must have used that corridor. A northern continuation of the Blanco Fracture Zone, the Juan de Fuca Ridge, is more of a low rise than a well-developed ridge. Seamounts and furrows are major topographic elements of this ridge.

Abyssal Plain--Seaward of ridges and fracture zones is the depositional topography of deep-sea fans and Tufts Abyssal Plain. Deep-sea channel systems played a major role in construction of the low, smooth topography (average gradient 1.4 m/km) cross this region. Gorda and Astoria Basins, which are part of the Cascadia basin, are sites of major deep-sea fans (e.g., Astoria Fan and Nitinat Fan, respectively).

Circulation Patterns--

Northwest coastal currents are generally parallel to local isobaths. They have much stronger alongshore than onshore components, are highly variable in both direction and speed on a time scale of several days, and fluctuate in direct correlation to sea level changes and the longshore component of the wind (Huyer and Smith, 1978). The longshore current system exhibits a significant seasonality, with flows being generally northward at all depths in the winter and strongly southward in the spring and summer (Figure 77). A northward undercurrent develops above the outer shelf and slope in late summer and early fall (Huyer et al., 1975).

The most prominent feature of Pacific Northwest shelf circulation is a southward coastal jet during the upwelling season (Hickey 1979b). In spring, the center of the southward flow moves from a summer position of 15 km (8 nmi) offshore to within 10 km (5.4 nmi) of the coast. The width of

the flow increases at this time, extending out over the continental slope (Huyer et al., 1978). Currents at 25 to 40 m (82 to 131 ft) depths have a net annual southward movement with average speeds being 10 cm/sec and 8.5 cm/sec at these two depths, respectively. Deeper, at 80 m (262 ft), the average flow is typically much weaker and there is little net displacement over long periods (Huyer and Smith 1978). Maximum monthly mean velocities for the mid-shelf area range from 20 to 40 cm/sec. Extreme currents at 20 m (66 ft) have exceeded 50 cm/sec in summer and 100 cm/sec in winter (Figure 78). Maximum surface currents are likely to be even higher than these values.

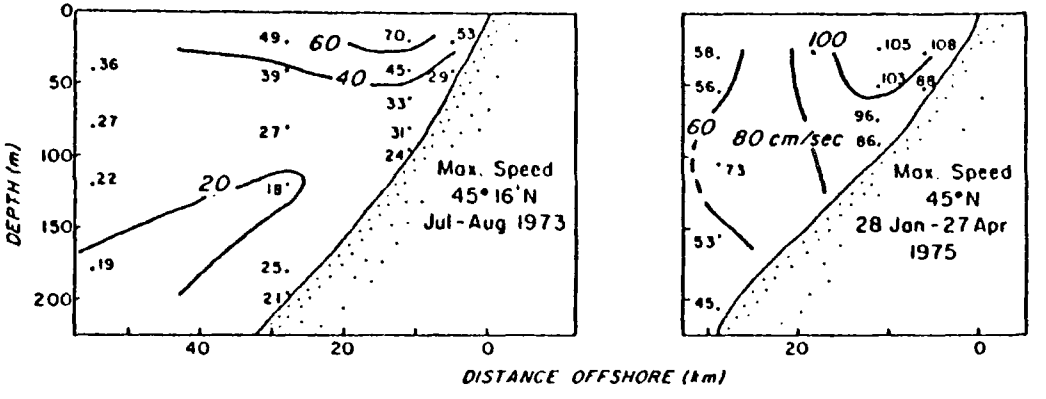
Over the inner-shelf, the currents are apparently much weaker than at mid-shelf. Measurements over 2-4 month periods between July and October near the 50 m (164 ft) isobath indicate a weak average southward flow, which at times reverses. When the wind stress remains southward for several days, an offshore flow develops (Figure 79), with surface speeds of up to 20 cm/sec. Deeper shoreward replenishment flows below 15 to 20 m (49 to 66 ft) water depths range from 5 to 10 cm/sec.

Although much less is known regarding the outer-shelf circulation patterns, surface currents are generally believed to be southward. Beyond the shelf, geostrophic calculations indicate a mean southward flow which is weaker than at mid-shelf. Flows of 13 cm/sec have been measured at 40 m (131 ft) depths in 500 m (1,640 ft) of water at the same section and time as shelf measurements indicating a continuum of southward flow seaward beyond the shelf (Figure 80).

At depths of 200 to 300 m (656 to 984 ft) there is a northward undercurrent (Favorite et al., 1976), whose presence has been verified off Oregon in spring and early summer (Huyer and Smith 1976) and off Washington in the late summer and early fall (Cannon et al., 1975; Reed and Halpern 1976). Between July and September, the northward flowing jet over the Washington continental slope has been observed to be 20 km (10.8 nmi) wide and 200 m (656 ft) thick, (excluding flow components below 5 cm/sec). A maximum core speed of 16 cm/sec has been measured at a depth of 192 m (630 ft) in 600 m (1,968 ft) of water (Hickey 1979b). Below 60 m (197 ft), slower northward flow was observed on the average over a six-week period (July-September) as far as 80 km (43.1 nmi) offshore, across the slope and over the entire shelf (Figure 65).

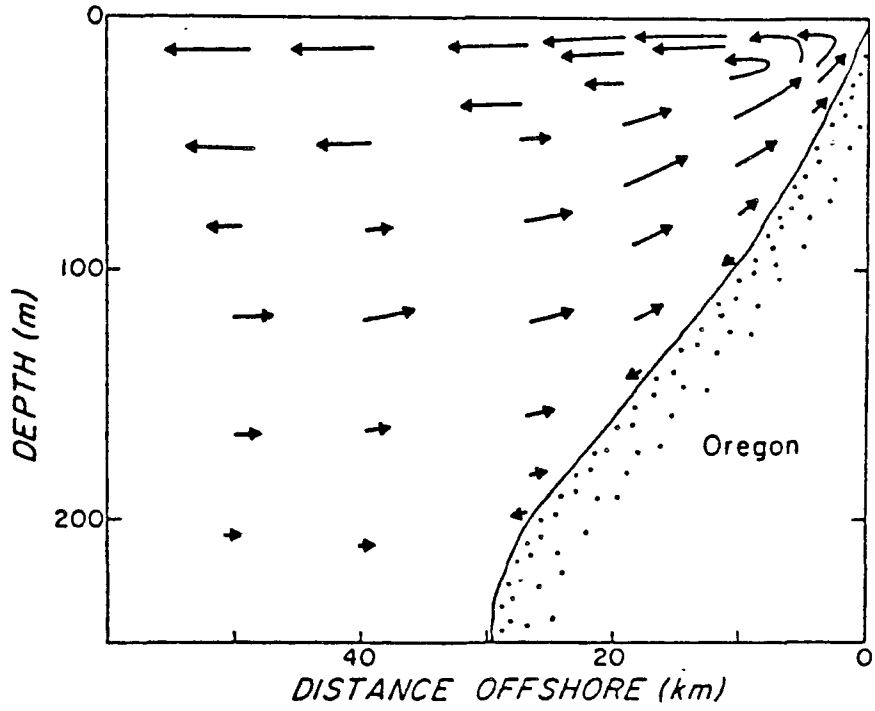
Representative Disposal Site Characteristics

Typical physical oceanographic conditions at shelf, slope, and basin sites off the Oregon coast are presented in this section. Although the salinity, temperature, and density profiles are isolated measurements, they do represent conditions expected during the winter and summer periods. The current profiles are mean currents over the winter and summer periods of deployment. Further offshore, over the lower-slope and deep-ocean basin where current measurements are not available, calculated geostrophic flows are presented. The physical oceanographic information presented is based on review of a relatively large number of technical reports (Table 54). The locations of the stations selected as representative of disposal areas are listed below and shown in Figure 81.



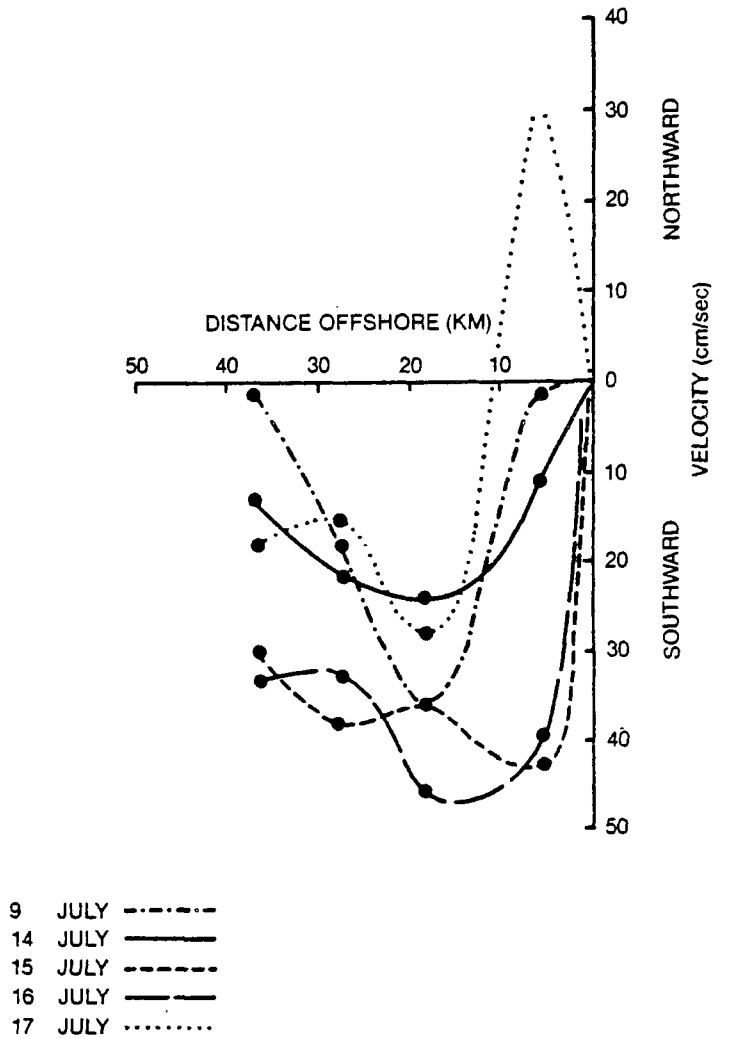
REFERENCE: Huyer and Smith, 1978.

Figure 78. The vertical-offshore distribution of the maximum current speeds observed during July and August, 1973, and during February, March, and April, 1975, off Newport, Oregon.



REFERENCE: Huyer, 1976.

Figure 79. Onshore-offshore circulation pattern during summer upwelling.



REFERENCE: Huyer 1974

Figure 80. Components of surface current vs. distance offshore the Oregon coast.

TABLE 54. REFERENCES REVIEWED TO COMPILE PHYSICAL OCEANOGRAPHIC INFORMATION ON CHARACTERISTIC DISPOSAL AREAS OFF THE NORTHWEST COAST

McManus 1964

Gross 1965

Shepard 1963

Byrne 1962

Byrne 1963a,b

Byrne and Panshin 1977

McManus and McGary 1967

Menard 1964

Dehlinger et al., 1970

Roden 1964

Tully 1964

Huyer and Smith 1978

Bourke and Pattullo 1974

Pattulo and Denner 1965

Barnes et al., 1972

Huyer 1977

Halpern 1974

Pak et al., 1970

Huyer et al., 1974

Halpern et al., 1973

Huyer et al., 1975

Hays and Halpern 1976

Huyer and Smith 1976

Huyer et al., 1978

Huyer 1976

Favorite et al., 1976

Cannon et al., 1975

Reed and Halpern 1976

Hickey 1979a,b

Huyer 1974

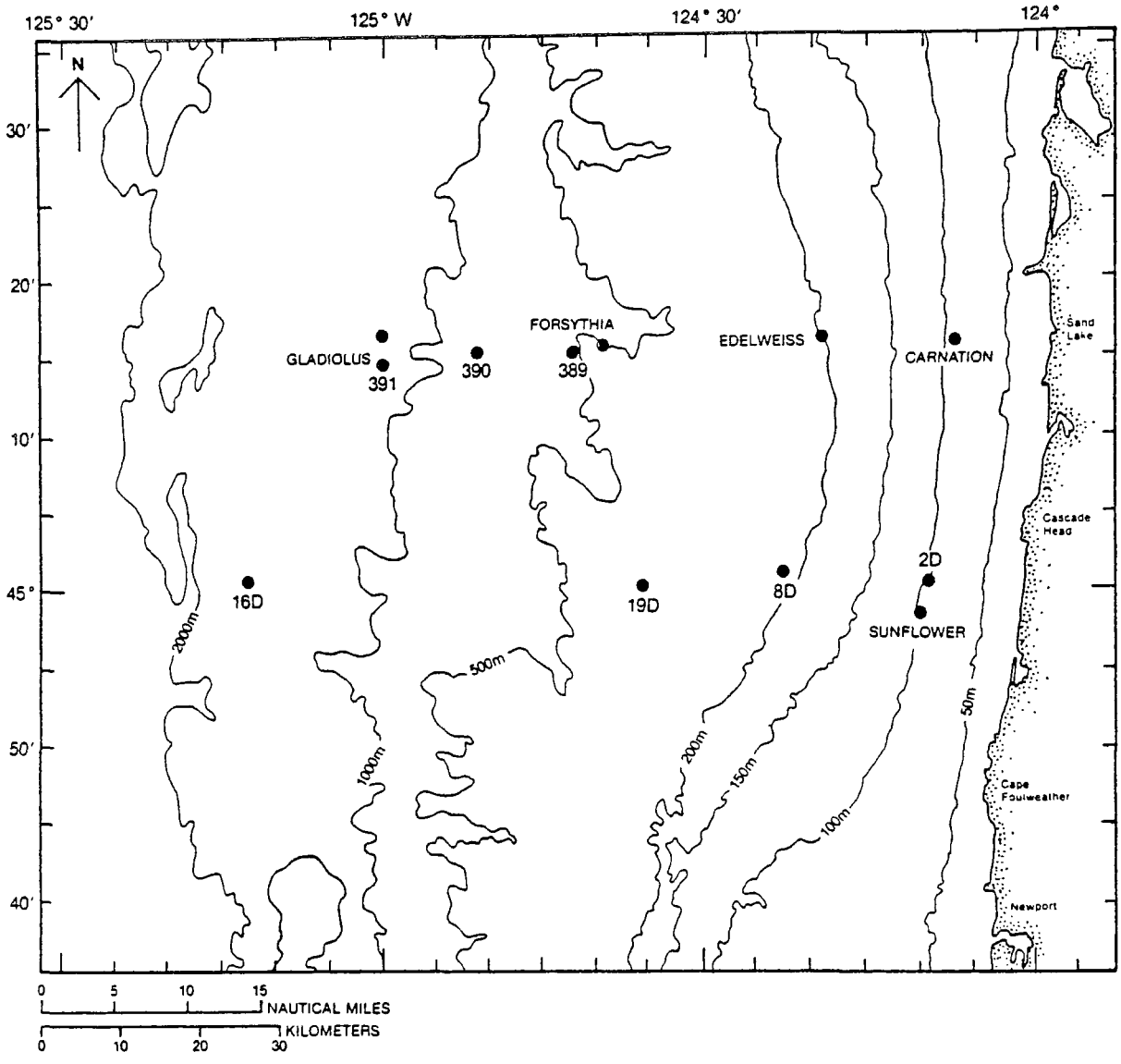
Stephansson and Richards 1964

Pak and Zaneveld 1978

Curl et al., 1965

Harlett 1972

Kitchen et al., 1975



REFERENCE: Huyer et al. 1975

Figure 81. Current meter locations during 1973.

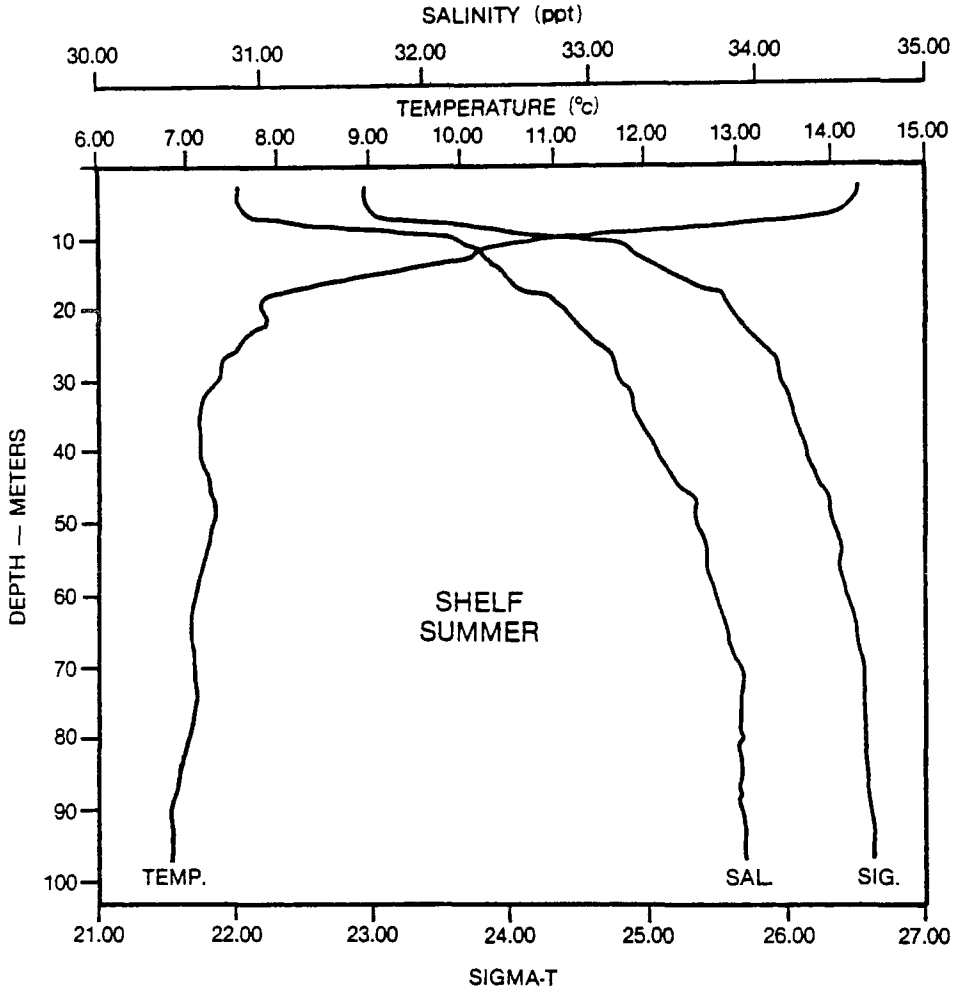
Location	Summer	Winter
Shelf	Carnation	Sunflower, 2D
Upper-slope	Edelweis	8D
Mid-slope	Forsythia, 389, 390	19D
Slope Edge/Basin	Gladiolus, 391	16D

Shelf--

August temperature, salinity, and density characteristics at station Carnation in 90 m (295 ft) of water on the Oregon shelf are presented in Figure 82 January data for the same parameters are presented in Figure 83. The 6^{0} C temperature gradient in the upper 20 m (66 ft) in summer becomes very small in winter down to the 40 m (131 ft) level. Beyond this depth, temperature variations are slight, decreasing to 6^{0} C in deeper waters. The density profile indicates a significant dependence on salinity in both the winter when the temperature gradient is small, and during the summer when a strong thermocline is present. Mean currents for the 99 m (324 ft) deep station Carnation and the 100 m (328 ft) station Sunflower during summer and winter months, respectively, are presented in Figure 84. As indicated, longshore velocity components are much greater than onshore components, and near surface flows are predominantly southward on the average in both summer and winter periods. Movement below 75 m (246 ft) is northward during both seasons.

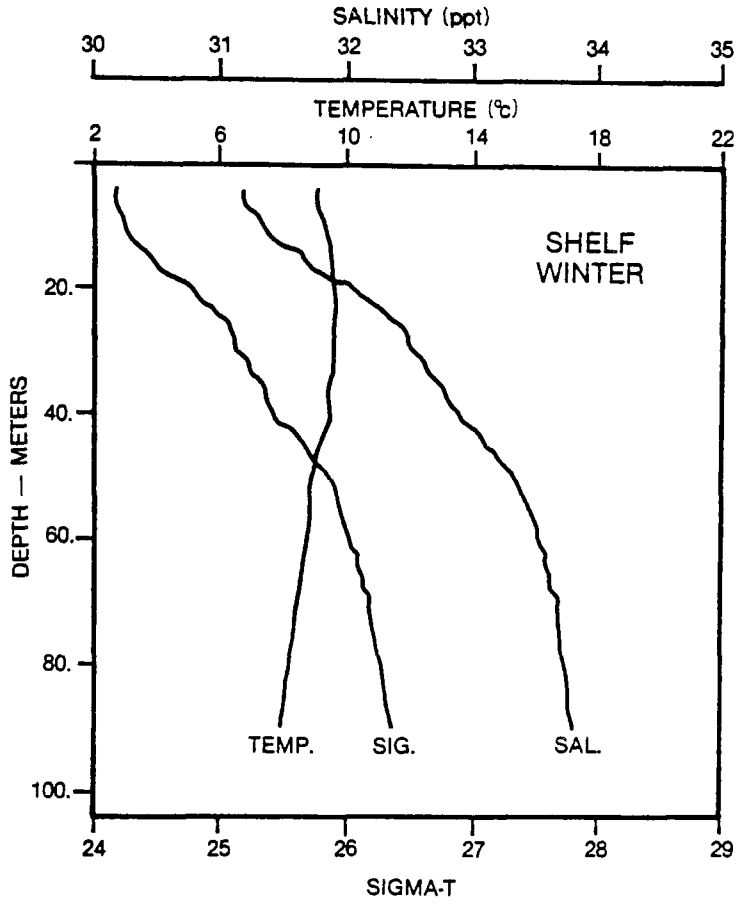
The distribution of dissolved oxygen (DO) in northwest coastal waters is complicated due to upwelling, freshwater discharges, entrainment of deep water and wave action (Stephansson and Richards, 1964). Biological activity nearshore is also more intense and more variable than farther offshore. Maximum surface DO values of 10.0 to 10.7 mg/l occur nearshore between June and July (Figure 85). The generally high surface values exceed levels expected for colder upwelled waters in atmospheric equilibrium, and are attributable to high photosynthetic production rates.

