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SCIENTIFIC ASPECTS OF POLLUTION ARISING FROM THE EXPLORATION AND EXPLOITATION OF THE SEA-BED



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IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts  
on the Scientific Aspects of Marine Pollution (GESAMP)

Scientific Aspects of Pollution Arising from the  
Exploration and Exploitation of the Sea-Bed



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## EXPLANATORY NOTE

This document is the edited and approved version, which appears in English only, of the report on scientific aspects of pollution arising from the exploration and exploitation of the sea-bed, which has been discussed, revised and approved by plenary sessions of the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). The Working Group was under the chairmanship of Dr. H. A. Cole, and the list of participating experts is given in annex II. Three meetings of the Working Group were held at the headquarters of the Intergovernmental Maritime Consultative Organization (IMCO), in London from 6-9 January and 21-23 April 1975 and from 19-23 January 1976.

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## I. INTRODUCTION

The Working Group to Consider Scientific Aspects of Pollution Arising from the Exploration and Exploitation of the Sea-bed was formed at the sixth session of GESAMP, held in 1974, and given the following terms of reference as set out in the report of the sixth session (GESAMP VI/10, annex VI):

(a) To identify the sources of information relevant to the scientific aspects of pollution arising from present and future activities related to the exploration and exploitation of the sea-bed. The suggested priorities for initial action are:

1. Petroleum (including natural gas)
2. Manganese nodules
3. Dredging for both mineral resources and construction projects, but excluding dredge spoil disposal
4. Off-shore construction (including platforms, artificial islands and reefs).

(b) To collate and evaluate, where possible, all such existing information within time to present an assessment to GESAMP VII of current and potential marine pollution hazards from these activities, and conflicts with other uses of the sea which may arise, with the intention of obtaining approval for its submission to the Third United Nations Conference on the Law of the Sea at its third session projected for June 1975.

(c) To assess the feasibility of extending this information to meet future needs, such as measures to prevent and control marine pollution from these activities and to make proposals on the future action of GESAMP concerning this area.

In planning its programme the Working Group took note of the objectives set out by GESAMP at its sixth session (GESAMP VI/10, para. 56); these are, in relation to the environmental aspects of the exploration and exploitation of sea-bed resources:

(a) To determine the possible range of effects of certain activities in different regions, such as the Arctic and the tropics, and to assess the hazards to marine living resources, human health, amenities and the environment; and

(b) To determine the measures required to prevent and control pollution from such activities.

At the request of the United Nations Technical Secretary for GESAMP, the Working Group also took note of Economic and Social Council resolution 1802 (LV) which, inter alia, called upon the United Nations to undertake an interdisciplinary study of the problems of and opportunities for coastal area development. In carrying out its tasks, as stated in the terms of reference, therefore, the Working Group gave

particular consideration to the problems of pollution arising from the exploration and exploitation of the sea-bed in coastal areas, including the effects of dredging for construction and similar activities. An additional memorandum on the problems of coastal area development as viewed from the standpoint of pollution was prepared and considered by the Working Group (GESAMP IV/19, annex IV).

In addition to the priority tasks described above, the Working Group reviewed and revised the list of other sea-bed activities to be considered, as given in the report of the sixth session (GESAMP VI/10, para. 57). The revised list covers the exploitation of:

Consolidated sedimentary deposits

sulphur

salt

potash

coal;

Unconsolidated superficial deposits

placer deposits of heavy metals and diamonds

sand and gravel

limestone shells and calcareous algae

metalliferous muds;

Crystalline rock metallic deposits

copper

lead

zinc

nickel

gold

silver

tin

mercury

beryllium;

Other deposits

phosphorite

glauconite

fresh water (sub-sea-bed deposits)

Materials not mentioned above (e.g. metalliferous brines).

For the purpose of its studies, the Working Group agreed that the term "sea-bed" should be regarded as including all benthic areas from the high-water line to the deep ocean floor; the range of ecosystems covered would be very wide.

The Working Group took note of previous papers and reports in this field, particularly those prepared by GESAMP, as listed in annex I of the present report. Although the Working Group was not able to consider off-shore tin mining, a report on this subject was prepared by the Working Group on Marine Pollution Implications of Sea-bed Exploitation and Coastal Area Development, established at the eighth session of GESAMP under the chairmanship of Dr. H. A. Cole. At its ninth session, the Group approved the sections of the Working Group report dealing with off-shore tin mining and an addition dealing with dredging for inclusion in the present report, with certain amendments.

In addition to the material which appears below, the Working Group prepared three background papers covering petroleum and natural gas, sand and gravel and potential pollution from marine mining on the continental margin, which provide more detailed information on these topics. These background papers were not considered by GESAMP; copies can, however, be obtained by application to the United Nations Technical Secretary for GESAMP, Ocean Economics and Technology Office, Department of Economic and Social Affairs, United Nations, New York, 10017.

Attention is also drawn to the report of the seventh session of GESAMP, annex IX, appendices I and IX, which deal with manganese nodule mining and the dispersion of fine-grained material, respectively.

## II. GENERAL CONSIDERATION OF THE EFFECTS OF SEA-BED EXPLORATION AND EXPLOITATION

All types of exploration and exploitation activities on the sea-bed result in changes, but these are often of a local and temporary character. Although they fall within the definition of pollution adopted by GESAMP at its first session 1/ it is desirable to assess the significance of such pollution in relation to local circumstances and the extent of the damage likely to result. The occasional killing of 10 or 20 fish, although it may seem to those on the spot to be a substantial act of pollution, is without significant effect on the stocks of which these fish form a part; the passage of a single large trawler will result in the incidental destruction of a great many more small fish of both commercial and non-commercial species. Nevertheless, it is necessary to examine and evaluate the effects of each and every type of sea-bed exploration and exploitation so as to be able to recognize those which, because of their scale, frequency, widespread distribution, persistence or the harmful nature of the by-products they release, may constitute significant pollution.

The principal methods by which non-living sea-bed resources may be exploited are through drill holes (e.g., for oil and gas), by surface excavation (e.g., dredging for tin, sand, gravel or manganese nodules) or by underground mining (e.g., for metallic ores). These may require a variety of structures to be placed on the sea-bed for the purpose of drilling, dredging unconsolidated sedimentary deposits and excavating bed-rock deposits. Explosives may be required.

Such activities may extend from the high-water line to the deep ocean floor, but almost all of the current activity takes place in shallow water near the shore or on the exposed beach. Most construction work involving sea-bed disturbance extends out from the shore, but there is increasing interest in the development of structures off shore for ship-mooring and unloading, for oil storage, for waste disposal (including incineration), for the siting of power stations, for mineral processing, for use as air terminals, for a variety of recreational purposes. The effects of building such works appear in the main to be quite local in extent, confined to within a few miles of the site, but the activities which take place subsequently on them (e.g., mineral processing or the operation of a nuclear power station) could have a much wider effect. In addition, the presence of the structures may cause local but permanent changes in the marine environment.

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1/ "Introduction by man of substances into the marine environment resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities." Estuarine waters are considered as falling within the marine environment (GESAMP I/11, para. 12).