Temperature, salinity, and density data for summer and winter periods at upper-slope stations Edelweis and 8D are presented in Figures 86 and 87, respectively. A strong thermocline and halocline persist during the summer in the upper 10 m (33 ft). In winter, smaller gradients occur and two stratification levels appear at approximately 10 and 60 m (33 and 179 ft), the upper one being due to cool low-salinity water very near the surface. Upper slope currents are strongly southward in summer down to 100 m (328 ft), beyond which a slow northward current occurs (Figure 88). average currents down to 150 m (492 ft) persisted in an onshore direction during the 30-day measurement period. In winter (January-April), the mean longshore current magnitudes are very low, with some southward movement down to 100 m (328 ft) and northward flow beyond to the sea floor. Mid-slope temperature and salinity profiles (Figures 89, 90) appear similar to those on the upper-slope during both the summer and winter periods. Southward currents persist from 50-200 m (164-656 ft) while movement in the onshore direction is very slight (Figure 91).



REFERENCE: Gilbert et al. 1976

Figure 82. Summer (August 23, 1973) temperature, salinity, and density profiles at Station Carnation (99 m). Lat. 45°14.7'N, Long. 124°06.9'W.



REFERENCE: Gilbert et al. 1976

Figure 83. Winter (January 28, 1975) temperature and density profiles at Station 2D (97 m). Lat. 45°00.2'N, Long. 124°09.8'W.

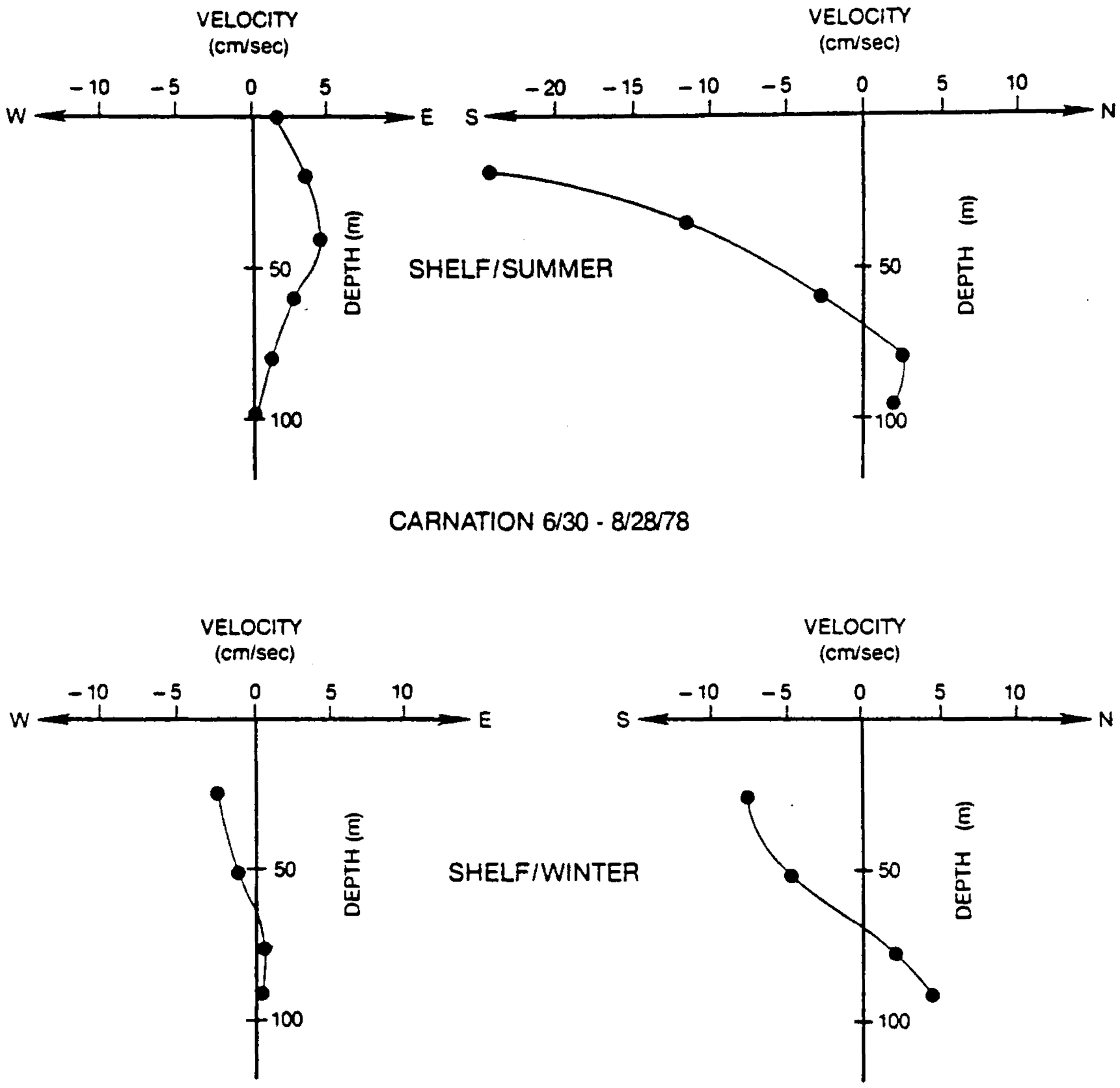
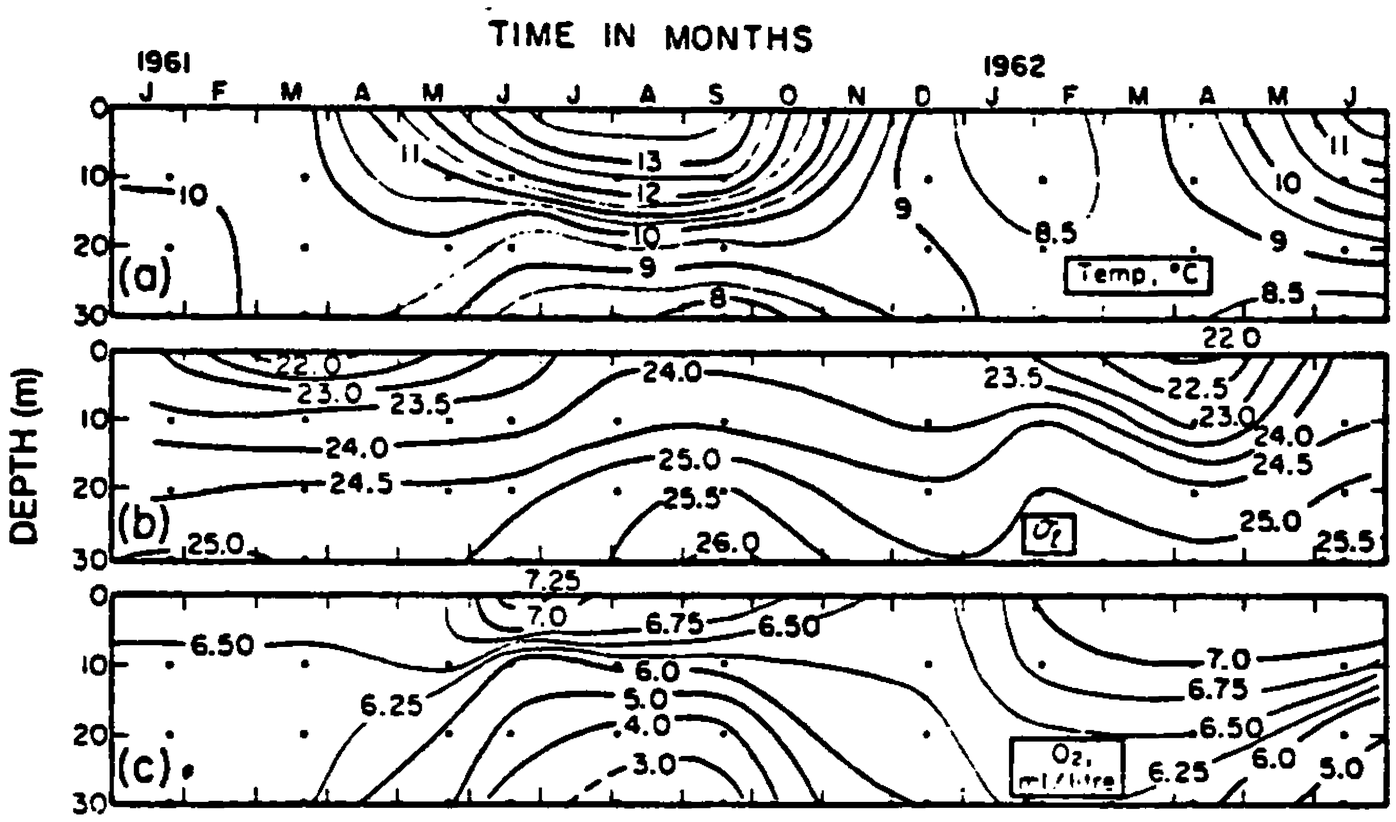


Figure 84. Mean current velocity profiles for Oregon continental shelf locations in summer and winter.



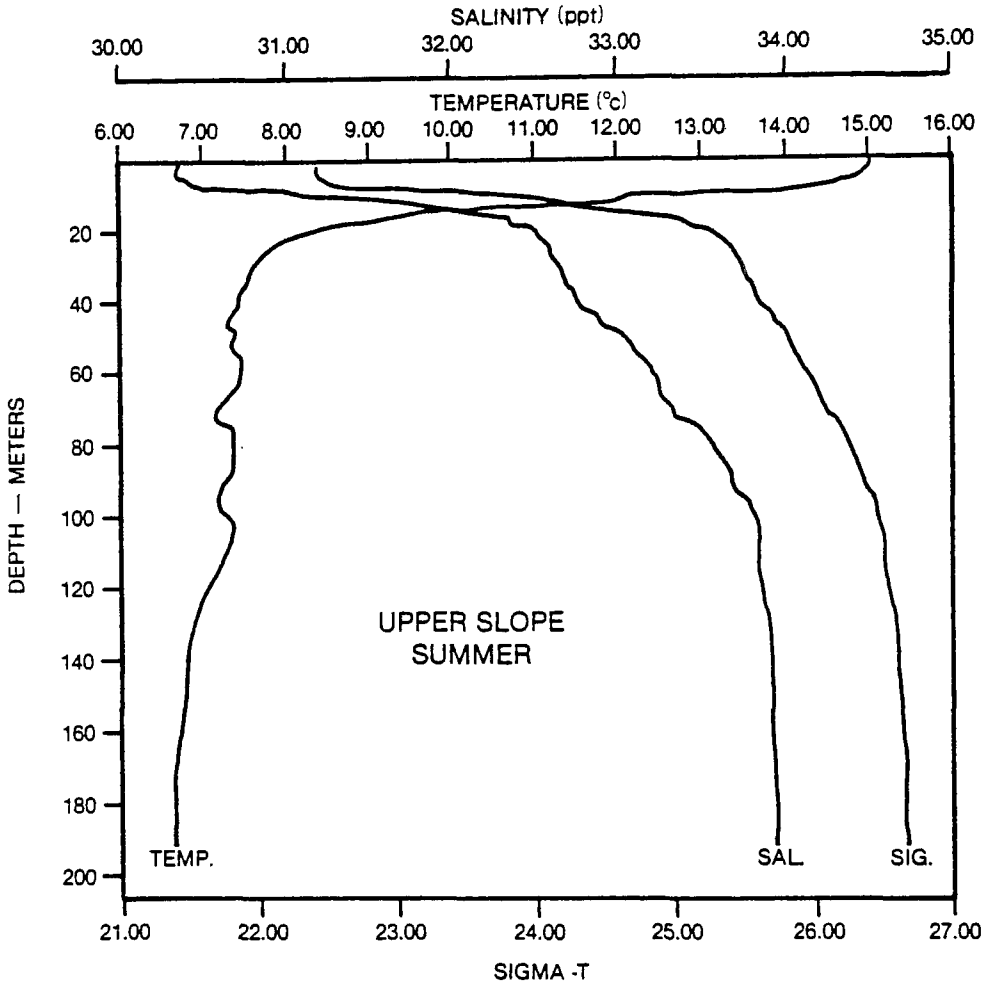
Temperature

Sigma-*t*

Oxygen concentrations (ml/l)

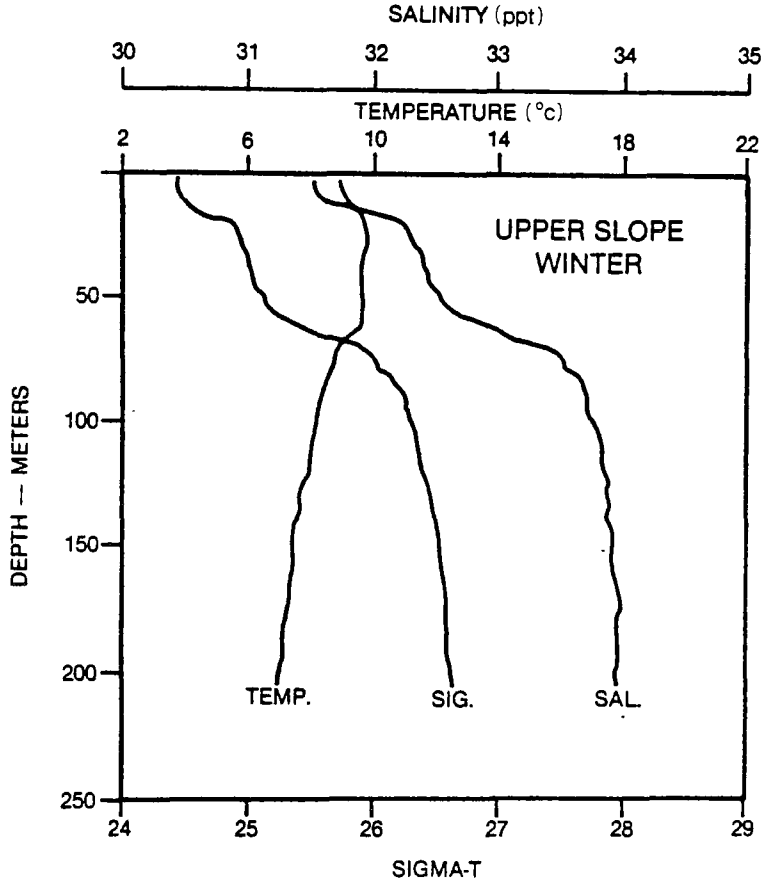
REFERENCE: Stefansson and Richards, 1964

Figure 85. Mean seasonal variations on properties in the upper 30 m inside the 150-m isobath between 46°50' and 47°40'N Lat.



REFERENCE: Gilbert et al. 1976

Figure 86. Summer (August 24, 1973) temperature, salinity, and density profiles at Station Edelweis (196 m). Lat. 45°15.3'N, Long. 124°18.0'W.



REFERENCE: Gilbert et al. 1976

Figure 87. Winter (January 28, 1975) temperature, salinity, and density profiles at Station 8D (218 m). Lat. 45°01.2'N, Long. 124°22.3'W.

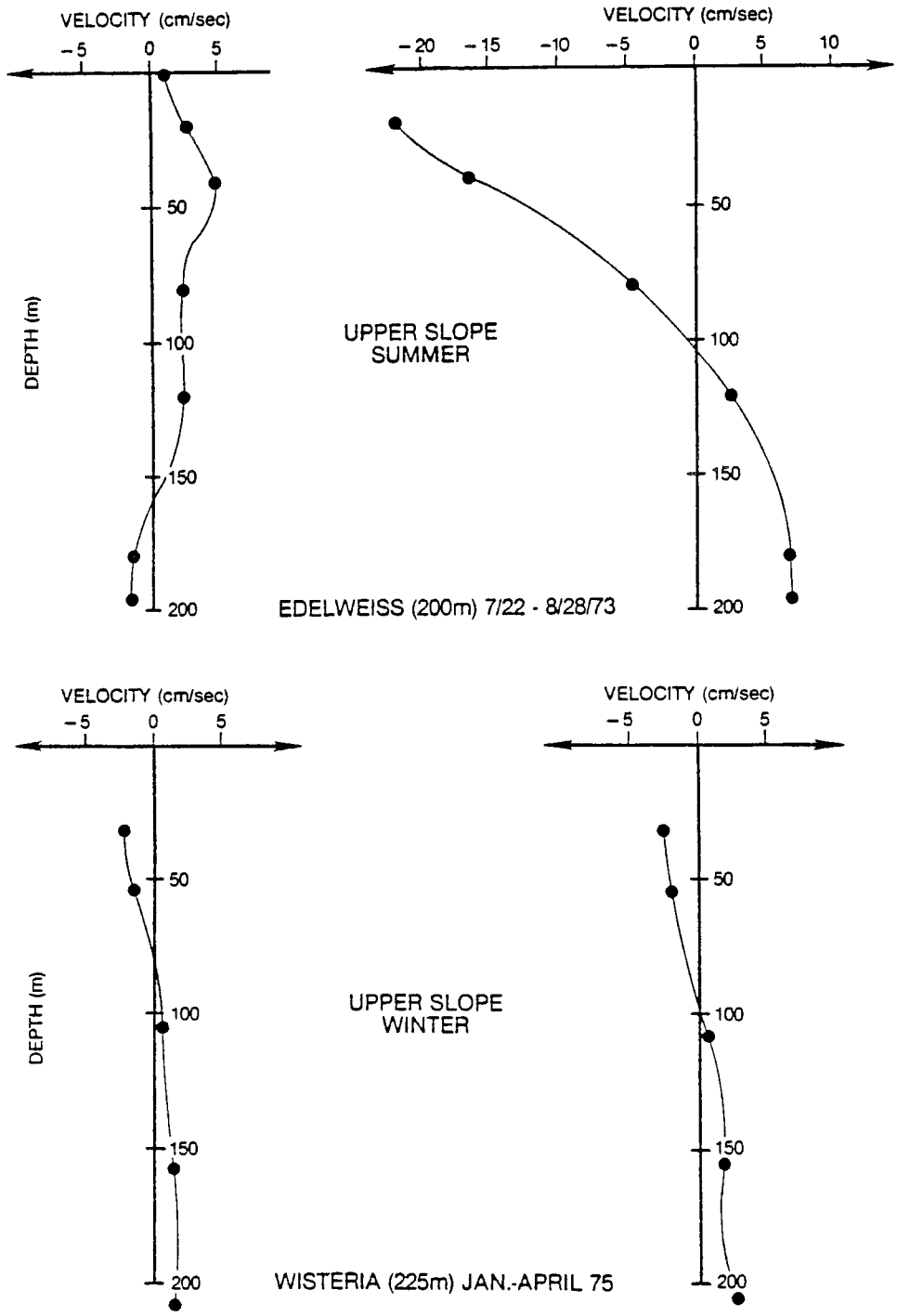
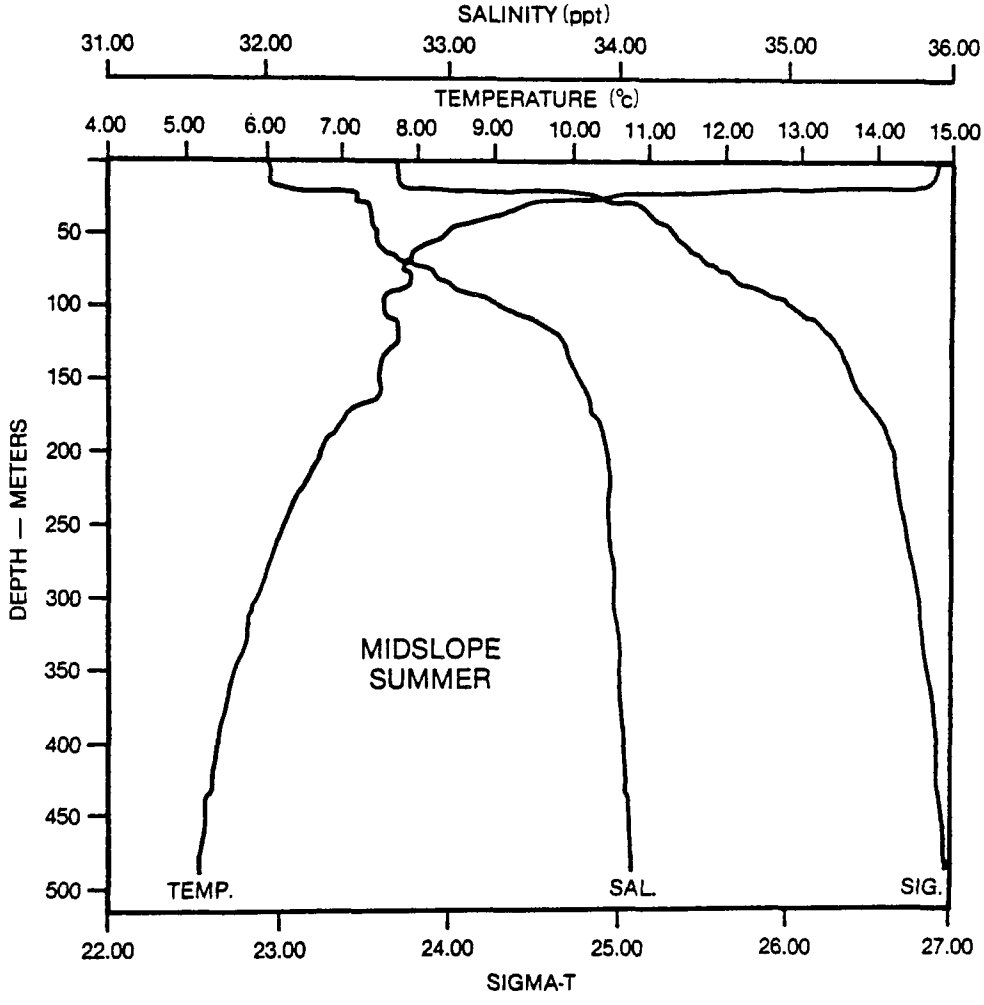
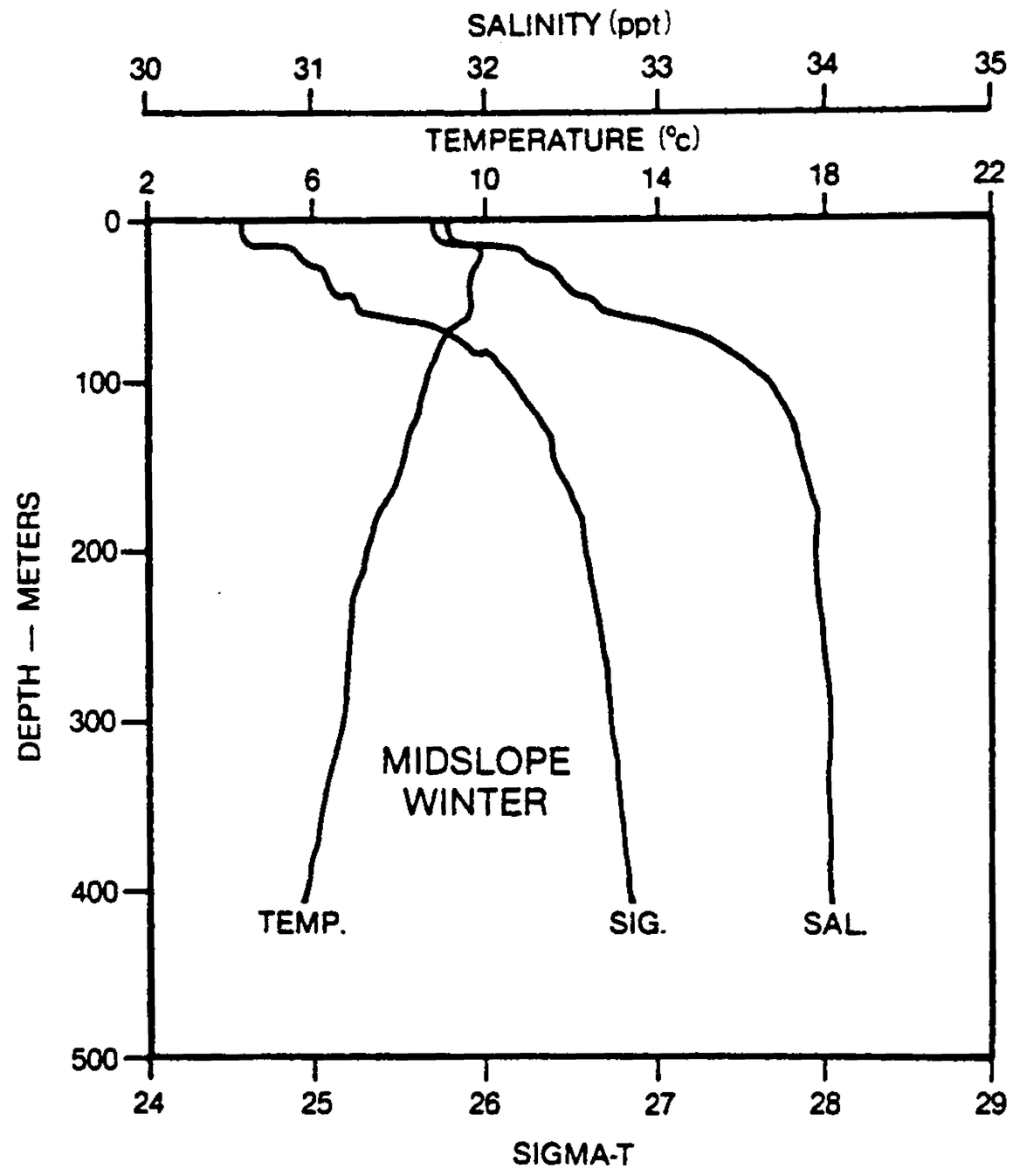


Figure 88. Mean current velocity profiles for Oregon upper-slope locations in summer and winter.



REFERENCE: Gilbert et al. 1976

Figure 89. Summer (August 24, 1973) temperature, salinity, and density profiles at Station Forsythia (492 m). Lat. 45°15.2'N, Long. 124°39.8'W.



REFERENCE: Gilbert et al. 1976

Figure 90. Winter (January 29, 1975) temperature, salinity, and density profiles at Station 19D (435 m). Lat. 45°00.0'N, Long. 124°16.0'W.

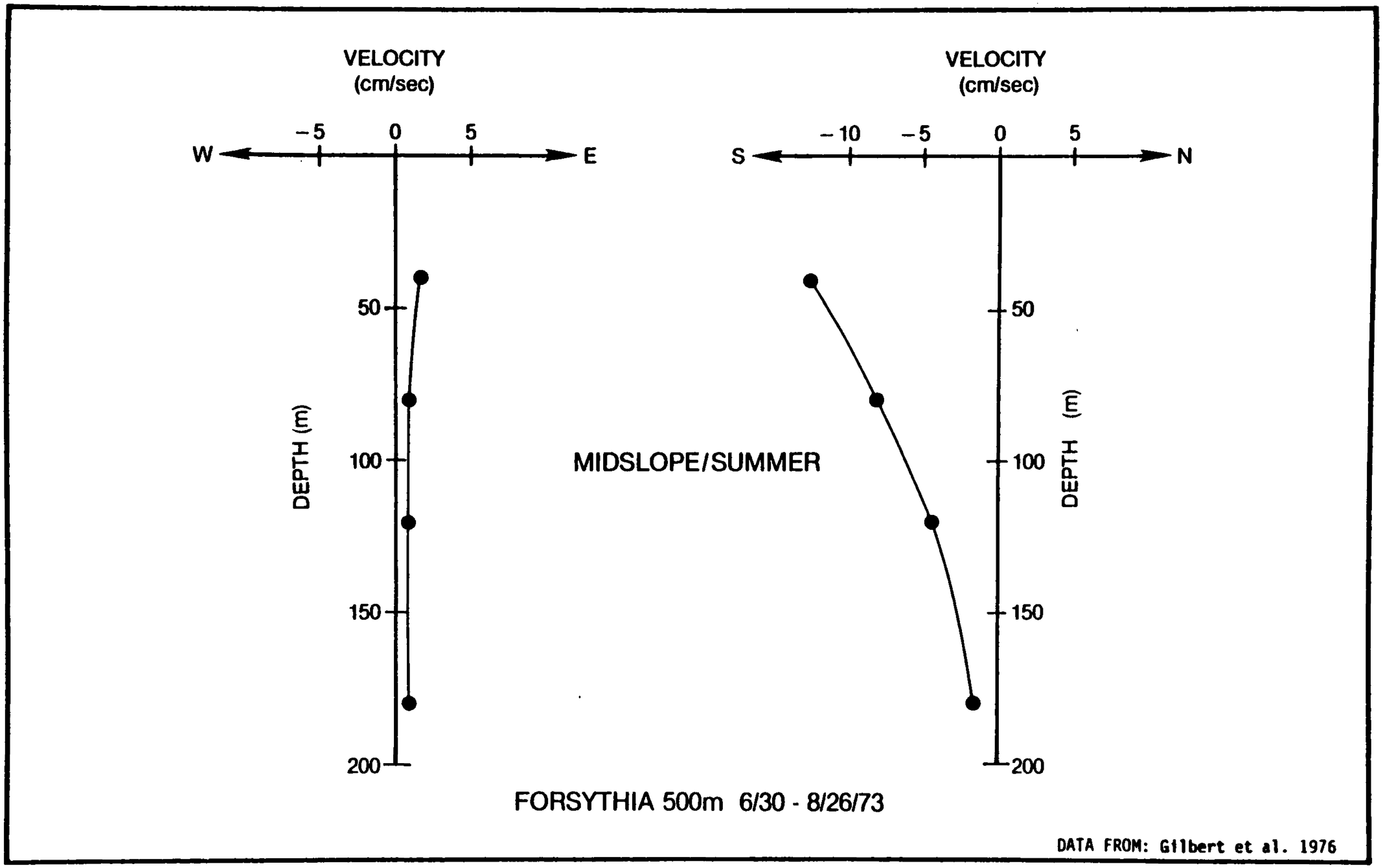


Figure 91. Mean current velocity profiles for an Oregon mid-slope location in summer and winter.

Lower-Slope and Upper-Basin--

In lieu of measured currents in the offshore area, calculated geostrophic flow profiles for the area between stations 389 and 391 are presented in Figure 92. Summer surface currents at 65 km (35 nmi) offshore are southward in summer, decreasing from approximately 6 cm/sec to no current at a depth of, 150 m (492 ft). In an adjacent area 10 km (5.4 nmi) further offshore, near-surface southward currents of 5 cm/sec decrease to negligible speed at 50 m (164 ft). Representative lower slope/upper basin temperature, salinity, and density profiles are shown in Figures 93 and 94 for summer and winter periods, respectively.

Beyond the continental shelf, upper DO values remain relatively constant in the upper mixed layer at near 9.0 mg/l. DO concentrations increase to maxima of 9.3 to 9.6 mg/l between March and May. As the temperature further increases in summer, lower DO solubility results in decreased surface concentrations of aproximately 8.2 mg/l in the upper 10-20 m. A subsurface maximum at depths of 20 to 50 m persists at the previously established winter concentration of 9.6 mg/l however. Figure 95 presents the mean seasonal variations in DO and other parameters in the upper 100 m for an offshore area.

Biological Characteristics

Open Ocean Environments off the Pacific Northwest--

In open ocean environments beyond the continental slope offshore from the Pacific Northwest coast, virtually all primary production is performed by phytoplankton. Due to its dependence on sunlight, phytoplankton production is limited to the upper (< 60 m) sunlit layers of the ocean in this region. All other life (with the possible exception of some benthic organisms which ingest organic matter carried into the deep sea by turbidity currents) in these environments is dependent on the fixation of carbon by phytoplankton, and hence production by the phytoplankton is essential to all higher trophic levels. Phytoplankton production in open ocean waters offshore from the Pacific Northwest coast is limited by low light levels and high turbulence during most of the winter months. There is generally a large increase in phytoplankton production in spring, coinciding with stabilization of the upper water column and increasing light levels. Due to an excess of precipitation over evaporation in this area, there is a permanent halocline at depths of 100-150 m. This has the effect of limiting the upward transport of nutrients to the euphotic zone, and consequently the increased phytoplankton production in spring depletes the nutrients (especially nitrogen in the form of nitrate) in the surface layer. Production throughout the summer is therefore limited by the availability of fixed nitrogen (Peterson et al., 1979). Regeneration of nutrients by animals is important, but due to losses from the upper layers (e.g., the sinking of fecal pellets), it cannot completely supply the required nutrients. While production in spring may be high, the summertime nutrient limitation of phytoplankton production is responsible for keeping the annual production low relative to coastal and nearshore areas (125 g C/m^2 in offshore areas vs. 300 g C/m^2 in coastal and nearshore areas; cf. Anderson

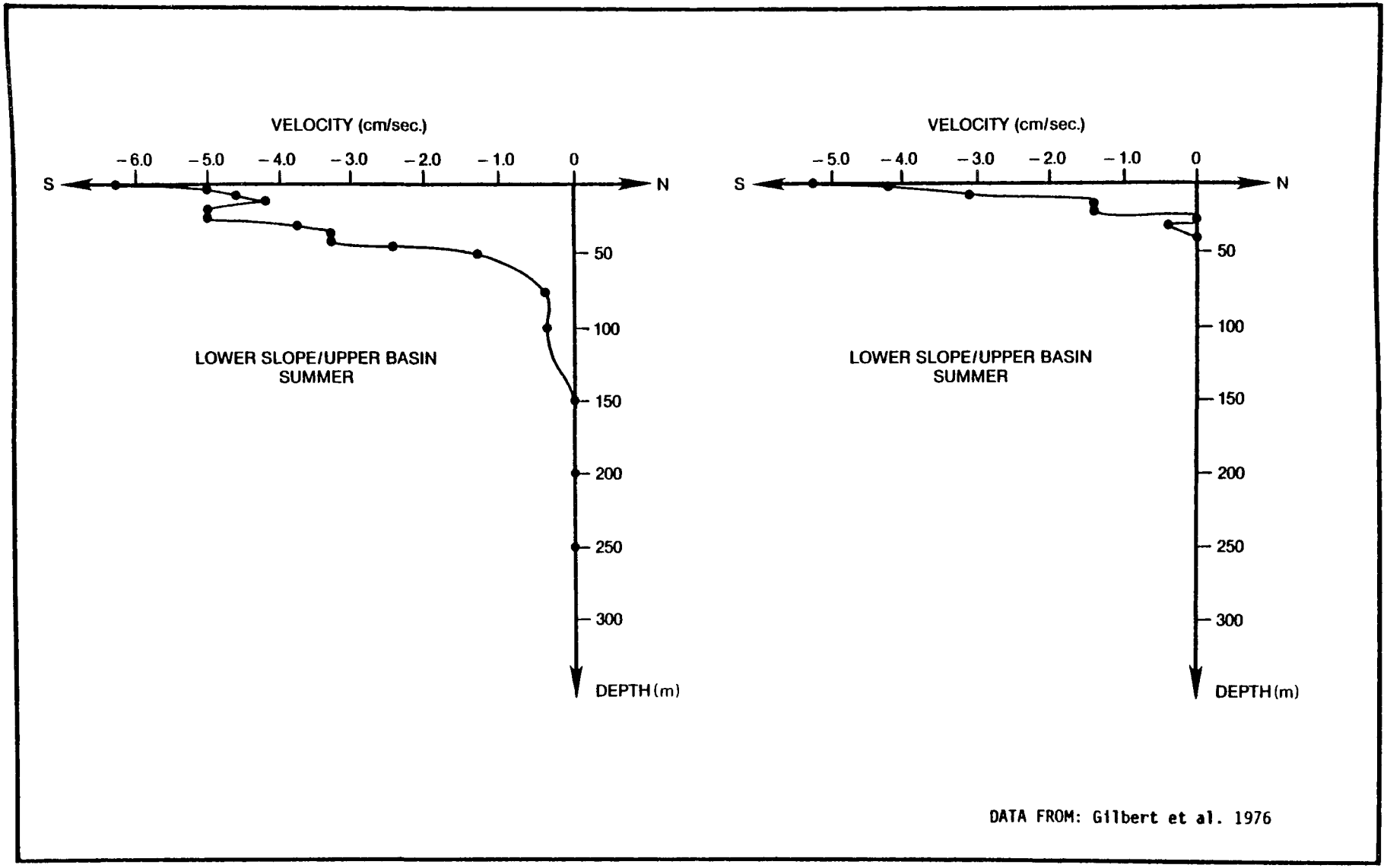
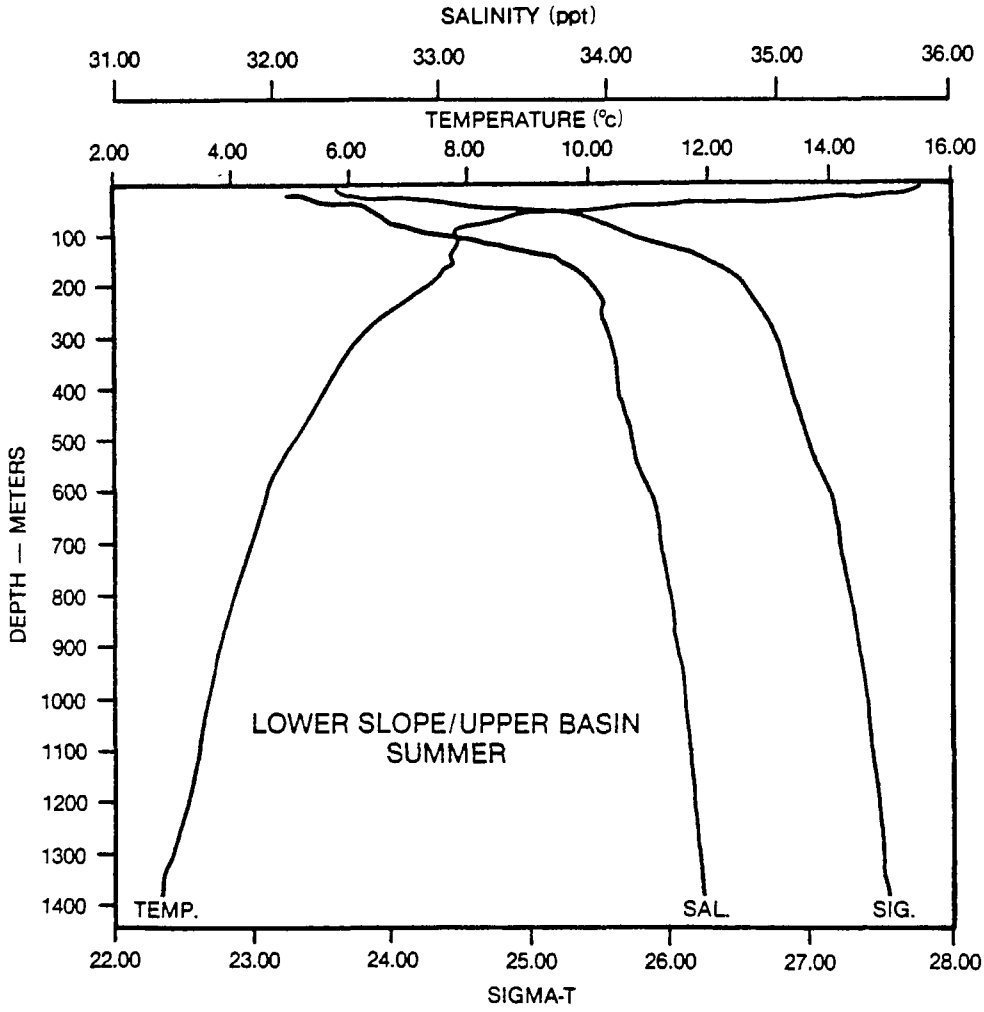
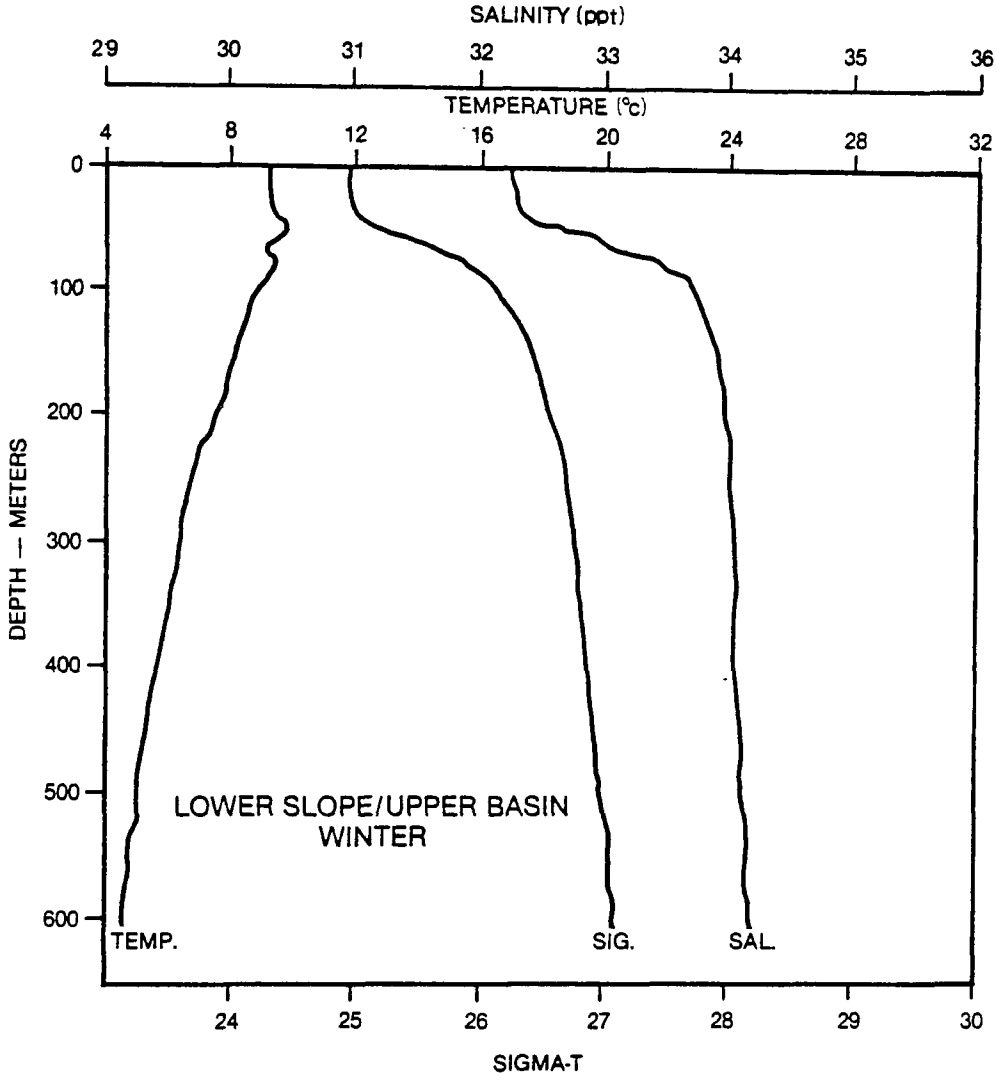


Figure 92. Summer (August 24, 1973) calculated geostrophic current profile, slope edge/basin location (Stations 390-391, Figure 6-34).