## Drilling and fluid extraction through drill holes

The principal pollution risks created by the use of drill holes arise from the uncontrolled release of the products which are being sought, e.g., oil, gas or sulphur. Supplementary hazards arise from the accidental or deliberate release of substances employed in the drilling, e.g., to lubricate the drilling head or prevent the escape of the product, or from materials used in other supplementary activities, such as bactericides or algicides, anti-corrosive treatments for power production etc. Quite apart from legislative control imposed for environmental protection by the country on whose shelf drilling takes place, industry takes the view that the value of the product being sought provides a strong brake on accidental losses. Similarly, supplementary materials such as the "muds" used in deep-hole drilling, are usually costly and their loss or wastage imposes delay, thus providing a marked disincentive to careless use or disposal. The situation is, however, quite the reverse in respect of waste materials generated on drilling rigs and off-shore platforms and, in consequence, directives to ensure the return to the shore and the safe disposal of such waste may be ignored only at the risk of local fouling of the sea bottom and possible obstruction to fisheries. In many countries near approach to drilling rigs and similar structures for purposes unconnected with the operation of the rigs etc. is forbidden by law, but it still remains possible for solid rubbish from the rigs to be dropped on the sea-bed away from the immediate vicinity of the structures by the vessels servicing the rigs and removing those wastes.

It has been established that drilling rigs and other large structures placed on the sea-bed, or moored for a substantial period, attract fish, probably because of the shelter provided for the growth of attached animals and plants or, possibly, the effects of vibration. This usually represents a local redistribution and concentration of existing fish and not an addition to the stock, unless breeding and/or escape from predators is facilitated.

## Dredging and beach mining

Dredging involves the removal of unconsolidated material from the sea-bed, usually from a ship or floating platform, but beach mining may involve the use of shore-based equipment working within the littoral zone or standard earth-moving equipment working behind protective dams. The immediate effects are alteration of the contours of the bottom of the beach, the release of fine material which is likely to be carried away from the operating site by tides and currents and increased turbidity. Secondary effects, especially if the exploitation is on a large scale or pursued over a substantial period, may include local alteration of sediment-transport and even current régimes; the disturbance of banks; beach erosion or enrichment; the blanketing of the bottom locally by fine deposits; interference with bottom-fishing activities, particularly trawling; and local de-oxygenation due to deposition of organic material (e.g., drifting seaweed) in the holes made on the sea bottom. In addition, anoxic or even toxic material may be released from sub-sea-bed levels.

Very commonly, fine sand and silt are washed out of dredged material during its passage from the bottom to the hold of the dredger, and this spreads the effects more widely since surface currents are often stronger than those near the bottom. The addition of substances to the discharges from dredges to accelerate settlements of fine material has been considered. However, a recent, careful study of the

action of the three major types of dredging plants (cutting head pipeline dredgers, grapple dredgers and trailing suction hopper dredgers) used in the San Francisco Bay area, showed the physical effects of dredging operations to be minor when compared to turbidity and the increase in suspended solids caused by natural events such as high run-off from land or wind and wave action. If dredging is virtually continuous, the area affected may be substantially increased. If the initial processing of dredged material is done on board the dredging vessel, then both the amount and the nature of the discharged fine material may be affected.

Dredging can have serious effects if it materially damages or destroys discrete spawning or nursery grounds for young fish, which are of critical importance in maintaining the stock. Local effects may also arise from alterations in behaviour induced by turbidity clouds or disturbance of the bottom. These would be changes in distribution patterns rather than losses of stock but might, nevertheless, reduce fishing success by preventing the concentration of fish or by presenting local fishermen with an unfamiliar distribution of their target species. Local effects on shellfish, particularly sedentary species, can be profound, rendering the habitat unsuitable or smothering the fish with fine material. Other local effects can arise from alterations in bottom-topography, currents, sediment transport and shore exposure arising from the removal of bottom material. There is, however, a possibility of beneficial effects from the same causes.

Regulatory agencies often specify that dredging operations should not be carried out during the periods of migration of commercially important fish. This particularly concerns downstream migration of anadromous species through estuaries, where deposition of undesirable materials is most likely to occur. Fishes which spawn near the shore on vegetation, such as Pacific herring, may also be seriously affected by dredging operations.

Certain special problems may arise in harbours and channels where regular maintenance dredging must be conducted, especially in areas of importance to both indigenous and migrating species of fish. The transport of disturbed materials by currents to other, possibly sensitive, areas must be taken into account with regard to three types of problems: turbidity; acute toxicity from noxious gases released from the sediments; and mobilization of metals and other persistent substances contained in the sediments.

Turbidity is a transient condition which arises in all dredging operations and is usually of little long-term consequence. Fish kills have occurred, however, in dredging operations disturbing sediments containing a high concentration of decomposing organic material and associated toxic gases, especially hydrogen sulphide. These toxic conditions are generally short-lived.

Sediments may contain heavy metals and such other persistent substances as organochlorine pesticides and PCBs. Chlor-alkali plants with mercury cells are known to have introduced mercury into receiving waters which eventually was fixed in the sediments at concentrations exceeding 10 ppm. In the same way, cadmium and silver might be introduced into sediments from industrial plants. Radionuclides may be released from sediments within the influence of nuclear reactors. Although this mobilization of persistent materials from the sediments is for a relatively brief period, there is some possibility of bioaccumulation to unacceptable levels by organisms present in the area.

Attention is drawn to the serious problems which may arise in the disposal of dredge spoil, a subject which was excluded from the terms of reference of the Working Group.

### Underground mining

The mining of sea-bed rock is at present rarely practised except for operations extending under the sea-bed from the land. Perhaps the best known examples of true sea-bed mining are the extraction of barytes from solid rock on the sea-bed in Alaska and the winning of sulphur. The latter is, however, obtained by drilling and in situ liquefaction and so is included in the preceding section on drilling.

Although in theory many valuable minerals could be mined from sub-sea rocks, in practice, off-shore mining generally gives rise to much higher production costs than exploitation on land. It has been forecast that land supplies will meet greatly increased needs for minerals over the next 30 years and off-shore minerals will be exploited only when they can be marketed competitively with those derived from land sources. Advances in mining and processing technology are likely to benefit land-mining as much as, if not more than, sea-mining, so that the prospects for a major extension of the latter in the immediate future are not high. Nevertheless, exploitation of otherwise uneconomic deposits of some minerals might be subsidized for strategic reasons or to achieve national self-sufficiency. The pollution implications of such mining must therefore be considered.

Pollution could arise in three ways: first, by the disturbance and incidental release of unwanted materials, including surface fine deposits, during the opening up and working of the mine; secondly, by the loss of the material while mining it, bringing it to the surface and transporting it to a processing site; and, thirdly, by the discharge of waste materials during the processing operation, if this is conducted at sea on ships or on a special structure (such as a platform or artificial island) placed in the sea or on the shore. Most of these effects would be quite local and comparable to those produced by dredging, but if the exploited material was a metal ore, or a metalloid, then some potentially dangerous fine material might accumulate in the bottom deposits and be subsequently released, and some soluble material might enter the water column directly. The importance of such pollution would be related directly to the amount, solubility, toxicity and persistence of the material concerned.

If explosives were used extensively in establishing an undersea mine, then additional local damage could be done.

### Construction work associated with the placing of structures on the sea-bed

To place structures on the sea-bed it may be necessary to drill, excavate, use explosives, drive piles, deposit foundation or protective material, possibly in very large quantities and sometimes derived from adjacent areas of the sea-bed (e.g., sand or gravel banks), and engage in all the processes normally associated with such an activity as dock construction. Clearly, this may entail small losses of a wide variety of the materials used in construction. Harmful effects of construction will, however, be local and damage to living resources will be

insignificant except in so far as the construction actually occupies a site of critical importance in the population dynamics of exploited species or so alters the current and sediment transport régimes as to affect, in a substantial way, such a critical site. An important fish spawning ground could be destroyed: major damage could be done to a highly productive shellfish ground. Otherwise, the effects are likely to be minor and of local importance only.