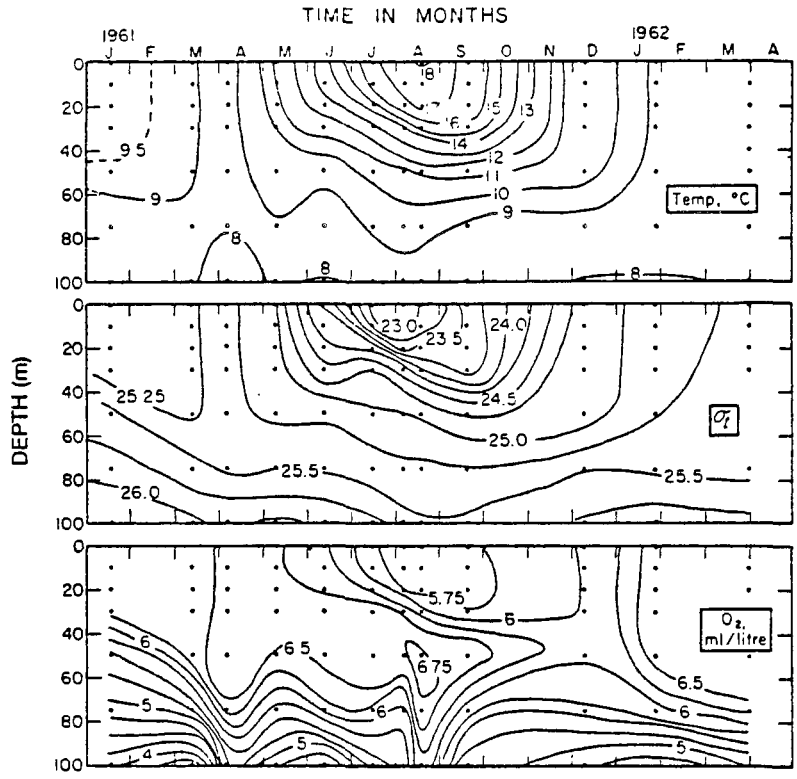
REFERENCE: Gilbert et al. 1976

Figure 93. Summer (August 24, 1973) temperature, salinity, and density profiles at Station Gladiolus (1,412 m). Lat 45°18.9'N, Long. 125°00.1'W.



REFERENCE: Gilbert et al. 1976

Figure 94. Winter (January 29, 1975) temperature, salinity, and density profiles at Station 16D (1,356 m). Lat. 45°00.0'M, Long. 125°12.0'W.



REFERENCE: Stefansson and Richards, 1964.

Figure 95. Offshore mean seasonal variations of properties in the upper 100 m inside the area between 14°30'-47°30'N Lat. and 126°30'-130°30'W Long., January, 1961 - March, 1962.

1972). Production at all higher trophic levels can be expected to be correspondingly lower in the offshore areas.

Above the permanent halocline, a seasonal pycnocline generally develops at a depth of 10-20 m in spring. This gradually deepens to a depth of ∿40 m in autumn (Anderson 1972). One result of the supply of nutrients from deeper waters is that phytoplankton biomass is often greater deep in the euphotic zone than at shallower depths. Anderson (1972) reported, for instance, that a subsurface maximum in chlorophyll a concentration (a commonly-used measure of phytoplankton standing stock) is typically found at depths of ∿60 m in this area in summer. Chlorophyll a concentrations within this subsurface maximum may be 5-15 times higher than those at the surface. Nitrate concentrations also increased rapidly at a depth of 60 m, suggesting that the phytoplankton at this depth have sacrificed living higher in the water column, where light levels are greater, for the sake of being near a source of nutrients.

Anderson (1972) reported that in winter in these offshore areas, diatoms dominated the phytoplankton community, although dinoflagellates, coccolithophorids, and other flagellates were also abundant. During the spring bloom, diatoms became even more dominant, while dinoflagellates decreased in importance and coccolithophorids disappeared completely. Net phytoplankton [defined by Anderson (1972) as cells > 35 um in size] were always a small part of the total phytoplankton community.

Due to the slow, southward flow of the California Current at distances of 300-800 km off the Pacific Northwest coast (Peterson and Miller 1975), zooplankton inhabiting the offshore region are predominantly subarctic in faunistic affinity. Calanoid copepods, many of which are filter-feeders, are particularly abundant (Marlowe and Miller 1975). While many zooplankton species inhabit the euphotic zone, others perform limited (< 200 m) diel vertical migrations which bring them into the euphotic zone only at night. Zooplankton occur at all depths throughout the water column in this area, but those occurring below about 200 m are almost exclusively carnivores and/or detrivores.

All animals larger than zooplankton which inhabit the water column are classified as nekton. This group includes not only fishes, but squid, shrimp, whales, dolphins, etc. Common fishes occurring within the epipelagic zone offshore from the Pacific Northwest include pomfret (Brama japonica) and several species of salmon. The salmon are noteworthy, not only because of their commercial and recreational value in nearshore fisheries, but also because of their anadromous life-cycle, which brings them back to freshwater rivers and streams of the Pacific Northwest for the purpose of spawning. Pomfret, on the other hand, are entirely pelagic. Other occasional residents of the offshore epipelagic zone include albacore, which, although it is more typically a southern species, may extend its range this far north during the summer if ocean temperatures are sufficiently warm. Marine mammals of the northeast Pacific include various whale and porpoise species. The larger nekton species are generally strong swimmers which range over large areas of the oceans and are not restricted to a single geographic area. Because these large species of nekton are a

number of trophic levels removed from the primary producers, they are quite rare considering the total expanse of the oceans. Nevertheless, certain species (e.g., whales, porpoises) are known to school, and consequently they may be abundant in a given area for a short period of time.

A number of small nektonic species in the northeast Pacific inhabit mesopelagic depths (100-1,000 m) and some of these perform diel vertical migrations into the epipelagic zone (< 100 m) [cf. Pearcy et al. (1977); Frost and McCrone (1979)]. While these species are widespread, individuals of these species are not as wide-ranging as those of the larger, epipelagic species.

With the notable exception of the anadromous fishes, most other pelagic fish species in offshore waters of the northeast Pacific lay and fertilize their eggs in the sea itself. The eggs and larvae, collectively referred to as ichthyoplankton, are carried about by the currents. The larvae are typically very small, and dependent on plankton for food.

Benthic animals, including both organisms living in and on the sea floor and demersal organisms swimming just above the sea floor, are largely dependent on the production of organic matter in the overlying waters. Organic matter is transported to the deep-sea benthos by sinking carcasses, fecal material, exoskeletons, and detritus, by the vertical migrations of some nektonic species, and in some areas by turbidity currents. Since the supply of organic matter is inversely related to the distance from the surface, deep benthic life in the northeast Pacific is sparse by comparison to benthic communities in shallow, nearshore areas.

The abundance of sea floor organisms generally decreases with increasing distance from shore off Oregon [Carey (1965); Griggs et al. (1969)]. Large benthic populations found in some areas may be associated with higher food input to the bottom environment. Griggs et al. (1969) reported, for instance, that while benthic organisms were relatively sparse at stations located over areas of the Cascadia Abyssal Plain far removed from the continental slope, there were four times as many organisms present at stations at the base of the continental slope and in the axis of the Cascadia Channel (a submarine canyon which crosses the Cascadia Abyssal Plain, and is apparently associated with the Columbia River discharge). The former stations were characterized as having postglacial depositional rates of 2-3 cm/1,000 years, while the latter stations had postglacial depositional rates of 8-10 cm/1,000 years. The higher rates are believed to be associated with the settling of large volumes of suspended sediments from the Columbia River discharge (Griggs et al., 1969). The higher organic carbon content of the surface sediments at the easternmost stations on the Cascadia Abyssal Plain, relative to that of those stations to the west (1.7 percent vs. 1.1 percent), may be associated with higher primary productivity of the overlying waters (due to coastal upwelling), and the large volume of suspended sediments and particulate matter from terrestrial runoff in the Columbia River discharge. The organic carbon content of the surface sediments within the Cascadia Channel is still higher (2.2 percent), and is believed to be a result of turbidity currents which originate on the outer continental shelf and the upper continental slope

where primary production in the overlying water column is high, and where terrigenous material from the Columbia River drainage is deposited (Griggs et al., 1969).

Many species of the benthic infauna at abyssal depths are deposit feeders which are dependent either on the settling of organic matter from the surface waters or on the transport of organic matter to abyssal depths by some other means, such as turbidity currents. Annelids are the numerically dominant infauna at all locations on the Cascadia Abyssal Plain (Griggs et al., 1969). They are, however, less abundant at the westernmost stations, perhaps due to the sand which underlies a thin (2-15 cm) layer of finer postglacial sediments on the surface. Annelids are numerically more abundant at the base of the continental slope and in the Cascadia Channel, but the biomass of benthic infauna (chiefly annelids) is higher at the latter location, presumably due to the higher organic carbon content of the sediments and the greater input of such sediments through turbidity currents. Other abundant infaunal organisms in this general area include arthropods and mollusks. Epifaunal organisms include holothurians, ophiuroids, and other forms (Griggs et al., 1969).

The Cascadia Channel thus appears to be an avenue for transporting terrestrial detritus into the deep sea. While terrestrial plant fragments may not be directly utilized by benthic macrofauna, they may be the initial step in an abyssal food web involving bacteria, other micro-organisms, and eventually the macrofauna (Griggs et al., 1969).

Demersal fish communities over the Cascadia Abyssal Plain are dominated both numerically and by weight by macrourids. While small macrourids prey largely on benthic organisms, the primary food of larger individuals appears to be pelagic organisms (Pearcy and Ambler 1974). These fishes are perhaps best characterized as both predators and scavengers. They are not dependent on large organic falls (e.g., sinking carcasses), but are instead adapted to utilize a wide variety of prey types. It is not clear whether they occasionally rise far above the bottom to ingest pelagic prey, or whether the prey itself approaches the bottom and is ingested there (Pearcy and Ambler 1974).

Outer Continental Shelf Environments off the Pacific Northwest Coast--

As in open ocean environments, virtually all of the primary production over the outer continental shelf of the Pacific Northwest is attributable to phytoplankton. Unlike open ocean waters, however, where both phytoplankton standing stock and primary production are typically low due to light limitation in winter and nutrient limitation in summer, phytoplankton production over the shelf may be considerably higher, due in large part to seasonal coastal upwelling (Peterson and Miller 1975). During fall and winter (October-March), the prevailing winds are from the south, and the resulting surface flow is to the north and onshore. During spring and summer (April-September), however, the prevailing wind is from the north, and the surface flow is to the south and offshore. This results in the upwelling of deeper, nutrient-rich water over the shelf. This upwelling is not a constant process, but varies with the strength of the wind. It is

often most pronounced during the months of July and August (Peterson and Miller 1975).

Upwelling is generally most intense at a distance of approximately 10 km from the coast, but it affects an area approximately 50 km wide, extending out over the upper continental slope (Peterson et al., 1979). The surface layer moving seaward may only be 5 m deep within 10 km of the coast, but deepens to 10-15 m farther offshore. The water which is upwelled originates over the outer continental shelf (20-35 km offshore) in depths of 100-200 m. Because this water is rich in nutrients, it is capable of stimulating phytoplankton production, which otherwise would be limited by the availability of fixed nitrogen, just as in the open ocean waters in summer. Hence, during intense upwelling, dense phytoplankton concentrations exhibiting high production are found near the surface from a few kilometers offshore to the edge of the continental shelf and sometimes beyond (Peterson et al., 1979). As a consequence, annual phytoplankton production over the shelf is high (300 g C/m^2) relative to offshore areas (125 g C/m^2) (Anderson 1972).

The Columbia River plume (a region of lower salinity water near the surface) may extend over parts of the continental shelf and slope in spring and summer. This plume may stabilize the upper water column earlier in the year than would thermal stratification, and therefore the spring bloom may occur earlier in areas affected by the plume. In such areas, however, the resulting halocline limits upward transport of nutrients in summer, and causes the phytoplankton to be nutrient limited. In areas affected by the plume, the annual primary productivity may be no greater than in offshore regions (125 g C/m^2) (Anderson 1972).

Anderson (1972) reported that over the shelf, diatoms dominated the winter and spring phytoplankton communities. Net phytoplankton (defined as cells > 35 um in size) were always a small part of the total phytoplankton community.

Zooplankton inhabiting the waters overlying the continental shelf are predominantly subarctic in faunistic affinity. Five copepod species dominate the zooplankton community, and each has a different pattern of distribution (Peterson et al., 1979). Acartia clausi is almost completely restricted to the upper 5-10 m of the water column and the first 5 km from shore. Pseudocalanus sp. is abundant from 0-15 km from shore and between 10-20 m depth, but it reproduces only within a few kilometers of shore. Acartia longiremis lives and reproduces offshore (10 km) in the surface (0-10 m) mixed layer. Oithona similis is abundant offshore (10 km) between 10-20 m depth. Calanus marshallae lives offshore as older copepodite stages, but the females return shoreward and lay their eggs at about 10 km from shore. The nauplii and younger copepodites of C. marshallae develop in the very nearshore zone. Other less abundant zooplankton species probably have distributions similar to one or another of the above. The population of each species appears to be maintained within the upwelling zone by a specific relationship between its distribution, life cycle, and the shelf circulation patterns (Peterson et al., 1979). Most of the abundant zooplankton species are herbivores, and hence their populations may be enhanced by the presence of coastal upwelling.

Some pelagic fishes of the open ocean are also common in waters over the continental shelf (e.g., salmon); other abundant pelagic fishes may be more or less confined to coastal waters [e.g., Pacific mackerel (Scomber japonicus), northern anchovy (Engraulis mordax); cf. Clemens and Wilby 1961].

Waters above the continental shelf of the Pacific Northwest coast represent an important migratory route for California gray whales (Eschrichtius robustus), which annually migrate between feeding grounds in the Bering Sea and breeding grounds off Baja California. Other marine mammals [e.g., killer whales (Orcinus orca), sea otters (Enhydra lutris), and porpoises] are known to inhabit the area.

Due to the relatively shallow water column over the continental shelf, there is essentially no mesopelagic fauna there.

Benthic communities on the continental shelves are strongly influenced by the physical-chemical environment. Important factors include the amount of wave energy reaching the bottom, the grain size of the sediments, and the organic content of the sediments. Off the Oregon coast, for example, the bottom out to a distance of approximately 20 km from shore is 100 percent sand, with a very low organic carbon content. This is a consequence of the large waves passing over the shelf, which apparently have enough energy down to depths of 80 m to keep smaller sediment particles in suspension. Beyond 20 km from shore, the silt and clay fraction of the sediments increases, until at the shelf break, silt and clay represent 30 percent of the sediments on the bottom. The organic carbon content of the sediments also increases with increasing distance from shore. This is in part a consequence of the decreasing particle size, since organic materials tend to be adsorbed onto clay and silt size particles. It also reflects the higher primary productivity over the outer shelf, which is a result of coastal upwelling (Carey 1972).

Over sand substrates on the inner continental shelf, macroepibenthic organisms are relatively rare, and dominated by mollusks (Carey 1972). Farther offshore, shrimps, echinoids, and ophiuroids are common, and by the time the shelf break is reached (depths of 150-200 m) shrimps have become the dominant macroepibenthic organisms (Carey 1972). On the outer shelf, crabs, polychaetes, and gastropods are also common. Both the numerical density and the biomass of the macroepibenthos increase with distance offshore to depths of 200 m. Carey (1972) reported, for instance, that the biomass of macroepibenthic organisms was 73 times higher at a depth of 200 m than at a depth of 50 m off the Oregon coast.

Unlike the epifauna, the infauna has a bimodal distribution; numerical abundance of infauna is high both close to shore and near the edge of the shelf (Carey 1972). Biomass estimates are not as readily available for infauna, although there are indications of a large standing stock near the edge of the shelf. Nearshore, the infaunal communities are dominated by filter-feeding organisms, such as gammarid amphipods. On the outer half of the shelf, the infaunal communities are dominated by deposit-feeding

organisms, especially polychaetes. The high abundance of filter-feeding organisms on the inner shelf reflects the fact that the bottom is within the euphotic zone, so these infaunal organisms have access to phytoplankton. The abundance of deposit-feeding organisms on the outer shelf is a consequence of the finer particle size and the higher organic content of the sediments (Carey 1972).

Demersal fishes are particularly abundant at depths of 91-411 m offshore of the Pacific Northwest coast (Alton 1972). On the outer continental shelf (at depths of 91-183 m) rex sole (Glyptocephalus zachirus), English sole (Parophrys vetulus), slender sole (Lyopsetta exilis), and blackbelly eelpout (Lycodopsis pacifica) are abundant. Rex sole are known to feed on polychaetes. Both English sole and blackbelly eelpout feed on polychaetes, clams, and brittlestars. Slender sole, on the other hand, apparently feed primarily on euphausiids and other pelagic crustaceans (Alton 1972). On the upper continental slope (at depths of 183-411 m) rockfishes (notably Pacific ocean perch, Sebastes alutus), Dover sole, and Pacific hake (Merluccius productus) are abundant. Rockfishes and hake ingest pelagic organisms, such as fishes and squid, while Dover sole prey on benthic organisms (Alton 1972). Seasonal changes in the availability of demersal fishes on the shelf appear to be related to onshore movements of several species: Pacific hake, Dover sole, arrowtooth flounder (Atheresthes stomais), and sablefish (Anoplopoma fimbria) (Alton 1972).

Nearshore Environments of the Pacific Northwest Coast--

The coastline of the Pacific Northwest includes rocky headlands, sandy beaches, and estuaries (e.g., Grays Harbor, Willapa Bay, Columbia River, Tillamook Bay). Only the open ocean environments (exclusive of the estuaries) will be discussed below. Each represents a unique habitat for marine organisms.

Along some sandy beaches of the Pacific Northwest, especially those in Washington, a curious community of diatoms is particularly abundant in fall, winter, and early spring (Lewin and Hruby 1973). These diatoms, primarily Chaetoceros armatum and Asterionella socialis, are abundant only in the surf zone. Chaetoceros armatum is particularly interesting because it is well adapted to growing when ambient light intensities are so low that planktonic diatoms are unable to achieve any net production. This centric diatom floats on the surface during the day, and alters the surface properties of the surf bubbles in such a way that a stable foam is formed (Lewin and Hruby 1973). Waves carry these foamy masses towards shore, retaining these cells within the surf zone. When the tide recedes, there is a tendency for this material to be left behind on the beach, which also tends to retain these cells within the area. Cells not deposited on the beach are dispersed throughout the water column at night. Flotation at the surface during the daytime and intermittent stranding on the beach positions the cells where they can receive the maximum available light (Lewin and Hruby 1973).

Pacific razor clams (Siliqua patula) appear to be the dominant herbivore utilizing these surf-zone diatoms (Lewin et al., 1979). These abundant burrowing clams inhabit the sandy beaches both intertidally and

subtidally. They must feed on the diatoms primarily at night when the cells are dispersed throughout the water column. Dissolved nitrate may be available in very low concentrations in the surf zone during the summer. During such times, the excretion of ammonium as a waste product by these clams may be important for the continued growth of the surf-zone diatoms, since ammonium can serve as another source of fixed nitrogen (Lewin et al., 1979).

Rocky shorelines of the Pacific Northwest provide hard substrate for the attachment of benthic algae and many animal species. While the benthic algae are important primary producers in this environment, the fact that the competitive dominant benthic organism on wave-swept rocky intertidal shores is a filter-feeder, the California mussel (Mytilus californianus (cf. Paine and Levin 1981), indicates that phytoplankton are also abundant. The communities inhabiting these rocky shorelines are complex assemblages of organisms which include representatives of many of those types common on rocky shorelines worldwide (e.g., starfish, limpets, chitons, barnacles, sea urchins, sea anemones, brown and red algae, etc.). These rocky shorelines also provide important habitat for Stellar sea lions (Eumatopias jubata) in Oregon and the recently re-introduced sea otters (Enhydra lutris) in Washington.

Extending offshore from just beyond the surf zone to a distance of approximately 10 km from the coast is a region where phytoplankton production may be influenced by many of the same factors mentioned above in conjunction with the discussion of primary production over the outer continental shelf. Coastal upwelling is an important feature in this region in summer, but is should be noted that during intense upwelling, the water found near the surface in this region has only recently been upwelled and is consequently high in nutrients but low in chlorophyll (an indicator of phytoplankton standing stock). Chlorophyll concentrations may be an order of magnitude lower than in the region farther offshore, where phytoplankton have had time to respond to the increased availability of nutrients (Peterson et al., 1979). During relaxed upwelling, the offshore surface waters will again move shoreward and large phtyoplankton blooms may develop within the nearshore region. If upwelling does not occur for an extended period of time, a subsurface chlorophyll maximum may form, and chlorophyll concentrations at the surface will again be low (Peterson et al., 1979).

The nearshore region constitutes a very special habitat for zooplankton, since a number of species (e.g., the copepods Acartia clausi and Centropages abdominalis; the cladocerans Evadne nordmanni and Podon leukartii) are virtually restricted to this region. Their mechanisms for remaining within this area, even during periods of intense upwelling, are not entirely understood (Peterson et al., 1979).

Abundant subtidal benthic organisms on sandy substrates in the nearshore environment include the previously mentioned filter-feeding amphipods and razor clams. Large epifaunal organisms are not as abundant as farther offshore, presumably due to the heavy wave action (Carey 1972).

Pelagic fishes of the nearshore environment off the Pacific Northwest coast include some of those species discussed previously with regard to the continental shelf environment (e.g., Pacific mackerel, northern anchovy, salmon).

Pacific Northwest Fisheries--

Fishing is an important economic activity in the states of Washington and Oregon. In 1980, nearly 128,000 mt of fish were landed in the two states with a landed value of over $141 million (Resource Statistics Division 1981). Fisheries range from those conducted on rather low-valued groundfish to those for high-valued species such as salmon and Dungeness crab.

Ocean currents are a major influence on the coastal and high seas fisheries of the Pacific Northwest. Coastal currents flow in a northerly direction over the shelf in the winter and then reverse direction during the spring (Glude 1971). The distribution and abundance of pelagic species are influenced by these current patterns. During the summer months, warm offshore currents bring albacore (Thunnus alalunga) to the Pacific Northwest region where an intensive, short-term fishery is conducted in some years.