Marine construction work can be considered under two categories: off-shore; and shore-connected. Among the former are constructions related to petroleum exploitation activities - drilling rigs, production platforms, well-heads, pipelines and storage tanks. Other works in this category include off-shore terminals, towers, semi-submersible platforms (e.g., sea thermal power plants) and artificial islands and reefs.

Among the shore-connected constructions, consideration must be given to tunnels, bridges and causeways, port installations, breakwaters, dams, tidal power plants and wave-damping structures, and pipes for discharge or intake. Although the presence of new structures may result in long-term changes in the marine environment, in nearly all cases the significant pollution aspects of these constructions are of short duration, limited to the actual construction-installation activities.

Although no serious pollution aspects appear to be associated with marine construction, it is recommended that careful environmental impact studies be carried out for each major construction on an individual basis prior to, and following, the completion of the installation. The permanent alterations in the marine environment arising from the presence of artificial structures need to be assessed. The more serious potentials for pollution associated with these structures, however, generally arise from their use rather than their presence in the marine environment.

### III. DISPERSION OF FINE-GRAINED MATERIAL

In considering aspects of the transport and mixing of fine-grained material in relation to dredging and mining operations, it is pertinent to deal separately with beach dredging and excavation, off-shore suction dredging and deep sea-bed mining. Although in all cases the present theoretical understanding of the processes occurring is limited and the available experimental data are few, an assessment of the possible range of physical effects of the operations can be made.

In the near-shore zone it can be shown that increases in turbidity can be considerable (on the order of 100 mg/l), and fine-grained material can be carried over large distances, both along-shore and off-shore. The possible implications of dredging for the material budget of the beach zone should always be considered. Dredging can change the topographic conditions and consequently the onshore-offshore material transport pattern. In the near-shore region, dispersion is primarily governed by wave conditions and, to a lesser extent, by current.

In the case of off-shore dredging, transport by currents and the mixing conditions normally can be expected to be effective enough to reduce the concentration of waste material from a discontinuous source to insignificant levels over time periods of 5-10 hours. This conclusion is based on commonly observed dilution factors in the wake of a ship releasing waste material and on known subsequent dilution factors in the surface layers. Present experience in Europe and North America supports this conclusion. The small-scale topographic disturbances on the sea floor, however, appear to be very persistent. It should also be noted that internal layers of suspended matter in regions of increased density stratification can be very persistent. Vertical mixing in such regions is very weak, compared with mixing in the surface layer. The possible influence of dredging on sediment transport and the material budget for adjacent areas also merits careful consideration.

In the case of deep sea-bed mining, no full-scale case study is available. Small-scale experiments have been carried out, but there is considerable danger in extrapolating the results of these to the full-scale case. The initial distribution of resuspended material in the water column will depend very much on the mining technique used. Taking manganese nodule mining as an example, and assuming that as much sedimentary material as the amount of nodules is brought to the surface and released with the mining effluent into the surface layer, an estimate of the turbidity increase in a single 24-hour operation suggests that the initial concentration will be of the order of 100-1,000 times the natural (ambient) concentration in the top 50-100 metres. Over a period of 10 hours this concentration will normally decrease by at least a factor of 100.

In connexion with all the operations mentioned, environmental observations should include physical parameters in addition to biological and chemical ones in order to make a reasonably reliable prediction of the possible consequences.

With respect to other physical aspects it is not possible to make definite statements which are generally applicable. Every case of near-shore construction must be investigated carefully on its merit. Some general considerations regarding special coastal zones as well as structures are given in chapters IV and V of this report.

#### IV. SPECIAL COASTAL CONDITIONS

Some coastal areas have characteristic physical features which, together with associated biological and chemical factors, imply that special attention is required when considering their exploitation. Estuaries are typical examples, and some of their physical characteristics are discussed below. It is emphasized that far from all pollution aspects are discussed and that biological and chemical consequences of exploitation are not dealt with.

##### Estuaries

An estuary is a zone where fresh and salt water are in the process of mixing. Two extremes can occur, depending upon the relative strength of tidal motion and river discharge. In the case of weak tidal influence, the light (brackish) water remains distinct from the heavy (salt) water, whereas in the case of strong tidal motion, mixing occurs and the density varies more smoothly over the whole depth. Due to density differences, the outflowing brackish water will override the sea water, which penetrates inwards in the form of a saline wedge. The drag of the brackish water generates an upward transfer of salt water (entrainment) which is carried seawards while a compensating landward current occurs at the bottom, which increases towards the nose of the wedge. Strong meteorological forcing can temporarily influence the conditions.

Salt can also be transferred from the wedge by turbulent diffusion, which is a two-way exchange. The relative rates of entrainment (one-way) and diffusion depend upon the levels of turbulence in the brackish and salt water. When the salt water mass is nearly stationary, due to weak tidal influence, entrainment is dominant and the outflow carries relatively more salt water. This implies that, up to a certain limit, the greater the river discharge, the greater the inward flow near the bottom. When the turbulence level is increased in the wedge, due to tidal or other motion, the net salt transfer through the interface decreases and the compensating flow at the bed is correspondingly reduced. Hence, this transfer will vary during a tidal cycle.

Since the exchange through the interface depends upon the magnitude and characteristics of the turbulence in the layers, it will vary greatly with the depth of the estuary as well as with the strength of the turbulence sources in the layers and at the interfaces (surface, internal and bottom). In partly or well-mixed estuaries the wedge will oscillate with the tide. The salinity distributions will vary periodically with both tides and river discharge. Long-term changes can be caused by alterations in the fresh water supply (for instance, by dam constructions and regulated discharge) by deepening for navigational purposes, or by alterations in the tidal régime by the construction of weirs, harbours etc. and by land reclamation.

Stratification and circulation in estuaries create special sedimentation and waste disposal conditions. The net bottom flow changes from downstream to upstream at the so-called "null-point", and sediment transported in the vicinity of the bottom will be carried towards this point. Techniques are available

to predict the position of the null-point for different conditions and from measurements of the flow distribution versus depth over a tidal period at several sections simultaneously, zones of shoaling can be estimated. It is important that an analysis of the sediment transport conditions at the bottom be carried out prior to changing the material conditions, e.g., by dredging (deepening) or altering the fresh water supply.

During strong flood conditions the sediments transported in the surface layer - the wash load - can be carried far out to the sea. They are also affected by the thermohaline conditions at the interface and some fractions can be caught in the upstream current, creating a closed loop.

An important question concerns the relative amounts of sediment brought to the estuary by the river and from the sea. It is clear that estuaries can silt up through sediment supply from the sea. Thus, it is important to give careful consideration to changes due to human influence on the long-shore (littoral) transport in the vicinity of estuaries. Effects of altering the fresh-water flow, e.g., to obtain fresh-water supplies or improve disposal conditions, should be carefully investigated so that new and more severe siltation problems are not created. In relation to siltation both precipitation of salts from sea water (giving rise to a high percentage of calcium carbonate in the sediment) and flocculation of clay products are other important processes.

Estuaries are of great economic importance as centres for many interests which need to utilize the abundant natural resources present there in often conflicting ways. The generation of rational management of estuaries requires the establishment of a management group which should include scientists and engineers. Every development and operation in estuaries should be carried out with as good an understanding as possible of the circulation, sediment supply and distribution patterns.

In connexion with estuaries, brief mention may be made of deltas or specially important coastal areas. Delta characteristics, such as length, area, maximum width and morphology, are often investigated by regression analysis to clarify the dependence upon river discharge, river shape, slope of continental shelf, tidal range, duration of storm waves and swell, swell direction, temperature and salinity of ocean water. The significance of the temperature régime should be stressed, indicating also latitudinal and climatic influences on the deltas.

### Bays

Certain types of bays can be formed by persistent natural forces at sedimentary coasts. A bay in equilibrium prevents longitudinal material transport, except for seasonal fluctuations. Such natural features can be used by man both without modification and as models for new constructions, e.g., for harbour purposes. Due consideration should be given to the local natural conditions when planning coastal construction in bays so as to avoid serious alterations of the natural equilibrium.

### Inlet entrances

Normally bars or shoals are formed across inlet mouths, and channels must be dredged through these for the inlet to become commercially useful. Long-shore drift, particularly in areas of small tidal range, often necessitates more or less continuous dredging in order to keep such a channel open and maintain its depth. Material arriving from upcoast is transferred to the downcoast side by dredging.

Outside inlet mouths with strong tidal currents, the material transported towards it from the upcoast side is swept seawards or upstream. In the former case a crescentic bar is formed. In general such bars or shoals will have to be dredged to provide a navigation channel.

Transport of material by some mechanical means downcoast of harbour entrances is commonly used. This can be done by ordinary dredging or by a pipeline under the entrance or across the harbour to create so-called "by-passing". The spoil material may be used to nourish downcoast areas if it is dumped outside the shadow zone of other structures but inside any off-shore bar. For other precautions, see the sections of this report on dredging and sand and gravel and the appropriate bibliographic references in annex I.

### Beach replenishment and artificial beaches

An important aspect of beach replenishment is the fate of the material at the new site. Prior to the operation the transport conditions in the vicinity should be considered as well as the amount of material required. In areas of long-shore drift, material will be removed unless carefully selected preventive measures are adopted. The most easily managed sites are those where the transport is essentially transverse to the coast line. Losses of material to the off-shore zone will depend upon the underwater slopes to be filled before a stable profile results. The volume of the fill can be estimated from a calculation of the equilibrium beach profile, which primarily depends upon the period of the predominant swell and the storm waves occurring in the area. Since seasonal variations of wave conditions occur, fillings should be carried out over a number of years to allow the varying wave conditions to generate a uniform distribution. Differences in size distribution between the filling and the natural material will influence the final beach slope. Careful consideration of all these engineering aspects, in addition to an evaluation of possible biological effects, is recommended prior to the operation.



## V. MARINE STRUCTURES, PHYSICAL ASPECTS

Marine structures installed by man imply alterations of the physical environment, and the possible effects of these changes should always be assessed in advance. The natural fluctuations of the environment should be considered as well as the influence the construction will have on wave and current conditions and sedimentary transport patterns. These constructions can have effects on the natural material budget, and the consequences should be considered.

The effects of large structures such as tidal power plants, placed on the sea-bed, on current conditions and water exchange in adjacent areas and on the sedimentary transport pattern should be assessed. This also holds for tunnels or pipelines across sounds or embayments where the rate of bottom water exchange may be influenced by the structure. Floating breakwaters may influence local wave climate and consequently may affect sediment transport.

Deleterious effects may be noticeable only after a considerable time has elapsed, partly because they can be difficult to separate from natural fluctuations. Thus, monitoring of the conditions after completion of the construction should be continued over an appropriate time period. Local conditions will always be the primary consideration, but possible distant effects, e.g., from dam or beach constructions, should also be borne in mind.

## VI. POLLUTION ARISING FROM MINERAL EXPLOITATION OF THE SEA-BED

### Petroleum and natural gas

The exploitation of off-shore hydrocarbon reservoirs may have a number of effects on the marine environment in addition to petroleum pollution per se. Some of the more important of these other effects are considered below.

The presence of off-shore structures, such as drilling and production platforms, suspended well-heads and pipelines, will restrict the activities of other users of the sea-bed, particularly bottom fishermen who, despite the comparatively small areas occupied by off-shore structures including their safety zones, may be denied access to traditional fishing grounds of local economic significance. Furthermore, the presence of off-shore structures, which, generally speaking, are attractive to fish, may lead to local redistribution of fish resources. There is, however, very limited published information on the quantitative significance of such changes in fish distribution. Off-shore structures would tend to become colonized by marine animals and plants similar to those of rocky substrates. The rate of colonization is usually restricted artificially by the use of anti-fouling paints.

Although the dumping of debris from off-shore structures and supply vessels is covered under the terms of the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (Oslo, 1972), and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (London, 1972), the uncontrolled dumping of debris by the off-shore hydrocarbon industry, although a comparatively minor problem, can have serious consequences for individual fishermen who may suffer damage to their fishing gear and vessels and, occasionally, contamination of catches.

Disposal of formation cuttings and losses of drilling muds from oil and gas wells may cause local alterations in the sediment structure of the sea-bed. It is possible that fish feeding in areas so contaminated may acquire undesirable taints from oil in the cuttings and muds, but documentary evidence to support this is lacking. Laboratory tests with drilling muds have shown that the components most toxic to fish are organic chemicals and compounds of lead and chromium, used in small quantities for such purposes as pH control, corrosion inhibition, disinfection, lubrication and emulsification. The suspended solid constituents of drilling muds generally have a low acute toxicity to fish (96h. TLM 7,500 mg/l, in most cases). On present (1976) limited field evidence, dumped drilling muds and cuttings have no acutely harmful effect on marine organisms other than that due to highly localized blanketing of bottom fauna. Similarly, there is no field evidence that drilling mud components are discharged at rates liable to lead to the attainment of undesirably high body burdens of lead or chromium in marine organisms used for food. Accidents may, however, create a potentially damaging situation. It should be noted that the marine disposal, by dumping, of the materials referred to in this paragraph is also subject to the provisions of the above-mentioned Oslo and London Conventions.

Petroleum and natural gas are frequently found in association with

oil-contaminated salt solutions known as "brine waters". These waters are commonly disposed of in off-shore waters. Such field evidence as there is suggests that this is a safe method of disposal. However, in confined waters, large discharges of brine waters could taint local fish and shellfish resources with unpalatable organic compounds derived from petroleum and might possibly contribute to the body burdens of heavy metals in marine biota. In some areas, for example, the Gulf of Mexico, brine waters may be reinjected. Further information on the pollution implications of substances other than oil is given in the appropriate bibliographic references.

The "heater treaters" used at petroleum production platforms to break oil/water emulsions may employ heat exchange fluids containing PCB's which, in the event of an accident, might be released to the marine environment. There is, however, no documentary evidence that operational losses take place.

Oil, gas and brine water are nearly always produced together at any oil or gas well, although the proportions of each vary widely. The exploitation of natural gas reservoirs associated with petroleum may therefore give rise to at least some pollution by oil mixed with the gas. All the available evidence suggests that accidental releases of natural gases unassociated with oil have no discernible polluting effect. If liquefaction of gas is done at production sites, then some additional pollution implications may arise, e.g., from the cooling and compression systems.

#### Manganese nodules

A working paper on this subject was presented to GESAMP at its seventh session (GESAMP VII/9, annex IX, appendix I). It addressed aspects of pollution arising from exploration and exploitation of manganese nodule deposits, excluding exploitation activities other than mining.