The second important oceanographic characteristic with respect to the fisheries of this region is the relatively narrow continental shelf. A maximum shelf width of approximately 65-70 km occurs off Central Oregon (Heceta Bank) and at the mouth of the Columbia River (PFMC 1980). The average shelf width is 50 km off Washington and 40 km off Oregon. The small area of the shelf limits the size of potential demersal fishery resources.

A variety of fishing gear is employed in the northwest; this includes bottom trawls, mid-water trawls, pots, set nets, longlines, and trolling gear.

Fishing Areas--The northwest trawl fishery is conducted over a range of depths on the continental shelf and slope. It is a multispecies fishery with catch composition gradually changing with distance along the coast. Forty-eight species define the management unit in the Pacific Fishery Management Council's Groundfish Fishery Management Plan (PFMC 1980). These species range from the underutilized sharks and skates to the 22 species of rockfish.

In Oregon, bottom trawls are fished in depths to 457 m, primarily in the area between the Columbia River and Tillamook Head, and off Newport. Target species include lingcod (Ophiodon elongatus), Pacific cod (Gadus macrocephalus), Pacific hake (whiting) (Merluccius productus), sablefish (Anoplopoma fimbria), rockfishes (Sebastes spp.), Dover sole (Microstomus pacificus), English sole (Parophrys vetulus), petrale sole (Eopsetta jordani), rex sole (Glyptocephalus zachirus), and other flatfishes (Glude 1971; PFMC 1980). Similar species are exploited by Washington fishing fleets to depths of 732 m (PFMC 1980).

Limited deepwater bottomfisheries for grenadiers (Coryphaenoides acrolepis), sablefish, longspine thornyheads (Sebastolobus altivelis), and Dover sole are conducted in depths ranging from 732 to 1,280 m along the continental slope (PFMC 1980).

Midwater trawls harvest Pacific hake, widow rockfish(Sebastes entomelas) and shortbelly rockfish (S. jordani) over the continental shelf. The rapidly developing widow rockfish fishery is currently centered off headlands such as Cape Blanco and Tillamook Head, on Heceta Bank, and over the Astoria Canyon (Schafer 1981). The hake fishery takes fish which have migrated into outer shelf and upper slope regions from spawning areas off Southern California.

Longlines and traps are the primary gear types used in fishing for sablefish at depths of 150 to 1,200 m on the outer shelf and slope, although the species is also taken incidentally in bottom trawl fisheries (Low et al., 1976).

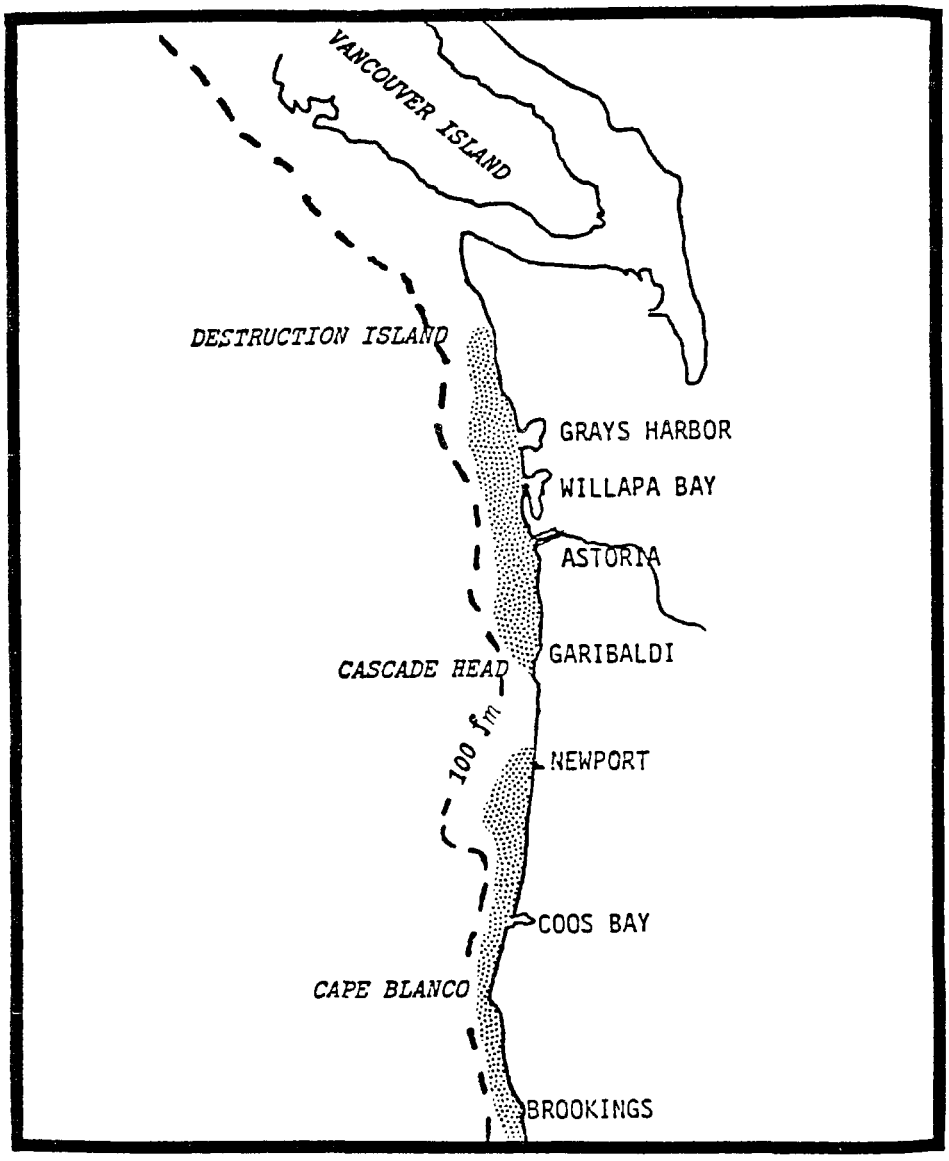
Trawls and longline gear are also used for harvesting rockfishes and lingcod (PFMC 1980).

Annual trawl landings along the Washington to California coast during 1970-1979 averaged 43,876 mt. The ex-vessel value in 1979 was over $19 million, about 75 percent of which was attributable to rockfishes, Dover sole, petrale sole, English sole, and sablefish (PFMC 1980). Pacific cod contribute about 10 to 15 percent to the annual trawl landings (Browning 1980).

Troll salmon fisheries generally occur in water depths of less than 200 m. In Washington, the majority of the catch is taken within 4.8 to 19.3 km of shore (PFMC 1978c). The two species which account for the majority of the troll catch are chinook salmon (Oncorhynchus tshawytscha) and coho salmon (O. kisutch), the former species generally taken closer to shore than the latter (PFMC 1978c). Small troll landings of pink salmon (O. gorbuscha) are also made during odd-numbered years. Nearly 4,000 vessels participated in the Oregon troll fishery during 1980, landing 592,588 salmon valued at $8 million (PFMC 1981a). In Washington, 502,200 salmon were caught by 2,700-2,900 vessels (PFMC 1981a). No data are available concerning the value of the 1980 fishery, although during 1971-1976, values ranged from $3.7 to $13.8 million (PFMC 1978c).

The northwest Dungeness crab (Cancer magister) fishery is conducted in shallow (<91 m) coastal waters from Destruction Island in Washington to Cascade Head in Oregon and also from Newport southward (Figure 96). The fishery is concentrated in areas where sand and mud substrates predominate (PFMC 1979). Annual landings in Washington have averaged over 3.6 million kg since 1951, and the average yearly value was $3 million during 1968-1976 (PFMC 1979). Comparable statistics for Oregon are 3.8 million kg with an average value of $3.5 million (PFMC 1979).

The pink shrimp (Pandalus jordani) fishery of the Pacific Northwest is a relatively new development. This fishery is concentrated beyond 4.8 km



[a] Adapted from Figure 2, PFMC 1979.

Figure 96. Pacific Northwest Dungeness crab fishing areas.

from shore in depths of 91 to 183 m and occasionally in depths as shallow as 64 m or as deep as 302 m over bottoms of green mud or a mixture of mud and sand (PFMC 1981b). Productive shrimp grounds are located from Destruction Island in Washington to Newport, Oregon, and also off the central portion of Oregon (Figures 97 and 98). In 1980, landings were 13.6 million kg valued at $16.6 million in Oregon and 5.7 million kg worth $6.76 million in Washington (PFMC 1981b). The 1980 Oregon shrimp fleet included 222 vessels, while in Washington, 37 boats were involved in this fishery (PFMC 1981b).

A sporadic fishery for albacore occurs off Washington and Oregon. Albacore are present when warm water masses extend into the northeast Pacific. Most albacore are taken between 80 - 241 km offshore during late summer and early fall (i.e., July to October), but they are occasionally caught as far as 482 km from shore (Browning 1980). It is estimated that up to 4,000 vessels enter the albacore fishery on the Pacific coast in years when large catches are predicted or when success in other fisheries is poor (Browning 1980).

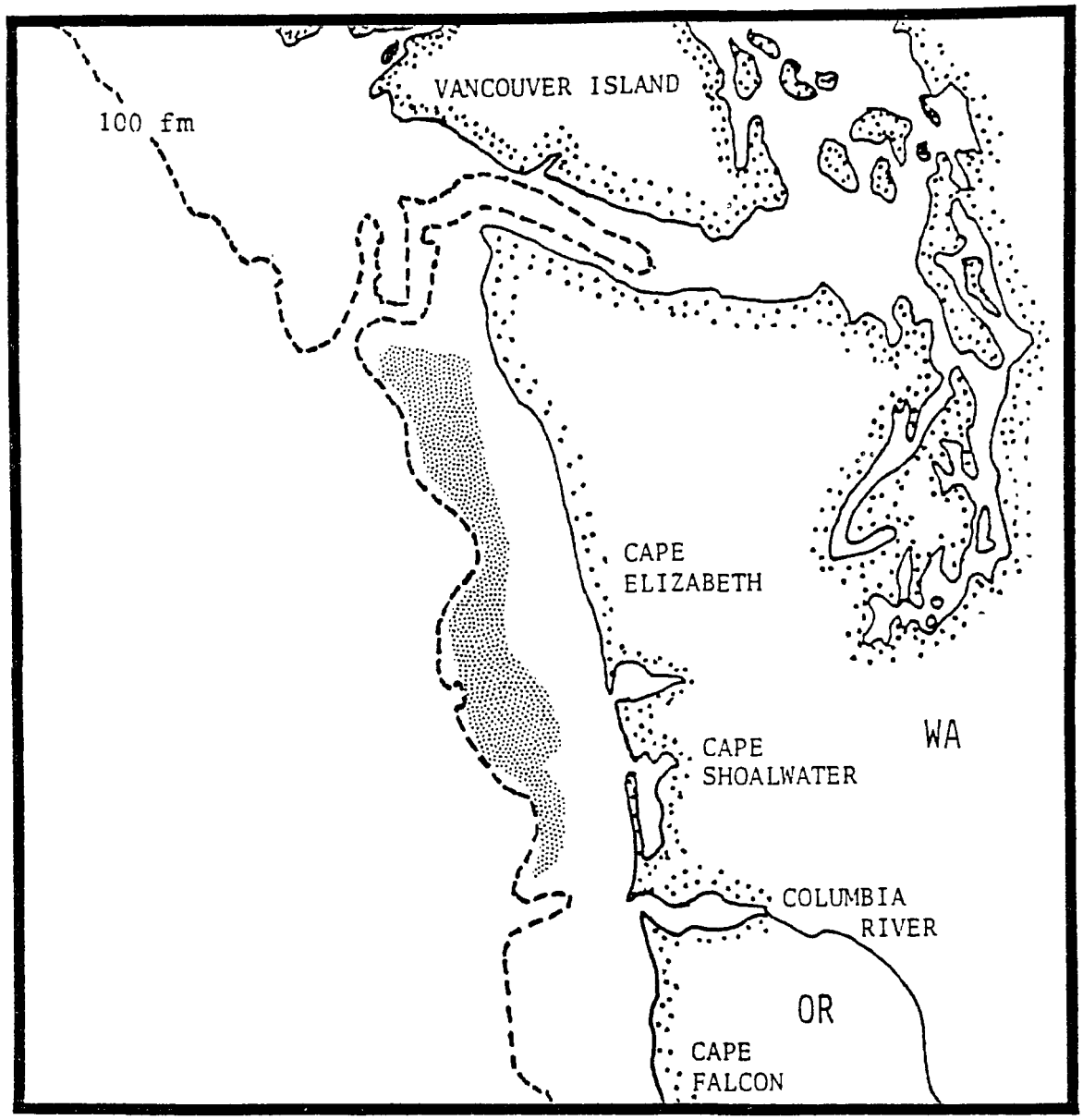
Currently, there are several fish species which remain underutilized by the Pacific Northwest domestic fleet. Groundfish species such as skates (Raja spp.), sharks (Squalus acanthias), Pacific hake, and some flatfishes have either not gained market acceptance or processing costs remain prohibitive. However, some of these species are sought by foreign fisheries, and recently joint venture operations between U.S. and foreign companies have begun exploiting some stocks such as hake.

Pelagic species also hold promise for fisheries development. Pacific herring (Clupea harengus pallasi) are now fished within bays and estuaries of Washington and Oregon. An experimental herring fishery off northern Washington has recently been initiated to determine whether further opportunities to harvest this resource exist (PFMC 1981c).

Pacific hake is another pelagic fish species which is currently underutilized in the Pacific Northwest fisheries. Additional pelagic species for which future fisheries may be developed include anchovies (Engraulis mordax), Pacific mackerel (Scomber japonicus), pomfret (Brama japonica), and squid (Loligo spp.).

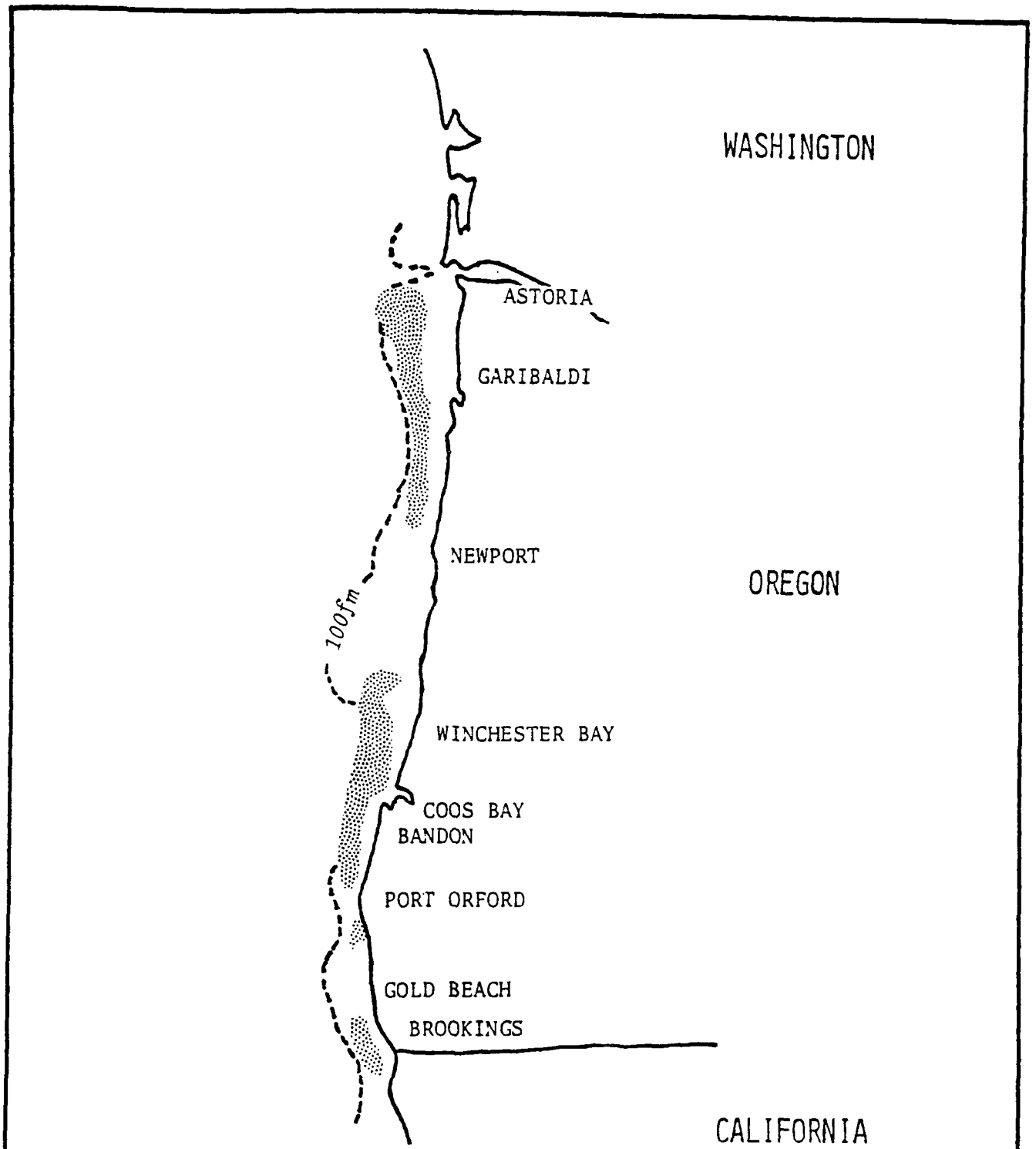
In summary, current Pacific Northwest fisheries are conducted over large areas of the continental shelf and slope from rather shallow coastal depths of less than 36 m to deepwater (1,554 m) areas of the slope. Pelagic fisheries occur at various distances from shore; the salmon troll fishery is conducted primarily within 19 km; the albacore fishery extends to 482 km. Fisheries for Dungeness crab and pink shrimp are located in specific areas off the coasts of Washington and Oregon in depths less than 183 m.

It is likely that in the future currently underutilized species will be taken in areas of traditional fishery activities. Selection of a site for the disposal of manganese nodule processing wastes should include consideration of potential impacts on these fisheries.



[a] Adapted from Figure A3-1 , PFMC 1981b.

Figure 97. Washington pink shrimp fishing areas.



[a] Adapted from Figure A2-1, PFMC 1981b.

Figure 98. Oregon pink shrimp fishing areas.

Fishery Biology--Since 48 species of groundfishes are taken in the fisheries, only general aspects of their species biology will be addressed.

Most groundfishes spawn during winter or early spring (Table 55), with a migration to deeper waters preceding spawning. The exception is lingcod, which migrates into shallow rocky reef areas to spawn during October and November. Rockfishes of the genus Sebastes are ovoviviparous (i.e., bearing young alive) and many species form dense schools at certain times of the year (PFMC 1980). Some rockfish species, such as splitnose (Sebastes diploproa), stripetail (S. saxicola), sharpchin (S. zacentrus), shortspine thornyhead (Sebastolobus alascanus), and redstripe (Sebastes proriger), exhibit slow growth and relatively low productivity when compared to other members of the group (PFMC 1980).

Oviparous (egg-laying) groundfish species demonstrate a range of reproductive strategies. Eggs may be pelagic (e.g., Pacific hake), semipelagic (initially demersal, subsequently pelagic) (e.g., Pacific halibut), demersal without parental care (e.g., Pacific cod), or demersal with parental care (e.g., lingcod) (Hart 1973).

The majority of groundfishes feed on macroplankton (e.g., euphausiids) or benthic invertebrates. Many are opportunistic feeders, and some are piscivores (Hart 1973).

Groundfishes occupy a wide range of habitats and depths. During northerly feeding migrations from spawning areas offshore of southern California in spring and summer, Pacific hake aggregate in midwater over the outer shelf and upper slope areas of the northeastern Pacific. Adult sablefish are generally found in the deeper waters of the continental slope over mud-sand bottoms. Pacific cod, lingcod, and most flatfish species occur predominantly on the shelf. However, Dover sole, rex sole, and petrale sole frequently inhabit slope areas as well (PFMC 1980). Mud and sand substrates appear to be the preferred habitat of flatfishes.

Table 55 lists the wide depth distributions of the rockfishes. These range from the extreme depth of 1,554 m occupied by the shortspine thornyhead to the nearshore areas inhabited by black rockfish (Sebastes melanops). Generally, rockfishes occur over hard, rocky bottoms (PFMC 1980).

Inshore areas are important in the life cycles of several groundfish species. The intertidal and nearshore areas serve as a nursery area for many species (Hart 1973).

Most groundfish species do not display extensive migrations along the coast. The exceptions are petrale sole, sablefish, and Pacific hake, which are known to travel long distances (PFMC 1980).

Salmon life cycles involve both freshwater and marine components. Chinook and coho salmon are the primary species caught in the ocean fisheries.

TABLE 55. SPAWNING PERIODS AND DEPTHS INHABITED BY PRINCIPAL GROUNDFISH SPECIES OFF WASHINGTON AND OREGON[a]

Species	Spawning Period	Depth Range (m)
Roundfishes:		
Lingcod (Ophiodon elongatus)	Oct-Nov	2-183
Pacific Cod (Gadus macrocephalus)	Jan-Mar	18-165
Pacific Hake (Whiting) (Merluccius productus)	Jan-Apr	36-503
Sablefish (Anoplopoma fimbria)	Nov-Apr	146-1,829
Rockfishes:		
Black (Sebastes melanops)	ND	0-91
Blue (S. mystinus)	Jan-Mar	0-91
Bocaccio (S. paucispinis)	Nov-Mar	73-219
Canary (S. pinniger)	Nov-Mar	91-219
Chilipepper (S. goodei)	Nov-Mar	110-274
Darkblotched (S. crameri)	Nov-Mar	91-457
Pacific Ocean Perch (S. alutus)	Feb-Mar	91-457
Shortbelly (S. jordani)	Jan-Apr	91-274
Shortspine Thornyhead (Sebastolobus alascanus)	Mar-May	274-1,554
Silvergray (Sebastes brevispinis)	Jun	91-274
Splitnose (S. diploproa)	Feb-Jul	183-457
Stripetail (S. saxicola)	Nov-Mar	91-274
Vermilion (S. miniatus)	Nov-Mar	18-201
Widow (S. entomelas)	ND	55-320
Yellowtail (S. flavidus)	Nov-Mar	73-219
Flatfishes:		
Arrowtooth Flounder (Atheresthes stomais)	Dec-Mar	55-640
Dover Sole (Microstomus pacificus)	Nov-Mar	36-1,463
English Sole (Parophrys vetulus)	Nov-Mar	18-274
Pacific Sanddab (Citharichthys sordidus)	Jul-Sep	18-110
Petrale Sole (Eopsetta jordani)	Nov-Mar	36-457
Rex Sole (Glyptocephalus zachirus)	Jan-Jun	36-457
Starry Flounder (Platichthys stellatus)	Nov-Feb	0-165

[a] Adapted from Table 12 of PFMC (1980).

ND = no data available.

Young chinook salmon migrate into marine waters after spending approximately 1 yr in freshwater (spring chinook) or less than a year (fall chinook) (Cumbow 1977). These species undertake wide-ranging migrations in the northern Pacific Ocean, feeding on small fishes [e.g, sand lance (Ammodytes hexapterus), eulachon (Thaleichthys pacificus), herring] and crustaceans (Cumbow 1977; Hart 1973). Chinook are known to venture out to 1,600 km offshore where they remain well below the surface (Hart 1973). The chinook spawning migration to coastal rivers occurs in late spring and early fall when the adults are 3 to 5 yr of age (Cumbow 1977). The adults feed on fishes, particularly herring and sand lance. The Columbia River chinook stock contributes substantially to the ocean troll fishery off Washington and Oregon (Cumbow 1977).

Coho salmon migrate out of freshwater streams after a 1 yr residence (Cumbow 1977). The marine migrations of juvenile coho are believed to be less extensive than those undertaken by chinook (Cumbow 1977). Young coho feed on squid, euphausiids, and fishes while at sea (Hart 1973). Adults return primarily as 3 yr olds, with spawning migrations occurring in September and October (Cumbow 1977). Mature coho also feed primarily on herring and sand lance.

Pink, chum, and sockeye salmon also spend portions of their lives in open ocean waters, but are not important in the ocean fisheries.

Dungeness crabs mate between February and June, with peak activity occurring during April (PFMC 1979). Egg-bearing females occur in Washington coastal waters during November to March and in Oregon during October to March (PFMC 1979). Eggs hatch during the winter in shallow nearshore waters.

Crab larvae are pelagic for approximately 3 to 5 mo while they drift offshore during the winter to distances of as much as 96 km from shore (PFMC 1979). Coastal estuaries and bays are nursery areas for juvenile crabs.

Dungeness crabs are opportunistic feeders, taking primarily crustaceans, clams, and fishes (PFMC 1979). Also included in the diet are echinoderms, snails, and polychaetes. Preferred habitat for Dungeness crabs is sand or sand and mud bottoms, although rock and gravel areas may also be utilized (Browning 1980). Dungeness crabs are common to a depth of 91 m but have also been taken in trawls fished at 274 m (PFMC 1979). Extensive large-scale movements of Dungeness crabs between major fishing areas have not been documented. However, seasonal onshore (spring-summer) and offshore (fall-winter) migrations have been observed (PFMC 1979).

Pink shrimp are protandric hermaphroditee (male changing to female). Mating occurs during September and October, with eggs hatching during late March through early April (PFMC 1981b). Larvae undergo 11 to 13 zoeal stages with an average duration of 6.8 days per stage (PFMC 1981b). Although larvae are thought to be pelagic, they do not occur in surface waters. Juvenile shrimp settle to the bottom beginning in July and extending through the fall.

Pink shrimp are primarily detritus feeders, utilizing the remains of polychaete worms, sponges, diatoms, amphipods, and isopods (PFMC 1981b). During diel vertical migrations, shrimp prey on euphausiids and copepods.

Pink shrimp range in depth from 36 m to 457 m and occur over green mud or mixed mud and sand substrates (PFMC 1981b). Maximum shrimp density is believed to occur off central Oregon.

Young, immature albacore occur offshore of Washington and Oregon when warm (14-21^{o} C) water masses extend into the northeast Pacific (Browning 1980). In this area, near-surface feeding albacore take juvenile rockfishes, sauries (Cololabis saira), anchovies, euphausiids, and squid (Hart 1973; Browning 1980). As waters cool, albacore return to the southern latitudes of the North Pacific.

While the fishery for Pacific herring is currently conducted only in the estuaries and bays of Washington and Oregon, important life stages occur in offshore areas. In the fall, adults migrate from ocean feeding areas into protected marine waters to spawn in winter and spring (PFMC 1981c). After spawning, adults return to ocean feeding areas. Schooling juvenile herring also move offshore to feed during March through July (PFMC 1981c). In the ocean, herring are opportunistic feeders, taking zooplankton, crustaceans, molluscs, cephalopods, larval fishes, and pelagic eggs (PFMC 1981c). Additional information on the offshore oceanic component of the herring life cycle is unavailable.

Summary--Several aspects of the biology of the species which support important fisheries should be considered in selecting a disposal site for manganese nodule processing wastes. Demersal eggs may be particularly susceptible to waste disposal, due both to potentially toxic substances and to the physical effects of deposition which may smother the eggs. Pelagic eggs and larvae may be affected by wastes in the water column, especially if toxic components are present. Young rockfishes may be highly vulnerable to wastes discharged in the water column. This is of particular concern for species which are slow growing and have low productivity (e.g., splitnose and sharpchin rockfishes).

Increased turbidity associated with the disposal of manganese nodule processing wastes may affect schooling behavior and migratory activity.

Alteration of the plankton community due to waste discharges may reduce the availability of food organisms upon which many species depend.

Accumulations of wastes on substrates may alter the preferred habitats of demersal species such as flatfishes, Dungeness crabs, and pink shrimp. These species remain in almost continuous contact with the substrate and may be susceptible to contamination from the wastes. Bioaccumulation of potentially toxic substances (e.g., trace metals and other components of the waste material) may induce diseases or other physiological abnormalities. Additionally, if wastes affect food organisms of demersal species, stock abundance may be altered.

In summary, the biological characteristics of important fish species warrant consideration in selecting an appropriate location for waste disposal. Particular areas of critical importance to the life stages of fishes (e.g., spawning, nursery, feeding) should be avoided. Also, specific productive habitats such as the green mud pink shrimp beds and the sandy Dungeness crab grounds warrant consideration of protection from potential adverse effects of nodule processing wastes.

HAWAII

Physical Characteristics

Bathymetry--

Figure 99 presents the bathymetric contours along the axis of Puna Canyon. The morphology of the adjacent Puna Ridge was surveyed using a submersible by Fornari et al. (1979). The ridge is a submarine continuation of the East Rift Zone of Kilauea volcano, and represents a principal locus of submarine volcanic activity and a major outbuilding site for Kilauea. The micromorphology consists of fresh lava pillows and cylinders with a lack of interstitial sediments and benthic fauna. Subaqueous extrusions have created narrow ridges oriented northeast-southwest. The ridge reportedly consists entirely of basaltic lava outpourings similar to those of Kilauea (Moore 1965). At the base of the ridge, lavas appear to "partially overlie the volcaniclastic and possibly pelagic sediments which mantled the early submarine slope of Mauna Loa" (Fornari et al., 1979).

Circulation Patterns--

The primary factors which influence current patterns in Hawaiian waters are the West Wind Drift, tidal motions, and an anticyclonic gyre northeast of the islands. Currents generally show strong tidal variations, frequently including direction traversals over a tidal cycle, but are modified locally by winds, internal wave motions, and other factors.

The small amount of literature on Hawaiian circulation patterns is summarized in Laevastu et al., 1964; Wyrtki et al., 1969; Patzert 1969; Patzert et al., 1970; and Bathern 1976. Data on currents near the Island of Hawaii are very limited. According to the Coast Pilot, along the northeast coast, from Cape Kumukahi the eastern extremity, to Upolu Point the northern extremity, the current sets generally to the northwest. A flood tidal divergence reportedly occurs off Point Kumukahi, driving the northwesterly flow. Laevastu et al. (1964) indicate that flow in this direction persists even on the ebb tide beyond the 183 m (600 ft) depth contour.

In examining data available near proposed dredge spoil disposal sites off of Hilo (Figure 100), it became apparent that previous oceanographic measurements were made either within Hilo Bay or much farther offshore in waters exceeding 3,000 m (10,000 ft) (Neighbor Island Consultants 1977). A very limited amount of current data are available for dredge spoil disposal sites 9 and 9B near Hilo Bay. At the Inner Hilo site 9 which is in 340 m (1,115 ft) of water, two days of surface current measurements (drogue

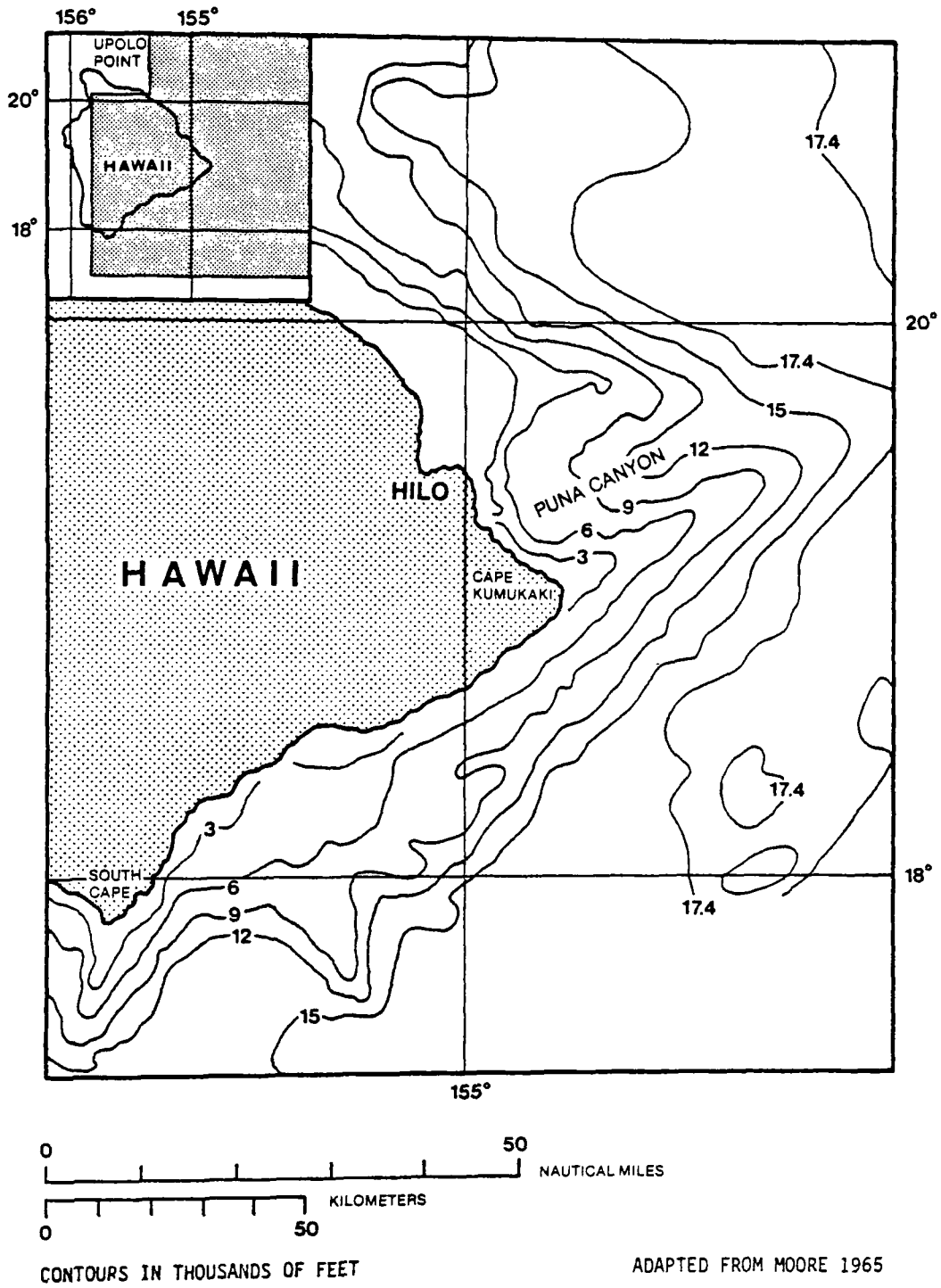


Figure 99. Bathymetry of the Puna Canyon.

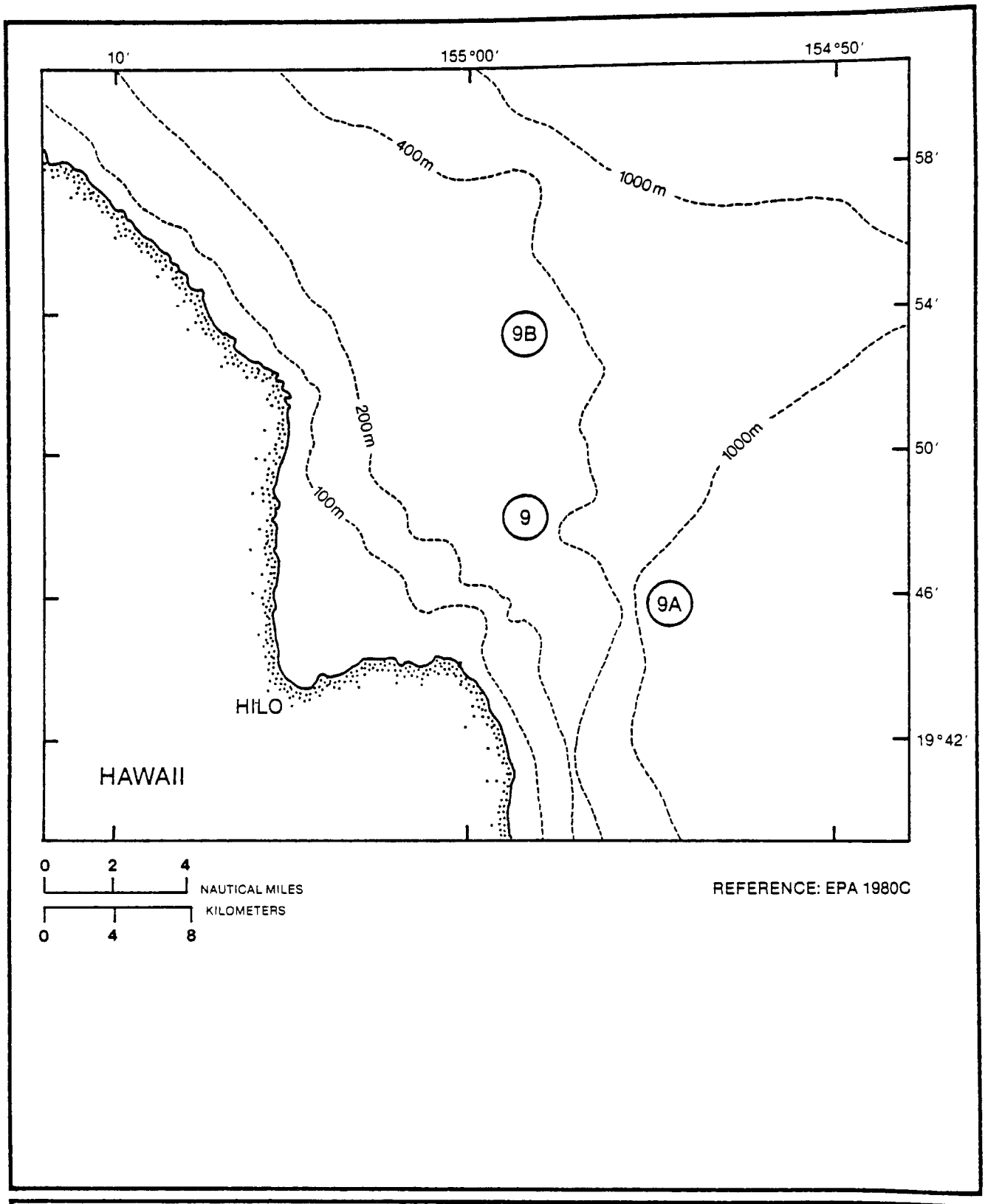


Figure 100. Proposed and alternative dredged material disposal sites.

movements) indicated northwesterly flows at between 15 and 36 cm/sec. Upper subsurface currents were highly variable with some tidal correlation. Deeper currents decreased in magnitude but became more uniform in direction, remaining between 338° and 20° of magnetic north. Surface currents had 180° reversals in direction. At 15 m (50 ft), currents ranged from 15 to 57 cm/sec, decreasing toward the bottom to between 0 and 15 cm/sec. At site 9B (Outer Hilo) which is in 329 m (1,080 ft) of water, surface drogue measurements indicated a moderate west-southwesterly flow. Subsurface currents of less than 26 cm/sec were generally oriented toward the northwest. A tidal influence was evident on all records. The EIS for Dredged Material Disposal Sites Designation (U.S. Environmental Protection Agency 1980c) indicates that current speeds at these sites were 29, 19, 16, and 11 cm/sec for meters at 15, 45, 183, and 340 m, respectively, with deeper flows being towards the north.

Current measurements have also been made at nearby University of Hawaii Station 212 off Alia Point to the north of Hilo in 210 m of water (Wyrtki et al., 1969). August 3 through 15 recordings for a meter at a 30 m (98 ft) depth indicated strong easterly (107° true) average current speeds of 32.7 cm/sec, with weak tidal currents superimposed.

Temperature, salinity, and density data for deepwater stations northeast of the Island of Hawaii, shown in Figure 101, are presented in Figure 102. Based on density data at adjacent stations (Figure 102), geostrophic flows have been calculated for this general area as well (Figure 103).

Additional physical oceanographic data is currently being collected in the Puna Canyon area in conjunction with a Sea Grant-sponsored geological and geochemical assessment of proposed manganese nodule processing waste disposal sites (John Wiltshire, personal communication, 1982). Measurements include temperature, salinity, currents, light levels, and dissolved oxygen.

In January, the surface water temperatures were 25° C, decreasing to 22° C at 152 m (500 ft). At this point, a relatively sharp thermocline occurred down to 243 m (800 ft). Beyond this depth, temperatures continued to decrease, reaching 9° C at 426 m (1,400 ft).

Currents nearshore appear to be southward and can reportedly be as high as 100 cm/sec. Deeper than 30 m (100 ft), currents decrease significantly, becoming negligible. Offshore, from 15 to 35 km, northward surface currents are weaker, being 25.7 cm/sec or less. Subsurface currents decrease quickly as a function of depth, and tend to flow to the south.

Currents along the canyon axis at 426 m (1,400 ft) range from 0 to 13 cm/sec, and directionally are a function of tides, being upcanyon on a rising tide and downcanyon on a falling tide. Bottom visibility is very high due to the lack of any sediment sources nearby, the closest drainage being 50 km (28 mi) away.

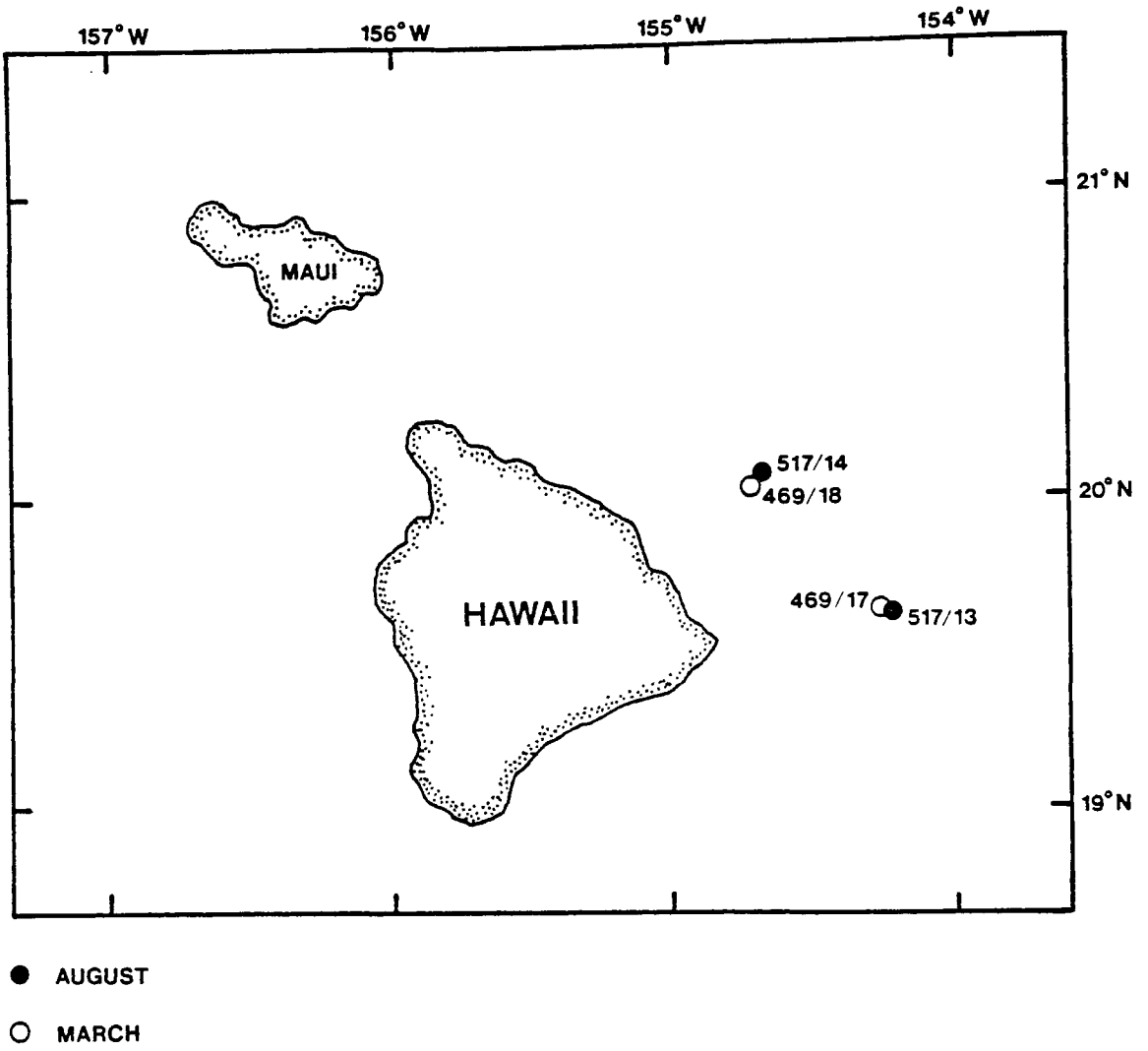


Figure 101. Stations used in the calculation of geostrophic currents.