Although detailed understanding of the distribution of manganese nodules on the ocean floor is incomplete, broad regional patterns have been mapped, and major deposits appear to have been delineated. No single theory adequately explains the origin and distribution of manganese nodules or the mechanism or mechanisms which concentrate economically valuable metals within them. Despite these outstanding questions, enough is already known about the ore value of deposits in specific areas to stimulate commercial interests. Attention is currently concentrated on other metals associated with manganese - mainly copper, nickel and cobalt - rather than on the manganese itself.

Commercial mining interests in several nations have made extensive efforts to explore and develop manganese nodules in the deep sea. It is expected that full-scale mining development of economic ores in the eastern Equatorial North Pacific Ocean in 5,000-metre depths may take place near the end of the present decade.

Two methods for mining manganese nodules in 5,000-metre depths - airlift hydraulic pumping and continuous bucket line dredging - are in an advanced state of development. Both methods will, in varying degrees, have potential pollution effects in the near-surface and near-bottom ocean environments. The near-bottom zone will be affected by the shallow dredging operation (upper half metre) and the consequent resettlement of disturbed sediment. The near-surface zone will have

increased turbidity in the vicinity of the mining vessel from the discharge of the airlift pumping system. This effluent will also have increased content of nutrients characteristic of deep ocean water, so that the surface discharge will result in increased biological productivity locally. Whether it will produce net harmful or beneficial effects cannot be determined until actual operations can be monitored.

Present information regarding mining disturbances is derived from small-scale tests and laboratory studies and is inadequate to predict the nature and scale of potential pollution expected from full-scale mining. Estimates of both the surface and bottom ocean effects of manganese mining are highly conjectural at the present time, and the most meaningful insights can probably be gained by careful study of natural phenomena analogous to mining disturbances. Preliminary comparison supports the view that no serious pollution will arise from manganese nodule mining activities. In reaching this conclusion attention was given to the reports of the fourth and fifth sessions of GESAMP (GESAMP IV/19 and GESAMP V/10), which examined the possible effects of disturbance of the sea-bed on the specialized ecosystems present on the floor of the deep ocean.

The evidence required to predict confidently the pollution effects of nodule mining can only be obtained through careful monitoring of full-scale mining operations. Recommendations for the monitoring of certain important parameters are given in the report of the seventh session of GESAMP (GESAMP VII/19, annex IX, appendix I). Such investigations will be aided by the baseline studies currently being conducted by the United States National Oceanic and Atmospheric Administration at selected Pacific mining sites, which appear to represent a timely and orderly pre-mining environmental inventory.

A unique opportunity exists to establish international agreement on regulations which would promote orderly development of these reserves and ensure against adverse environmental effects arising from their exploration and exploitation prior to the advent of large-scale mining activities.

#### Sand and gravel

Sand and gravel are extracted from the sea for use mainly in concrete construction work, road-making, engineering, infilling, land reclamation and beach replenishment. They are low-value minerals existing in vast reserves on land; they are worked at sea only where there are special, locally favourable economic factors. The presence of salt in marine aggregates (and the cost of removing it) affects its use for construction work. The marine sand and gravel industry has developed mostly in countries around the southern North Sea, in Japan (mostly sand) and in the United States of America (mainly in estuaries). In many other countries, however, there is local extraction from beaches, sometimes on a considerable scale.

The annual rate of extraction is increasing, and future projections indicate the continuance of this trend with a rising proportion of the total demand for sand and gravel being met from marine sources. At present, dredging, mainly by trailing suction hopper dredgers but also from anchored dredgers, extends to depths of about 35 metres, but somewhat deeper extraction may become commercially feasible within the near future. Trailing dredges lower the sea-bed more or less uniformly over the area of work, but anchored dredgers excavate pits in the sea-bed which may be up to 20 metres deep, although they are usually substantially shallower. These

pits may be semi-permanent in gravel but are liable to collect fine deposits and organic materials which may become anoxic in areas of weak bottom-water exchange.

The effects of sand and gravel extraction are local. Principally they comprise alteration of the bottom topography and composition, with consequent effects on wave climate, water circulation and sediment transport, increased turbidity and deposition of released fine material on the bottom. Where extraction occurs in estuaries or channels carrying industrial wastes, the release of pollutants held by the fine sediments may occur and the possible redistribution of these pollutants should receive attention. Excavation of these channels may be done for other purposes, for example, navigation, with sand or gravel as a useful by-product.

Of the possible effects on living resources, interference with bottom areas of critical importance to particular fish or shellfish stocks, e.g., as areas of egg deposition for herrings and certain rays, or as habitation for sand eels or scallops (Pecten maximus), is judged to be most important. Changes in the character of the bottom and its fauna and flora, due to the disturbance or deposition of fine sediments, are considered to be less important but may do local damage of significance to particular groups of coastal fishermen. If dredging for sand or gravel affects the seasonal aggregation of fish for spawning or feeding on particular grounds, this may reduce the catching efficiency of small groups of fishermen who have been accustomed to relying upon these areas as part of their seasonal fishing pattern. Alternative, equally productive fishing grounds may not be available or may be out of reach of the vessels concerned. Although these local changes may not significantly affect regional productivity, they may damage the livelihood of local fishing communities, especially those dependent upon small vessels which are relatively immobile.

It is not considered that commercial sand and gravel dredging is likely to produce a human health risk by the liberation and redistribution of pollutants with consequent effects upon the quality of seafood, but particular care is necessary when channels carrying industrial effluents are dredged for any purpose. The content of potentially toxic pollutants in such dredgings should be determined and their disposal regulated accordingly.

Amenity beaches may be affected if dredging is carried out close to the shore so that additional turbidity is created and fine materials are brought into suspension and deposited on shore.

Rational management of the extraction of sand or gravel from beaches requires, inter alia, an understanding of the patterns of accretion and erosion in the exploited area and of the significance of the beach structures in coast protection. Sand replenishment of beaches, by extraction immediately off shore, besides possibly interfering with fish nursery grounds, may affect local sediment transport patterns and result in beach changes - perhaps unwelcome ones - beyond the area of replenishment.

Among other uses of the sea possibly influenced by sand and gravel extraction, fishing and navigation are considered to be the most important. Alteration of the topography of the sea-bed, particularly the digging of pits and the residue of boulders which may remain after gravel extraction, may seriously restrict local use of trawls, seines, long lines, set nets, and other bottom fishing gear. In consequence, the livelihood of particular groups of fishermen may be affected. Such

alterations to the topography of the sea-bed, in particular, the in-filling of channels due to removal of the protection of banks, may also create difficulties for navigation.

All forms of aquaculture require water of a particular quality and, since they are practised in areas specially selected because of the general suitability of conditions and involve substantial capital expenditure, should receive special consideration when areas for sand and gravel extraction are being allocated. The potential of presently unused suitable areas should be borne in mind.

Sand and gravel extraction from estuaries, although frequently desirable on navigational grounds and economically attractive because of shelter and accessibility, needs special consideration on both fishery and health grounds. Many estuaries are highly productive, particularly of shellfish, and may also serve as nursery or spawning grounds for fish and crustaceans exploited off shore. Moreover, as mentioned above, such estuaries may carry industrial effluents which may be released and redistributed when fine material is disturbed by dredging.

International implications of sand and gravel dredging include the possibility of the spreading of effects across national boundaries, if extraction sites are located close to such boundaries; the possible importance to several countries of particular fish stocks, which may be damaged by interference due to dredging at a particular stage in their life cycle, e.g., herring at spawning; and a common interest among many countries in the maintenance and safety of important navigation channels.

#### Phosphorite

The growing world need for agricultural phosphate ( $P_2O_5$ ), used mostly as a plant fertilizer and to a lesser extent as animal feed supplement, has stimulated the search for new sources of phosphate ore. Marine phosphorite deposits have been examined as potential resources to augment supplies from traditional land-based phosphate mines.

Although deeply buried marine sediment layers containing phosphate have been reported in scientific ocean drilling results, the only marine phosphorite deposits whose recovery appears economically feasible at this time are those which lie exposed on the sea floor in areas of the continental shelf and continental margin.

Phosphorite, a form of calcium phosphate, occurs as a surficial marine deposit in the form of nodules or crusts on boulders and sometimes as sand-sized or finer material. Nodular phosphorite samples show a wide range of  $P_2O_5$  content (10-35 per cent) but generally are poorer than on-shore phosphate rock deposits.

Deposits of phosphorite have been surveyed in areas off the coast of southern California, United States, associated with elevated topographic features (banks and ridges) where sedimentation rates are low owing to relatively strong bottom currents. Most of these deposits, like those elsewhere, lie within a depth range of 30-350 metres. Limited surveys of the California off-shore deposits indicate that about 1 billion tons of phosphorite nodules occur in areas totalling 15,000 square kilometres, although only a small percentage (representing about 100 million tons of phosphate) constitutes a potential resource.

Another off-shore phosphorite deposit of possible economic importance has been studied in an area 25 kilometres off the coast of Georgia, United States, in water depths of 15 metres. This fine-grained, unconsolidated deposit is about 7 metres thick and is overlain by 1 metre of sandy bottom sediments. It appears to be an extension of a phosphatic sand deposit which underlies an area of coastal marsh. Exploitation of this deposit would probably involve suction dredging and at-sea separation and concentration of the phosphorite (10 per cent) from quartz sand (90 per cent) resulting in a widespread redistribution of sand sediments. Some concern has been expressed that extensive mining of this deposit could adversely affect an underlying formation which is an important artesian aquifer in the adjacent coastal land area.

Estimates of the pollution aspects of submarine phosphorite recovery remain hypothetical, since no economic mining has yet occurred. In most respects, the methods for exploration and exploitation of sea floor phosphorite deposits (and hence the attendant environmental impact) will be identical with those of marine sand and gravel mining, discussed above, with the following exceptions:

(a) Initial exploration will be aided by the use of radiometric survey methods, since phosphorite deposits contain significant amounts of uranium oxide ( $U_3O_8$ );

(b) The recovery methods for phosphorite would probably utilize continuous bucket line dredges or drag-dredges in order to work in depths as great as 350 metres. In shallower locations suction dredging might be employed;

(c) Owing to the recovery methods and generally greater depths and distances of the deposits from land, the turbidity plume problems will be of lesser consequence;

(d) Where phosphorite deposits are surficial ones, there will be a minimal alteration of the topography in their recovery. However, one deposit off the south-eastern United States extends to a depth of 8 metres beneath the sea floor;

(e) Separation and concentration of fine-grained phosphorite sands by sieving would redistribute sediment over a wide area near the mine-site;

(f) Shore-site beneficiation and treatment may result in the release of some form of fluorine into the atmosphere or in waste water as well as discharge of particulate and dissolved phosphate. (See also foot-note m to table 1);

(g) Separation by froth flotation using sea water and selected chemical reagents has been practised in the past. This could create a pollution hazard in cases of accidental spillage, particularly in operations at sea.

#### Off-shore tin

Tin occurs as the inert mineral cassiterite,  $SnO_2$ , in off-shore alluvial deposits that have been derived by the weathering of land-based tin-bearing rocks. Commercial production is confined at present to Indonesia and Thailand, and there are some prospects of future extension to Malaysia and Burma. Although it is anticipated that production of tin from off-shore mining areas will increase (the total tin production increase is projected at 2 per cent per annum), this will be achieved mainly by the use of larger dredges.

In off-shore tin mining by dredges, more than 99 per cent of the material extracted from the bottom is returned to the sea. There is sometimes an overburden of clay-like material removed before the tin-containing gravel is dredged. The tin ore, consisting of SnO<sub>2</sub>-rich sand and pebbles, is separated according to size and density. Generally, only up to about 0.3 kg of cassiterite is extracted from a cubic metre of gravel. At present, further cleaning of tin ore is carried out at plants on shore before being delivered to smelters in the area for refining.

The most visible effect of dredging is a marked turbidity around the dredge, with a plume extending downstream for about 1 kilometre. The bulk of the suspended material has been found to settle out rapidly when the dredging operation ceases. This will have the normal environmental effect of reducing the light penetration and perhaps locally inhibiting primary productivity. The impact on the higher trophic levels is unknown but is likely to be insignificant. Although most of the existing dredging operations are well removed from reefs, in those areas where coral reefs are present, there could be an ecological effect due to suspended solids.

Dredges disturb bottom habitats, and there may be local interference with the placing of fish traps. The main concern is over destruction of spawning grounds for fish and invertebrates, although it is unknown whether any commercial species in fact spawn on the grounds now exploited for tin. Fish are reported to be somewhat fatter and more abundant near dredging rigs than elsewhere, and this may be due partly to the bottom organisms made available by dredging and perhaps partly to discards from the dredge. Because the dredge residues are returned to the sea often, in an order different from that of the original, the sedimentary structure is usually rearranged. Therefore, it is conceivable that recolonization may occur largely with organisms different from those present originally on the bottom. The bottom topography remains essentially the same, however, since an orderly return of dredge residues is practised in a tin mining operation. It is conceivable that parts of the shoreline could be modified by dredging in shallow river mouths or adjacent coastal areas, but no instances of this actually occurring could be cited.

In conclusion, the pollution implications of off-shore tin mining would be local and would not differ substantially from those of other sea-bed dredging operations for heavy minerals. Certain tin compounds can be biologically alkylated in the marine environment, and the compounds produced are known to be highly toxic. Analytical methods for their estimation at very low concentration have not yet been fully developed. There is, however, no evidence to suggest that such substances are produced in the off-shore mining of tin. The procedures for separation and enrichment of the tin mineral, cassiterite, are entirely mechanical. No chemical agents are added during the process.

### Other minerals

#### Resources

Three major classes of mineral resources are found on the continental margin, namely, dissolved minerals in sea water, minerals in unconsolidated deposits which occur in a variety of locations from coastal beaches to the deep sea-bed, and minerals in consolidated deposits in bedrock.

Commodities in sea water are basically fresh water and minerals dissolved as salts, or in elemental form. Fresh water is also commonly found as submarine



springs and constitutes a potential source worthy of additional attention. Metalliferous brines are essentially highly enriched sea water and, although they may represent an important resource, the subject of dissolved mineral recovery was not within the terms of reference of the Working Group.

Unconsolidated deposits are defined here as naturally occurring concentrations of minerals which are not indurated and are amenable to recovery by dredging. On the continental shelf (to depths of 200 metres) unconsolidated deposits of major interest are non-metallics including sand and gravel, glass sands, lime shells and calcareous algae, phosphorite and aragonite ( $\text{CaCO}_3$ ); heavy minerals including alluvial tin, iron sands and titanium sands; and native elements including gold, platinum and diamonds. On the continental slope (to depths of 2,000 metres) unconsolidated deposits of major interest include phosphorite, carbonaceous muds and metalliferous muds.