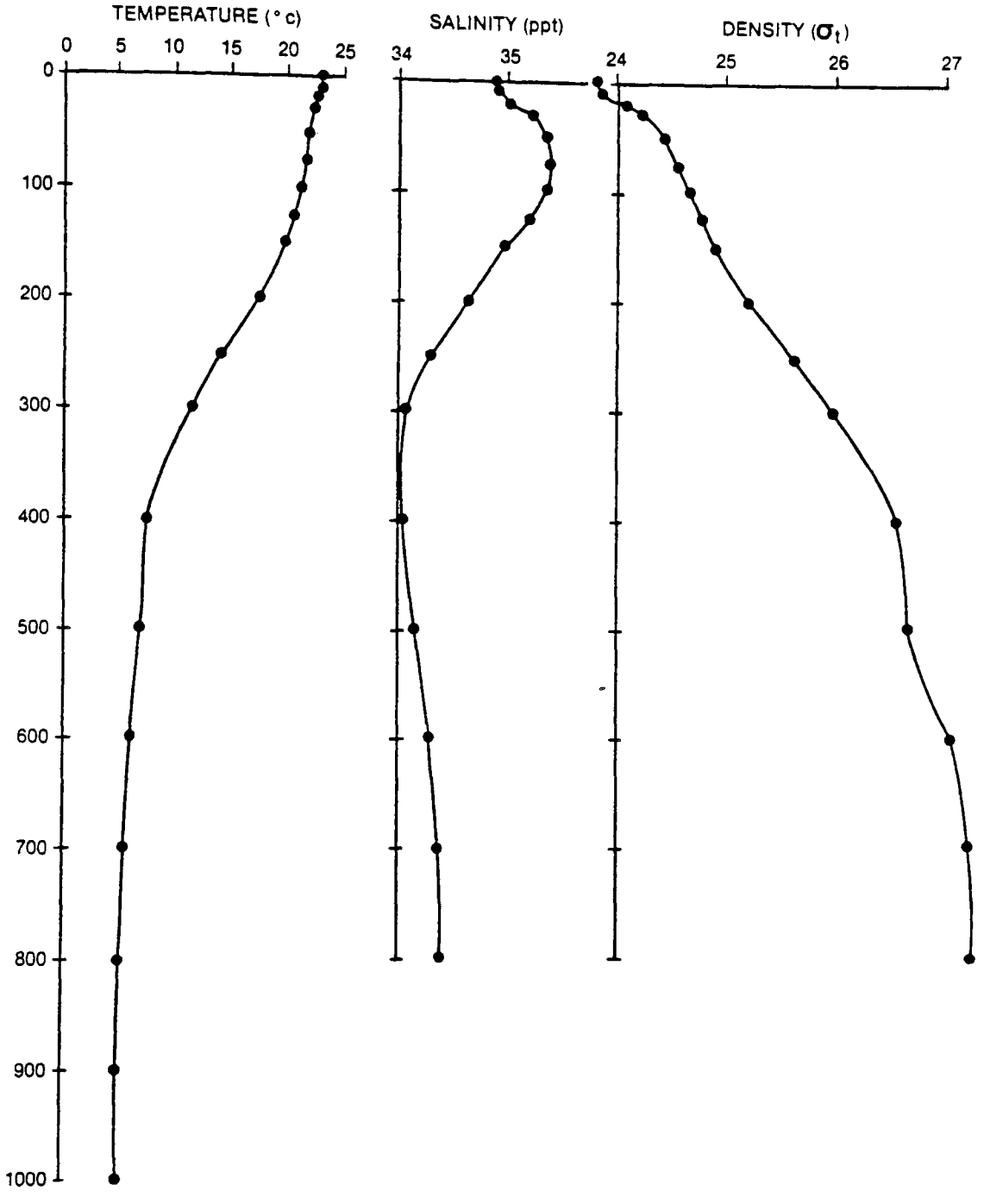


Figure 102. Temperature, salinity, and density at Station 469/18, 20°02'N, 154°44'W, March 17, 1953.

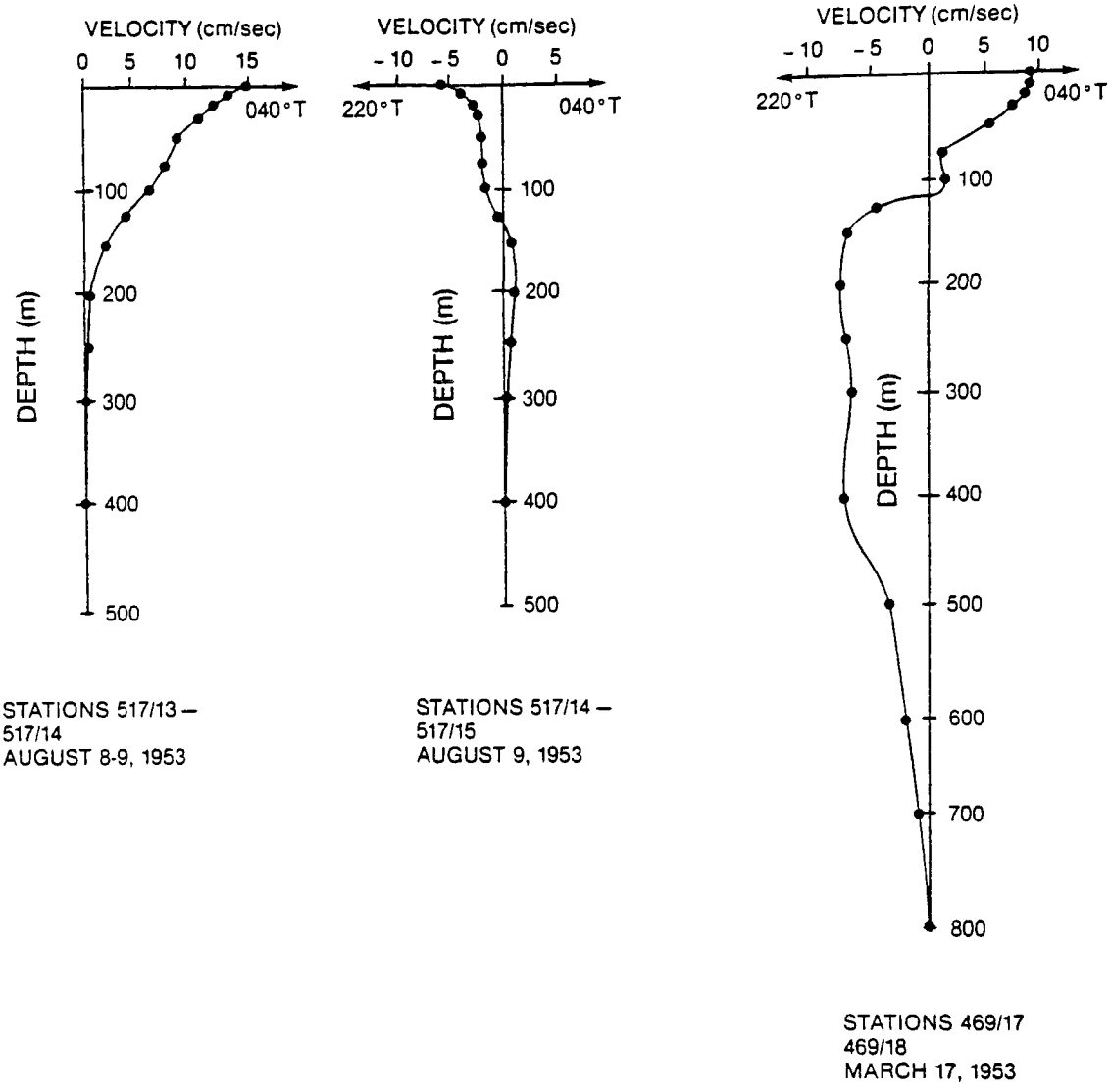


Figure 103. Geostrophic current profiles for waters northeast of the Island of Hawaii.

Representative Area

For the purpose of this project, the Puna Canyon area is discussed in view of its proximity to an existing dredge material disposal site (9B). It should be noted that site 9A in 2,103 m (6,900 ft) of water (Figure 100) was relocated to site 9B due to intense commercial fishing at 9A (Neighbor Island Consultants 1977).

Biological Characteristics

Open Ocean Environments off Hawaii--

In open ocean environments (> 4,000 m depth) of the tropical North Pacific which are far removed from effects of proximity to the Hawaiian islands, virtually all primary production is performed by phytoplankton. Due to its dependence on sunlight, phytoplankton production is limited to the upper (< 100 m usually) sunlit layers of the ocean. All other life in these environments is dependent on the fixation of carbon by phytoplankton, and hence production by the phytoplankton is essential to all higher trophic levels. Phytoplankton production in the tropical Pacific is primarily limited by the availability of nutrients (especially nitrogen as nitrate or ammonium), which are typically in very low concentrations in the upper 100 m (Anderson 1979). Nutrients are supplied to the phytoplankton either by upward transport from deeper, nutrient-rich water, or by excretion of animal wastes. As a consequence of the strong vertical stratification of the water column, the supply of nutrients from deeper waters is slow. Regeneration of nutrients by animals is important, but due to losses from the upper layers (e.g., the sinking of fecal pellets), it cannot completely supply the required nutrients. Since nutrients are in short supply, phytoplankton production is quite low [100-200 mg C m^{-2} day^{-1}; Chan and Anderson (1981)], and consequently, production at all higher trophic levels is also low, relative to coastal and nearshore areas.

One result of the supply of nutrients from deeper waters is that phytoplankton biomass is often greater deep in the euphotic zone than at shallower depths. Venrick et al. (1973) reported, for instance, that a subsurface maximum in chlorophyll *a* concentration (a commonly-used measure of phytoplankton standing stock) was typically found at depths receiving only 0.1-1 percent of the incident light at the surface, and that more than half of the total chlorophyll within the water column was observed below the depth penetrated by 1 percent of the surface radiation. While much of the chlorophyll *a* in the euphotic zone may be contained within nanoplankton (cells < 20 um in size), the relative contribution of net phytoplankton (cells > 20 um in size) may be somewhat greater in the subsurface chlorophyll maximum. This may be a consequence of nutrient deficiency and the resultant sinking of diatoms (Venrick et al., 1973).

Oceanic phytoplankton are primarily consumed by zooplankton, many of which filter these small cells from the seawater. Since body-size of the grazer is often smaller when the food is predominantly small, oceanic zooplankton are typically small relative to those in coastal and nearshore areas. There is a great diversity of zooplankton species in the tropical

Pacific, perhaps best represented by the calanoid copepods, of which there are dozens of species in this environment. While many zooplankton species inhabit the euphotic zone, others perform limited (< 200 m) diel vertical migrations which bring them into the euphotic zone only at night. Zooplankton occur at all depths throughout the water column in the tropical Pacific, but those occurring below about 200 m are almost exclusively carnivores and/or detritivores.

All animals larger than zooplankton which inhabit the water column are classified as nekton. This group includes not only fishes, but squid, shrimp, whales, dolphins, etc. Common fishes occurring near the surface in tropical Pacific waters include flying fishes, dolphin (mahimahi) (Coryphaena hippurus), yellowfin and skipjack tunas (Thunnus albacares and Euthynnus pelamis), marlins, and barracuda (Sphyraena spp.) (Gosline and Brock 1960). Other large pelagic fish species, such as albacore (Thunnus alalunga), bigeye tuna (T. obesus), and broadbill swordfish (Xiphias gladius), occur very infrequently near the surface, and more typically inhabit depths of 37 m or more (Gosline and Brock 1960). Marine mammals of the tropical Pacific include various whale and dolphin species. The larger nekton species are generally strong swimmers which range over large areas of the oceans and are not restricted to a single geographic area. Because oceanic primary production is low in the tropical Pacific, and because these large species of nekton are a number of trophic levels removed from the primary producers, they are quite rare considering the total expanse of the oceans. Nevertheless, certain species (e.g., tunas, whales, dolphins) are known to school, and consequently they may be abundant in a given area for a short period of time.

Many small nektonic species in the tropical Pacific inhabit mesopelagic depths (100-1,000 m), and many of these perform diel vertical migrations into the epipelagic zone (< 100 m) [cf. Clarke (1973, 1974); Clarke and Wagner (1976)]. While these species are widespread, individuals of these species are not as wide-ranging as those of the larger, epipelagic species.

With the exception of flying fishes, which attach their eggs to floating objects, all other pelagic fish species in these environments lay and fertilize their eggs in the sea itself (Gosline and Brock 1960). The eggs and larvae, collectively referred to as ichthyoplankton, are carried about by the currents. The larvae are typically very small, and dependent on plankton for food.

Another important, although temporary, component of the open pelagic community is the young of reef and inshore fishes. While in some cases the occurrence of these young fishes in the epipelagic zone of the open sea may be a chance effect of currents carrying small fishes with limited swimming abilities away from their normal inshore habitat, in other cases, the young of certain species (e.g., surgeonfishes, goatfishes, eels) may possess certain characteristics which represent adaptations to an open sea existence (Gosline and Brock 1960).

Benthic animals, including both organisms living in and on the sea floor and demersal organisms swimming just above the sea floor, are entirely

dependent on the production of organic matter in the overlying waters. Organic matter is transported to the deep sea benthos by sinking carcasses, fecal material, exoskeletons, and detritus, and by the vertical migrations of some nektonic species. Since the supply of organic matter is inversely related to the distance from the surface, and since primary production in the tropical Pacific is very low, deep benthic life there is sparse by comparison to benthic communities in shallow, nearshore areas. Very little is known about the life histories, reproductive strategies, modes of feeding, etc. of the deep-sea benthos in the tropical Pacific. Suffice it to say, however, that these communities are ill-adapted to environmental perturbations of any kind, since temperature, salinity, chemical concentrations, rate of sedimentation, etc. are virtually constant at any given location. Deep-sea benthic organisms are typically either large, mobile scavengers able to locate and utilize large organic "windfalls" such as carcasses, or very small (less than a few millimeters in length) and not very mobile organisms living on or in the sediments.

In a study of the deep-sea benthos at a site underlying the North Pacific Central Water Mass north of Hawaii, Hessler and Jumars (1974) reported that macrofaunal abundances ranged from only 84-160 individuals/m^2, with polychaetes dominant. Other abundant taxa included tanaids, bivalves, and isopods. Meiofaunal abundances were at least 1.5-3.9 times larger than those of macrofauna, with nematodes dominant. Other abundant taxa included foraminifera and xenophyophoridans, although separating living from dead individuals of each was impossible. The primary mode of feeding for the benthic fauna appeared to be deposit feeding. Diversity was high, but the abundances of individual species were very low.

Shelf Environments of Hawaii--

Due to the relatively narrow shelves surrounding the Hawaiian islands, the available shelf environment is small. Nevertheless, there are some important differences between the shelf communities and those in either open ocean or nearshore environments.

As in open ocean environments, virtually all of the primary production in the shelf communities surrounding the Hawaiian islands is attributable to phytoplankton. Unlike open ocean waters, however, where both phytoplankton standing stock and primary production are typically quite low, phytoplankton communities near the Hawaiian islands are apparently influenced by a so-called "island mass effect," which increases both the phytoplankton production and standing stock, especially on the leeward side of the islands. Gilmartin and Revelante (1974) reported, for instance, that phytoplankton standing stocks (as measured by chlorophyll a concentrations) at stations less than 1 km from the coast were approximately double those in offshore waters, while rates of primary production were 4-5 times higher at these stations than in offshore areas. Whereas phytoplankton in offshore open ocean areas were apparently nutrient limited, those at stations less than 1 km from the coast did not appear to be nutrient limited. Gilmartin and Revelante (1974) attributed this apparent "island mass effect" to turbulence and vertical mixing in the channels between the islands. Although such an effect would be expected on the leeward side of the

Hawaiian islands (i.e., to the west of the islands, since the prevailing ocean currents are towards the west), due to tidal reversals of the currents in the island channels, there may be a similar, albeit less pronounced, effect on the windward (i.e., eastern) side of the islands. Gilmartin and Revelante (1974) noted an increased proportion of net phytoplankton (including a number of neritic diatom species) and a decreased proportion of nanoplankton at stations close to shore, relative to those in offshore waters.

Due to the narrowness of the Hawaiian shelves, it is unlikely that a resident zooplankton community would develop there. Instead, it is more likely that zooplankton present in this environment would be composed of a mixture of oceanic and neritic species.

In inshore Hawaiian waters at depths less than 30 m, the pelagic fish community consists of both some of those species listed previously which are more typically found farther offshore, and other species which are to a major extent restricted to this area [e.g., bonito (Euthynnus yaito), bigeye scad (Selar crumenoptalmus), mackerel scad (Decapterus spp.); cf. Gosline and Brock (1960)].

Nearshore waters of the Hawaiian islands represent important habitat for the endangered humpback whale (Megaptera novaeangliae). These whales, which spend the summers in subarctic waters and overwinter near Hawaii, are commonly found in nearshore waters around the island of Hawaii, especially off the northwest and southern coasts (cf. U.S. EPA, 1980c). Humpback whales are present in Hawaiian waters from November to May, and calving occurs mainly between January and March. Other marine mammals occur in Hawaiian nearshore waters, but none apparently have critical habitat requirements around the island of Hawaii.

Due to the volcanic origin of the Hawaiian islands, there is a precipitous increase in depth with distance offshore, and consequently there is not an extensive shelf benthic community as found on the shelves surrounding the continents. Benthic animals at these depths (< 200 m) may be detritivores, suspension feeders, or carnivores. The shallower portions of this habitat grade into the nearshore environment.

Some important commercial species occur at depths greater than 100 m around the Hawaiian islands. Included are the precious corals (e.g., black coral, gold coral, and pink coral), which feed on sinking detrital material, and various crabs, shrimps, and demersal fish species [e.g., groupers (Epinephelus quernus), red (Aphareus rutilans, Etelis marshi, and E. carbunculus) and pink (Pristipomoides filamentosus and P. sieboldii) snappers, amberjacks (Seriola dumerilii)]; cf. Hawaii Department of Land and Natural Resources (HDLNR) (1980).

Nearshore Environments around Hawaii--

The nature of the nearshore environments around Hawaii is largely determined by the position of the coast relative to the prevailing winds and currents. Hence, the windward (or eastern) sides of the islands have

distinctly different nearshore environments than do the leeward (or western) sides. On the windward side of the island of Hawaii, for instance, depth increases quite rapidly with distance from shore, and the nearshore environment can best be described as a high-energy environment. Consequently, the growth of coral is very limited there. On the leeward side of Hawaii, however, the coastline is more protected, and extensive coral reefs have developed.

As in waters slightly farther offshore, the phytoplankton found in the nearshore environment are not likely to be nutrient-limited. With good vertical mixing and an adequate supply of nutrients, both phytoplankton production and standing stock are likely to be higher here than in offshore regions. In addition to the primary production by phytoplankton, however, is the contribution of benthic algae.

Unlike some other coral reef communities, where coelenterate corals are the dominant reef builders, crustose coralline algae are much more important in this role in Hawaiian waters (Littler 1973). Benthic algae and aquatic vascular plants may be very abundant in tide pools or anchialine pools [i.e., shoreline pools without surface connection to the sea but having waters of measurable salinity (0.5-30 percent), and showing tidal fluctuations; cf. Gosline and Brock (1960), Brock and Brock (1974)]. Hence, there is an appreciable contribution to nearshore primary productivity by benthic plants.

Zooplankton are still the primary consumers of phytoplankton in the nearshore environment. There are a variety of benthic organisms which consume benthic plants.

The community of fishes and benthic organisms inhabiting coral reef environments should be considered as a whole. Both fishes and benthic organisms are influenced by physical factors (e.g., wave exposure, salinity, turbidity), they interact in ways which structure their environment, and each affects the distribution of the other.

Whereas large portions of the coasts of the other Hawaiian islands are fringed by coral reefs, only a small section of the northwest coast of Hawaii has a fringing reef (Devaney and Eldredge 1977). The presence of a fringing reef at this location is likely due to its leeward position on the island with respect to the dominant winds and waves. However, the semi-protected nature of the area north of Keahole Point on the Kona coast of Hawaii may also be the reason that coral growth is less vigorous there than in areas south of Keahole Point. Gosline and Brock (1960) felt that this might be attributed to occasional occurrences of muddy water there as well as fine sediments in some of the bottom deposits.

Following a biological reconnaissance of the northern Kona coast of Hawaii, Brock and Brock (1974) divided the nearshore environment there into three zones: the intertidal zone, a subtidal "A" zone, and a subtidal "B" zone.

The intertidal zone extends from the highest tidepools down to the level of the lowest low tides. Since tides in Hawaii are of limited amplitude (< 1 m) the vertical extent of this zone is small. The intertidal zone is subject to heavy surf and is consequently well supplied with oxygen and food. Sixty-eight species of invertebrates were identified from this zone, including mollusks, crustaceans, echinoderms, and cnidarians including some corals (Brock and Brock 1974). Sea urchins and snails were abundant where wave action was strong, while corals, sea cucumbers, rock oysters, hermit crabs, encrusting sponges, tube worms, and brittle stars were common in the more protected tidepools. The fishes found in the intertidal zone were for the most part juveniles of many species which as adults are found in deeper water farther from shore (Brock and Brock 1974).