Consolidated bedrock deposits of interest occur as surficial deposits of coral, barite and phosphorite crusts; and deeply buried deposits of coal, iron ore, sulphur, potash and various metallic salts.

The potential for discovery and exploitation of marine hard minerals on the continental margin is high and the variety of deposit types is of the same order as that on land.

Some marine mining operations on the continental margin are economically viable at the present time, and more are likely to be so within the next decade, both in deeper water and farther from land.

The methods used for the mining of hard minerals are more variable than those for oil and gas production and are highly dependent on the nature of the ore body and the particular marine environment.

### Pollution potential

Potential pollution from marine mining operations is dependent on both the mining methods and the specific environmental conditions of the operation. Generalizations based on either a commodity or a location by itself could be misleading. Apart from some broad guidelines, assessments of potential pollution from marine mining must be operation- and site-specific.

Most physical and chemical effects of marine mining pollution can be measured, but field application requires considerable technical development. The state of the art of productive modelling is similar in this respect.

The biological effects of marine mining are very site-specific. In many cases intensive and long-term study would be required to develop adequate measurement and prediction capabilities.

The processing of mined materials, if practised on board vessels or platforms, or if done in shore-side installations, may have substantial pollution implications, including the release of finely divided or ionic materials which may accumulate in sediments or biota. The released material may not be of the same character as the parent material.

Present estimates of pollution from marine mining are largely unsubstantiated. In some cases they are reasonable deductions from established facts; in others, extrapolations, sometimes unjustified, have been made from studies in other fields. Other less obvious impacts may be disclosed by field investigations of specific activities.

During the present development period of marine mining, accelerated research and systematic monitoring are needed to develop rational management and pollution prevention measures.

Check lists and models for environmental impact analysis are needed which will direct attention to induced or cumulative effects of operations and permit the effective exchange and use of data between different workers.

Table 1. A summary of sea-bed materials which may be mined

Mineral deposit a/	Typical ores	Associated minerals or elements	Occurrence	Known deposits on margin	Potential mining method	Special considerations on pollution potential b/
<u>Consolidated sedimentary deposits</u>						
Sulphur	Native sulphur (S)	None	Salt domes, cap rock	United States, Middle East,	Underground solution	c/
	Metal sulphides	Cu, Fe, Ni, Pb	Veins, massive deposits	None		
Salt	Halite (NaCl)	None	Salt domes, beds	United States, Middle East, Europe	Underground solution	
Potash	Sylvite (KCl)	NaCl	Beds	United Kingdom	Underground solution	d/
Coal	Coal	FeS <sub>2</sub> Gas	Beds and seams	United Kingdom, Turkey, Japan, Chile	Underground solution (gasification)	e/
<u>Unconsolidated superficial deposits</u>						
Placer deposits of heavy metals and diamonds	Cassiterite (SnO <sub>2</sub> ) Magnetite (Fe <sub>3</sub> O <sub>4</sub> ) Rutile (TiO <sub>2</sub> ) Monazite (ThPO <sub>4</sub> ) Chromite (FeCr <sub>2</sub> O <sub>4</sub> )	Au, Pt or other stable minerals	Near shore, shallow water, old river courses or beach lines	Indonesia, Japan, United States, United Kingdom, South Africa, New Zealand	Excavation by dredging	f/
Sand and gravel	Sand and gravel	None	Surficial sea-bed, bars, beaches	Prolific	Scraping or excavating by dredging	See pertinent paragraphs in report
Limestone, shells and calcareous algae	Oyster shells Aragonite Corals	None	Estuaries, bays, shallow tropical	Prolific	Scraping or excavating by dredging. Corals may require blasting	g/

Table 1 (continued)

Mineral deposit a/	Typical ores	Associated minerals or elements	Occurrence	Known deposits on margin	Potential mining method	Special considerations on pollution potential b/
Metalliferous muds	Oxides and sulphides of Zn, Cu, Pb, Ag, Au	Fe, Mn	Small basins in sea-bed near hydrothermal active zones. Occurs as very unconsolidated muds. High temperature	Red Sea	Slurry excavation by dredging	h/
<u>Crystalline rock metallic deposits</u>						i/
Copper	Chalcocite (Cu <sub>2</sub> S)	Fe, As, Sb, Ni	Vein, porphyry massive	Canada	Excavation, underground solution	i/
	Bornite (Cu <sub>5</sub> FeS <sub>4</sub> )					
	Cuprite (Cu <sub>2</sub> O)					
Lead	Galena (PbS)	Cu, Zn, As Sulphides	Veins	United States, Greece	Excavation, underground solution	
Zinc	Sphalerite (ZnS), zincite (ZnO), franklinite ((Fe, Zn, Mn)O)	Fe, Cu, Pb, Ag, Sulphides	Veins	United States, Greece	Excavation, underground solution	
Nickel	Pertlandite (Ni <sub>2</sub> S)	Cu, Fe	Veins, massive	Canada	Excavation, underground solution	
	Garnierite (Ni <sub>1</sub> Fe)S					
Gold	Native (Au), tellurides (Au Te)	Ag	Veins, stocks	None	Excavation, tunnelling	k/
Silver	Native (Ag), argentite (Ag <sub>2</sub> S), polybasite (AgSbS <sub>2</sub> )	Pb, Cu, Zn, Au, As	Veins	None	Excavation, tunnelling	
Tin	Cassiterite (SnO <sub>2</sub> )	Cu, Pb, Zn, As	Veins	United Kingdom	Excavation, tunnelling	

Table 1 (continued)

Mineral deposit a/ Typical ores	Associated minerals or elements	Occurrence	Known deposits on margin	Potential mining method	Special considerations on pollution potential b/
Mercury	Cinnabar (HgS)	As, Sb Veins, stocks	None	Excavation, tunnelling	
Beryllium	Beryl ( $3\text{BeO}, \text{Al}_2\text{O}_3,$ $6\text{SiO}_2$ )	Sn, Wo, Mo Pegmatites, veins	None	Excavation, tunnelling	l/
Other deposits					
Phosphorite	Apatite ( $\text{Ca}_5\text{FPO}_4$ )	V, As, Si, Cl Nodules, sands, crusts	United States, South Africa, Australia, New Zealand	Scraping	m/ Also see relevant paragraphs in text.
Clauconite	Clauconite ( $\text{KFeSiO}_2, \text{nH}_2\text{O}$ )	Other black sands	United States, Australia	Scraping or excavating by dredging	
Fresh water	Ground water Sea water	Minerals in solution	Prolific	Solution mining or fluids handling	n/
Materials not mentioned above					
Metalliferous brines	Enriched sea water (Zn, Cu, Pb, Ag, Au)	Fe, Mn, S and other	Red Sea	Solution mining or fluids handling	

(Foot-notes on following page)

a/ Each of the types of mineral deposit can be mined in more than one way and, likewise, any given mining method may have application to more than one type of deposit.

Relationship between alternative mining methods available and known mineral deposit types

	Mineral deposit			
	Continental shelf		Continental slope	
	Unconsolidated deposits	Consolidated deposits	Unconsolidated deposits	Consolidated deposits
<u>Mineral mining</u>				
Trailing suction hopper dredge	Sand and gravel, shells			
Suction dredge, anchored	Heavy minerals		Phosphorite	
Cutterhead pipeline dredge	Sand and gravel, shells			
Bucket-ladder dredge	Heavy minerals			
Drag dredge			Phosphorite	
Continuous line bucket			Phosphorite	
Underground mining		Various		Various
Solution mining		Various		Various

b/ For the most part, the pollution potential may be inferred from the potential mining method, as generalized in the body of the report. Where special considerations must be given to an unusual or unique pollution potential, reference is made to explanatory foot-note material.

c/ Superheated water (120°C) and acidic solutions are contained in sulphur production pipelines on the sea floor. Accidental spillage could cause local and temporary pollution.

d/ At the present time potash mining takes place only on land, and there is little knowledge available of the environmental consequences of marine mining which might arise from either the method of mining or the effect of the discharge of effluent resulting from the extraction process.

Potash bearing materials might be recovered in two ways, by conventional excavation techniques or by solution mining. Excavation of potash by removal of overburden seems improbable because of the solubility of the potash. Wherever it takes place, the effects of mining would seem essentially to be those arising from disturbance of the sea-bed, the suspension of deposits and changes in the

(continued)

character of the sea-bed. These effects are likely to be similar to those resulting from any underwater mining activity, i.e., sand and gravel extraction. Where solution mining takes place, holes are drilled into the potash-bearing strata and is water introduced; after exposure, the saturated solution is recovered and potash extracted. Drilling the boreholes and the rejection of cuttings may affect the marine environment, and the physical structures may reduce the area of sea-bed available for fisheries. Large amounts of liquid effluent are produced during the extraction of potash from mined materials. These effluents have a high salt content, mainly of sodium chloride (up to 200 parts per thousand) and of suspended solids derived from the crushed minerals. The nature of the suspended material depends on the method of crushing, but up to 80 per cent of it may be less than  $63 \mu$  in length, and is generally less than  $250 \mu$ ; concentrations may reach 10,000 mg/l of effluent. In addition, small amounts of inert substances are added to assist in the separation process.

From a typical installation, effluent flow may be up to 1,000 tons per hour. Thus, the amount of salt and suspended solids is considerable. These substances may affect the local marine environment in a variety of ways, depending on the method of disposal, the local hydrography and the proximity of marine resources. The high silt content of the effluent may increase the turbidity of the water, and may settle on the sea-bed, affecting the habitat and its associated benthic life. This could be important in areas where commercial crustacean species are found on hard bottoms. The high salt content, if not diluted sufficiently, can prove toxic to larvae and mature organisms. Providing discharge of the effluent takes place in a hydrographically suitable area, all or most of these effects can be avoided.

e/ Coal mining off shore may require the construction of large artificial islands and involve the dredging of large amounts of fill material from the nearby sea-bed.

f/ Dredging for heavy minerals is particularly significant because operations are normally close to shore and the major part of the material dredged (about 95 per cent in the case of iron sand and 99.9 per cent in the case of tin, for example) must be returned to the sea-bed after removal of the valuable constituent. A normal swell factor of 150 per cent for the material dredged may cause significant shoaling, particularly in shallow water. Certain minerals, such as gold, may require some additional treatment of the concentrates on board the dredger. Close control of the materials cycle will be required in these cases. Many of the effects of dredging for heavy minerals are similar to those, described above, for sand and gravel in relation to the dispersion of fine grained material. See also the discussion of this matter in the report of the seventh session of GESAMP. (GESAMP VII/9, annex IX, appendix II.)

g/ Ancient oyster reefs, no longer living and frequently covered by several meters of sediment, are mined in several coastal areas of the United States, normally in sheltered bays or estuaries. Either cutter head suction or bucket-ladder dredges may be used. The effects of the operations are similar to those described for sand and gravel, except that the amount of fine silt and muds suspended may be as great as the amount of shells removed. Live oyster beds are commonly closely adjacent, and the overburden may contain considerable quantities of organic debris and associated gases. These activities have attracted

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considerable public interest because of their proximity to parks or population centres. Depending on the end use, it may be necessary to wash the shells with fresh water, thus presenting a possible problem of wash water disposal.

The exploitation by dredging of deposits of calcareous algae (mainly Lithothamnion spp) has developed in recent years off the coasts of France and is under consideration in the United Kingdom and Ireland. The workable deposits occur in shallow waters near the coast and in estuaries and inlets. The dredged material is ground and sold as a soil conditioner and fertilizer. It is principally a source of calcium carbonate and trace elements, with a small amount of organic material.

The reserves of this material seem to be quite modest but are slowly being renewed by the growth of the algae. The extent to which similar algae are found in other parts of the world sufficiently close to a potential market outlet has not been determined.

The effects of dredging deposits of calcareous algae are similar to those of dredging other surface deposits - destruction of benthos, alteration of the topography and nature of the bottom, with possible effects on the current régime, and release of fine material which may cause local modifications of water and bottom conditions. The wisdom or otherwise of working particular deposits of calcareous algae can only be judged by a careful assessment of local conditions and probable effects.

h/ Metalliferous muds may be highly chemically active and occur at relatively high temperatures. Pollution potential would depend largely on the choice of handling methods throughout the materials cycle and particularly on site. The metallurgical plant could give rise to a variety of problems dependent on whether it was sea- or land-based.

i/ Excavation of hard-rock ore bodies on the sea-bed or close to the sea coast present similar problems with regard to the disposal of waste materials after the excavation of the valuable constituents. Exposure of fresh ore by excavational spillage or dumping may result in local solution of metals. Taconite may be considered here as an interesting example occurring in Lake Superior, where dumping of fine grained waste from a shore-side mining operation, to the amount of about 100,000 tons each day, causes considerable pollution. Effects on water quality due to siltation and a mixture of asbestos fines are noted as well as massive build-up and spreading of the material on the lake bottom.

j/ Solution mining of a sulphide copper ore body off shore might require the drilling of several hundred deep holes through the ore body and a complex network of pipelines on the sea-bed, connected to a hydrometallurgical plant on shore. Development work might also require explosive fracturing of the ore body. Potential impacts which might occur from this operation may be surmised. During the development period the impact of drilling will be similar to that for any production drilling programme of this nature and will include the possibilities of mud or fuel spillage, some sea-floor disturbance and deposition of materials from the hole. Similarly, disturbances of the sea floor may occur during the installation of the pipelines and the injection complex. These structures will in most cases project from the sea floor but they could be buried or protected by smooth-surfaced housings. Possible impacts due to the operations are mostly due to the chance of accident-induced spillage resulting from fracture of the pipeline



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(continued)

or the injection system by earthquake movement or collision. The sea-floor system which could drain in the event of such an accident at the deepest well-head, assuming 60 miles of 15-inch lines, would contain around 4.5 million gallons of solution. Recycling of all toxic solutions within the plant is assumed and the disposal of toxic solid wastes from the shore plant is not considered here.

k/ Gold mining operations frequently use potassium cyanide as an extractive medium. Mines located on the coast could present a problem in the handling and disposal of these highly toxic solutions.

l/ Although beryllium compounds are hazardous, the common beryllium mineral, beryl, is usually considered to be inert.

m/ Phosphorite deposits may be above or near the thermocline and are generally found on moderately hard, current-swept bottoms. A production of 360,000 tons of phosphorite per year would require the stripping of nearly 8 square kilometres each year, if the density measured a not unusual  $5\text{g/cm}^2$ . Treatment of phosphorite ore may involve screening, flotation, leaching and/or roasting. These are standard metallurgical procedures except that flotation, using sea water, has been employed on at least one occasion in the past. If these processes were used, careful control of the materials cycle would be required to prevent loss of potential pollutants.

n/ The removal of a fresh-water source for consumption would alter the temperature and salinity of the area with consequent effects on existing biota. It might also affect shore supplies dependent upon the same aquifer.

## Annex I

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