One curious feature of certain nearshore areas on the island of Hawaii is the presence of a fresh water lens overlying more saline seawater. Since the lava rock is porous, fresh water from the land percolates through it and at the land-water interface this fresh water may mix with the seawater and appreciably lower the salinity (Brock and Brock 1974). This subtidal zone "A" includes both coastal ponds with connections to the sea and the aforementioned anchialine ponds without surface connections to the sea. Organisms found in subtidal zone "A" are euryhaline (i.e., they can withstand extended periods of lowered salinity). The invertebrate fauna includes an encrusting alcyonarian, polychaetes, attached bivalves, and crustaceans (e.g., some species of shrimps, crabs, and amphipods). Echinoderms are conspicuously absent, and are probably not capable of tolerating the reduced salinity (Brock and Brock 1974). Only a few species of fishes were found in this zone.

In areas with little or no freshwater influence, the subtidal zone "B" extends from just below the intertidal to greater depths. In areas where freshwater is mixing in the shallows, subtidal zone "B" begins at a depth below the effect of this mixing. While many invertebrates found in the intertidal occur in increased abundance in subtidal zone "B", the region was dominated visually by corals, while other invertebrates were hidden within the corals or in the surrounding areas. Brock and Brock (1974) identified 95 species of invertebrates and 137 fish species from this habitat.

Sandy beaches occur along some areas of the coast. The resident organisms on these beaches are influenced by the particle size of the sand, the slope of the beach, and the color of the sand (which is usually black on the island of Hawaii). The beaches may be inhabited by amphipods, isopods, ghost crabs, mole crabs, and various polychaetes and mollusks (HDLNR 1980).

In some locations along the Kona coast of the island of Hawaii, the remains of ancient lava flows extend offshore as a solid pavement of exposed basalt, containing many cracks and crevices which provide shelter for a variety of organisms. In such habitats, the maximum water depth is only 3-4 m. The predominant benthic organism in this shallow, reef-flat habitat is the coral, Pocillopora meandrina, which grows as isolated heads 10-50 cm wide (Hobson 1974). Other coral species may be interspersed among the P. meandrina, and various sea urchins may also be present (Devaney and Eldredge 1977). Since this type of habitat is generally found where wave

action is high, the organisms living there must be able to tolerate considerable water movement and wave shock. Among the fishes found in such areas, for instance, species of wrasse and damselfish apparently take refuge in small holes and cracks in the rock, while surgeonfishes seek refuge in open water areas farther from shore (Gosline and Brock 1960).

In other areas of the Kona coast having exposed shorelines, basalt boulders cover the bottom from shore to depths of about 15 m. Various algae and corals, mostly encrusting varieties, are found on the surfaces of these boulders (Hobson 1974). While the upper part of this habitat is often swept by a strong surge, the lower portion (at depths > 12 m) is calmer and grades into fields of the fingerlike coral, Porites compressus (Hobson 1974). Fishes within the boulder areas must be capable of tolerating the strong wave surge there.

At the offshore edge of the shallow reef flats, and at other locations along the shore, a sheer basalt face is found which drops precipitously to depths of 10-15 m. This reef-face produces a variety of habitats, ranging from an area dominated by wave surge and therefore resembling the reef-flat, to an assemblage of boulders at the base of the reef face, having a community of encrusting corals and algae. Planktivorous fishes tend to congregate adjacent to such reef faces (Hobson 1974).

Beyond depths of approximately 25 m, the sea floor increases rapidly in depth with increasing distance from shore. Near the rim of this drop off, the sea floor is generally overgrown with the fingerlike form of Porites compressus, interspersed with massive heads of P. pukoensis, bare basalt boulders, and sand patches. Planktivorous fishes are especially abundant in the overlying waters (Hobson 1974).

Different coral assemblages dominate in areas protected from large ocean waves. Along the Kona coast at depths of 2-12 m, the coral Porites pukoensis grows in a variety of massive formations. If there is increased exposure to waves, however, P. pukoensis is replaced by P. compressus as the dominant coral. Habitats dominated by one or the other of these forms are distinct from one another in many of the other resident organisms as well (Hobson 1974). The resident organisms may include slate pencil urchins, heart urchins, cowries and other mollusks, soft corals, filamentous algae, crustose coralline algae, bryozoans, and sponges (HDLNR 1980). This community is particularly vulnerable to anthropogenic alterations such as reductions in visibility associated with wastewater discharges, increased sedimentation, and freshwater flooding. It is important to note that the fish fauna of these coral-rich habitats varies considerably between day and night. In particular, fishes inhabiting deeper waters by day may move into the shallower coral reef habitat at night (Hobson 1974).

While the preceding generalized discussion of coral reef habitats on the Kona coast of the island of Hawaii is based largely on Hobson's (1974) study of the southern coast, no major differences would be expected between this area and the northern Kona coast. Similarly, the preceding description of the intertidal and shallow subtidal habitats is based largely on the work of Brock and Brock (1974) on the northern Kona coast. In general terms, that description should apply as well to the southern Kona coast.

As previously mentioned, the eastern shoreline of the island of Hawaii is considerably different from the Kona coast. The prevailing winds, currents, and waves all impinge upon the eastern shoreline, and consequently there is little coral development there. The bottom drops off rapidly in most areas, and in that respect would be expected to be somewhat similar to the reef-face environment on the Kona coast, which was described above. Certainly a greater diversity of both benthic animals and the associated fishes would be expected along the Kona coast than along the windward side of the island of Hawaii. Invertebrates along the eastern shoreline of Hawaii are those capable of seeking refuge in rock crevices. The fishes inhabiting this area are strong swimmers tolerant of strong wave surges.

Hawaiian Fisheries--

Hawaiian fisheries primarily occur within 32 km of the coast. Several factors are responsible for having restricted the fisheries to the nearby coastal waters. These include the narrowness of the insular shelf, the rather small size of Hawaiian fishing vessels, the lack of good harbors and facilities, the need for live tuna baitfish which cannot be transported long distances, and the markets which depend primarily on fresh seafood products (HDLNR 1979).

The island of Hawaii supports an expanding fishing industry. Hilo and Kona are the main commercial fishing ports (HDLNR 1979). The largest sport fishery in the state is also centered in Kona, which annually hosts a number of billfish tournaments. Around the island of Hawaii, tuna (Thunnus spp.) fisheries are the most important, followed by those for limpets (opihi) (Cellana spp.), wahoo (Acanthocybium solandri), scads (Selar crumenoptalmus, Decapterus spp.), and blue marlin (Makaira nigricans). Landings on the island of Hawaii in 1977 totaled 1.2 million kg, with a value of $2.3 million (HDLNR 1980). During 1978-1979, 712 commercial fishing licenses were issued on the island and 369 vessels participated in the various fisheries (HDLNR 1980). Handlines and trolling are the major fishing methods employed on the island of Hawaii.

Fishing Areas--The night tuna handline or ikashibi fishery around the island of Hawaii has been rapidly developing since the early 1970s (HDLNR 1979, Ikehara 1981). In 1977, 40 Hilo vessels participated in this fishery, while 10 boats fished out of Kona (HDLNR 1979). Gross revenues to fishermen from this fishery exceeded $2.9 million in 1980 (Ikehara 1981).

Ikashibi fishing areas are located 24-80 km offshore of Hilo and Kona. The best fishing occurs at the steeply sloping edge of the shelf; about 400 m depth in the Hilo area and 200 m in the Kona area (HDLNR 1979). Handlines are fished at depths of 23 to 60 m. Yellowfin tuna (ahi) (Thunnus albacares) is the predominant species taken in this fishery, followed by albacore (ahipalaha) (T. alalunga), and bigeye tuna (T. obesus) (Ikehara 1981). Several billfish species (istiophorids, Xiphias gladius) and dolphin (mahimahi) (Coryphaena hippurus) are also caught in this fishery. These species as well as wahoo (ono) are also taken in the day handline, surface troll, and flagline (longline) fisheries conducted within 32 km of the Kona coast (HDLNR 1979).

Deep-sea handlining for a number of bottomfish species around the island of Hawaii is concentrated in rocky areas having dropoffs, pinnacles, and depressions in depths ranging from 55 to 274 m (Ralston 1979). During 1966-1977, the island of Hawaii accounted for nearly 19 percent of the bottomfish landed in the state (Ralston 1979). Important species for the island include the red snappers [lehi (Aphareus rutilans), ehu (Etelis marshi), onaga (E. carbunculus)], pink snappers [kalikali (Pristopomoides sieboldii), opakapaka (P. filamentosus)], gray snapper (uku) (Aprion virescens), blueline snapper (taape) (Lutjanus kasmira), amberjack (kahala) (Seriola dumerilii), and jack crevalle (ulua) (11 spp. of carangids).

Most fishing for bottomfishes occurs in waters 3.2 to 32 km offshore, except for the catch of blueline snapper and carangid species, about half of which is taken closer to shore (Ralston 1979). The average annual reported catch of bottomfishes during 1973-1977 was 5,729 kg and 3,460 kg for waters adjacent to Kona and Hilo, respectively (HDLNR 1980).

The midwater handline and net fisheries for bigeye scad (akule) (Selar crumenoptalmus) and mackerel scad (opelu) (Decapterus spp.) are important in the nearshore waters of the island of Hawaii. Most fishing occurs within 3.2 km of shore in 27-107 m depths (HDLNR 1979). This island typically accounts for 3 to 8 percent of the state's annual catch of bigeye scad; however, during some years the percentage increases to 10 to 18 percent (HDLNR 1979). The majority of the state's catch of mackerel scad (90 percent in 1977) is taken in the nearshore waters off the Kona coast (HDLNR 1979). A local fishery for this species is also conducted near Hilo.

Table 56 lists the major species taken in statistical areas adjacent to Hilo and Kona during 1977. The inshore area encompasses the waters to the edge of the outer reef, approximately 3.2 km out from the coast. The offshore region extends from the reef edge out to 32 km. Inshore fishes landed in 1977 include amberjack, jack crevalle, and red snapper (Etelis carbunculus). Shallow water schooling species such as bigeye scad, mackerel scad, and mullet ('ama 'ama) (Mugil cephalus) are also taken inshore by nets and hook and line. Apparently, yellowfin tuna are also caught in the nearshore zone. Fishes caught in the offshore waters are primarily tunas and wahoo. During 1978, the offshore area of Kona produced the largest catches of yellowfin tuna (~317,515 kg), blue marlin (~90,718 kg), and wahoo (~18,144 kg) in the state (HDLNR 1980).

A small-scale crab fishery is conducted off the Kona coast. The Kona crab (Ranina ranina) is harvested in certain areas on sandy bottoms at depths of 27 to 91 m.

Precious corals support a minor commercial industry on the island of Hawaii. Pink coral (Corallium recundum) occurs off Keahole Point on the Kona coast. The deepwater (400 m) bed, which occurs on a hard substrate free of sediment, is estimated to cover an area of 0.24 km^2 (HDLNR 1979). Black coral (Antipathes dichotoma, A. grandis, A. ulex) is collected at shallower depths (40 to 80 m) within 4.8 km of shore. Small black coral beds are located off South Point and Mahukona on the island of Hawaii (Poh

TABLE 56. MAJOR FISH SPECIES CAUGHT IN WATERS ADJACENT TO HILO AND KONA, ISLAND OF HAWAII, 1977[a]

Area	Species Rank[b] Based on Total Pounds Landed				
	1	2	3	4	5
Hilo					
Inshore[c] (HDFG Block 105)	yellowfin tuna	bigeye scad	mullet	amberjack	red snapper
Offshore[d] (HDFG Block 125)	yellowfin tuna	skipjack tuna	albacore tuna	bigeye tuna	wahoo
Kona					
Inshore (HDFG Block 101)	mackerel scad	yellowfin tuna	bigeye scad	wahoo	jack crevalle
Offshore (HDFG Block 121)	yellowfin tuna	blue marlin	mackerel scad	wahoo	bigeye tuna

[a] Adapted from Table 6.2 of HDLNR (1980).

[b] (1 = largest catch, 5 = smallest catch).

[c] From shore to edge of outer reef ∿3.2 km.

[d] From edge of reef out to 32 km.

1972; HDLNR 1979). A sparse bed is also found off the northeastern coast of Hawaii (Grigg 1974). However, Grigg (1974) notes that many areas remain to be explored around Hawaii, and thus additional commercial quantities of black coral may exist.

It is unlikely that major new fisheries will develop within 32 km of the coast of the island of Hawaii since many of the available fish stocks are already heavily exploited. However, as newer, more sophisticated vessels enter the fleets, tuna fisheries, which also exploit billfish, may develop further offshore.

Currently, underutilized stocks include sharks and shrimp. Apparently, market resistance is the major impediment to the shark fishery. Surveys have indicated an abundant shark resource along the insular shelves of the main Hawaiian islands at depths of less than 91 m (HDLNR 1979). Major species include sandbar shark (Carcharhinus milberti), tiger shark (Galeocerdo cavieri), grey reef shark (C. amblyrhynchos), and Galapagos shark (C. galapagensis). Oceanic sharks such as white-tipped (C. longimanus), blue (Prionace glauca), and mako (Isurus spp.) are currently being harvested in the longline tuna and billfish fisheries. Incidental catches of demersal sharks are also made in the bottomfisheries at depths of less than 27 m. It is estimated that shark landings for the Hawaiian islands could potentially range from 240,000 to 1,070,000 kg annually (HDLNR 1979).

The extent of Hawaiian shrimp resources remains uncertain; however, shrimp are believed to be widely distributed in the water surrounding the islands (HDLNR 1979). Three caridean shrimp species (Heterocarpus ensifer, H. laevigatus, Pleisioneka sp.) appear to be most abundant at depths of 274-640 m over a variety of bottom types. H. laevigatus occurs primarily over steep, rough terrain. The penaeid shrimp (Penaeus marginatus) is a somewhat shallower species, occurring as subadults at depths of 64 m and gradually moving to deeper waters of 237 m as they mature (HDLNR 1979).

In summary, there are important inshore and offshore fisheries conducted in waters adjacent to the ports of Hilo and Kona on the island of Hawaii. Because Kona is located on the leeward side of the island, its fisheries are more diversified and its landings are greater than at Hilo, where rough waters limit fishing activity. Most fisheries occur within 32 km of the coast; bottomfisheries are conducted in areas where rocky habitats are prevalent and tuna fisheries are conducted at the edge of the insular shelf. Selection of a site for the disposal of manganese nodule processing wastes should certainly include consideration of possible effects on these productive fishing areas.

Fishery Biology--Four tuna species support fisheries in the waters of the island of Hawaii. Since they are wide-ranging oceanic fish, little detailed information is available concerning life histories of the individual species. The pelagic tuna eggs hatch within 48 hours or less, and the larval stages persist for 2 to 3 weeks (Wise 1974).

Skipjack tuna spawn throughout the year in tropical waters, and from late spring to early fall in subtropical areas. Spawning is primarily influenced by warm water temperatures and occurs in the central Pacific between longitude 150° E and 150° W (HDLNR 1979). Skipjack larvae occur in surface waters where temperatures are above 24° C and are widely distributed in the Pacific. In the Western and Central Pacific, larvae occur west of longitude 145° W between latitudes 20° N and 10° S, and east of longitude 145° W between latitudes 10° N and 10° S (HDLNR 1979).

Yellowfin tuna and albacore have peak spawning periods during June and July. Hawaii is the easternmost spawning area of the North Pacific albacore stock. Yellowfin larvae are abundant in oceanic waters during May and June but absent during November to March (HDLNR 1979).

No data are available concerning the seasonality of bigeye tuna spawning. Larvae of this species are found less regularly than yellowfin or skipjack tunas, and appear to be associated with land masses, since they are seldom encountered in oceanic areas (HDLNR 1979).

The four tuna species display specific depth preferences. Skipjack tuna are primarily surface dwellers, while yellowfin tuna occur in the upper 137 m of the water column. Albacore are common at depths ranging from 137 to 183 m, while bigeye tuna are the deepest dwelling of the four species, occurring between 183 and 274 m (HDLNR 1979).

Wide-ranging migrations are an important component in tuna life cycles. Skipjack migrations have been intensively studied, revealing a roughly circular migratory pattern, clockwise in the North Pacific and counterclockwise in the South Pacific (HDLNR 1979). Of primary importance in the vicinity of the Hawaiian Islands are the short-term movements and behavior of small (< 2.7 kg) skipjack tuna. These fish appear to aggregate in schools in specific areas during the day, a behavior which may be associated with feeding (HDLNR 1979). At night the school disperses, only to reform by sunrise in the same locale.

Blue marlin and striped marlin (Tetrapturus audax) are the two major billfish species taken incidentally in the tuna fisheries. As with tunas, little specific information is available concerning the life cycles of these oceanic fish. Both species are highly fecund, pelagic spawners. Blue marlin spawn throughout the year in tropical and subtropical waters, while striped marlin spawning occurs during the early summer (WPFMC 1981). Blue marlin larvae are distributed in warm (26-29° C) surface waters.

The distribution of blue marlin is influenced by the abundance of skipjack tuna, its principal prey. Other forage items include dolphin, squid, mackerel scad, and the pelagic juveniles of inshore reef fishes (HDLNR 1979). Striped marlin feed opportunistically on squid and a variety of pelagic fishes including scombrids, anchovies, and sardines.

Striped marlin typically occur in surface waters where temperatures range from 20-25° C, but also are found to depths of 183 m.

Little information is available concerning the life histories of the lutjanid and carangid species which support Hawaiian bottomfisheries. It is known that these species occur in areas of high relief such as rocky ledges, pinnacles, and in depressions (Ralston 1979). Depth distributions for the bottomfish species are shown in Table 57. In some cases, this is the limit of knowledge concerning a particular species.

The red snapper (Etelis carbunculus) and the two pink snappers are believed to be shoaling species (Ralston 1979).

Bottomfishes utilize a wide variety of prey items, including larval and juvenile fishes, and invertebrates (e.g., copepods, polychaetes, cephalopods, mollusks, crustaceans). Spawning periods for the gray and pink snappers, amberjack, and the carangid species are believed to be during the summer months. It is speculated that gray snapper and amberjack may be migratory; however, movement patterns are poorly understood (Ralston 1979).

Bigeye scad and mackerel scad spawning occurs over an extended period from late winter-early spring through August (HDLNR 1979). Mackerel scad spawn in relatively shallow (i.e., 18-91 m) inshore areas (HDLNR 1979). Schools of bigeye scad spawn over flat, sandy bottom areas at depths less than 22 m (Gosline and Brock 1960). Both species produce buoyant, pelagic eggs. The diets of these species include planktonic organisms (e.g., amphipods, crab megalops, fish larvae) and small fishes. Mature scad occur in schools in shallow nearshore waters. Juveniles remain offshore however, as far as 129 km from the coast (HDLNR 1979).

Little information is available concerning the biology of precious pink coral. This species is found at depths of about 400 m only on hard substrates which are constantly swept clean of sediment by strong currents (HDLNR 1979).

Black coral species are found in habitats which include an irregular calcium carbonate substrate associated with overhangs, caves, ledges, and dropoffs (Grigg 1965). Grigg (1965) postulates that their larvae are negatively phototactic and will not settle or survive unless light penetration is less than 25 percent of surface light. Adult colonies apparently can withstand light intensities to 60 percent of incident surface light (Grigg 1965). Current speeds of 25 to 100 cm/s appear to be optimal for black coral growth (Grigg 1965). However, colonies are limited in high-energy wave surge zones. Suspended particulates increase the abrasiveness of currents and also reduce the habitable range of black coral (Grigg 1965). The food of black coral includes amphipods and copepods (Grigg 1965).

Life histories of Hawaiian deepwater shrimp species are not well known. Year-round spawning has been suggested (HDLNR 1979). Heterocarpus ensifer is abundant between 274-457 m depth in water temperatures of 8-10° C. H. laevigatus occurs somewhat deeper (457-640 m) on steep rough bottoms where temperatures range from 6-9° C.

TABLE 57. DEPTH DISTRIBUTIONS OF HAWAIIAN BOTTOMFISHES[a]

Species	Depth Distribution (m)
Red snappers:	
Aphareus rutilans	110-183
Etelis marshi	183-293
E. carbunculus	201-293
Pink snappers:	
Pristipomoides filamentosus	73-146
P. sieboldii	146-256
Gray snapper (*Aprion virescens*)	inshore-73
Blueline snapper (*Lutjanus kasmira*)	91
Snapper (*Tropidinius zonatus*)	146-219
Grouper (*Epinephelus quernus*)	128-219
Amberjack (*Seriola dumerilii*)	46-229

[a] Data from Ralston (1979).

Summary--Overall, the biology of most commercially-important Hawaiian species is not well understood. Given this lack of knowledge of critical life stages, it is in most cases difficult to predict the potential impacts of manganese nodule processing waste disposal on Hawaiian fishery resources. However, this does not mean to imply that potential impacts on fish are negligible. Some species have particular characteristics which should be carefully considered in determining the location of a Hawaiian disposal site. For example, tunas, billfishes, and scads have pelagic eggs which may be affected by manganese nodule processing wastes. Increased water turbidity associated with the disposal of these wastes may also affect the schooling behavior of small skipjack tuna.

In addition to direct effects on developing fishes, it is also important to consider the impacts of the wastes on fish food resources. For example, alteration of the plankton community may adversely affect fishes with planktivorous pelagic larvae.

Demersal fish habitats are susceptible to the accumulation of waste sediments. Species supporting fisheries inhabit waters ranging in depth from a few meters (e.g., scads) to over 600 m (e.g., shrimps). Bottomfishes are abundant in areas of high topographic relief, while pink and black corals exist only on hard substrates free of sediment. Many of these habitats are highly localized. Therefore, potential waste sites should be thoroughly surveyed to document the presence or absence of productive fisheries habitat.

In summary, given the current state of knowledge, it is difficult to predict the magnitude of potential waste disposal impacts on Hawaiian fishery resources. However, consideration of fisheries should not be lessened as a result of this lack of information. It is important that the disposal method and site be carefully chosen to avoid interfering with fishing areas or the life cycles of economically valuable fish species.