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OFFSHORE MINERALS
EXPLORATION TECHNIQUES

INTRODUCTION

This paper describes the techniques used in the exploration for minerals in relatively shallow water depths. They are presented in three parts: geophysical, geological and geochemical methods. These techniques are summarised in Figures 1 and 2.

GEOPHYSICAL METHODS

These methods use measurement of physical properties (e.g. density, conductivity, magnetism) to explore not only the topography of the sea-floor but also aim to provide information below the sea bed. The measurements can be interpreted in terms of favourable rock structures and may indicate the presence of mineralization. The measurements are normally carried out from surface ships or aircraft.

Bathymetry

Bathymetric surveys are used to determine the depth of water and are often used for the systematic mapping of the seafloor. A short sound pulse is sent to the seabed from a ship-mounted transducer and reflected back to the transducer. The intervening time period is used to calculate the depth of water.

Photography and other visual techniques

Still photographs can provide the basis for detailed mapping of the seafloor. When operating the cameras may be fixed or towed. Stereo cameras are useful in showing bottom relief. Motion picture and videotape camera can be used to provide a continuous visual record and can cover large areas of the seafloor in a short time. Photography by divers, with or without submersibles, can also be used.

In all cases it is necessary to provide powerful illumination in order to observe the seafloor's features.

Side-scan sonar

This is a device similar to sonars used for hunting submarines. A survey vessel tows a compact "fish" containing a set of transducers which generate high-power, short-duration sound pulses. The pulses are emitted in a thin fan shaped beam which scans a seafloor segment ranging from directly underneath the fish to a distance as far as 500 m away from the fish. The sonar display is analogous to an oblique aerial photograph of land.

Seismic surveys

Seismic surveys delineate the various layers of rock below the seafloor by means of sound reflection and refraction techniques. Seismic surveying can save the expense of employing coring and drilling techniques.

Seismic reflection is similar to sonar sounding, except that it uses higher energy sound impulses. The sound impulse is emitted from a towed electronic transducers, such as a sparker (which produces electric sparks at intervals), a compressed air gun (bubble impulse), boomers and pingers (electromechanical impulse), or a gas explosion. The echoes are received by hydrophones towed by the survey ship. Echoes are received not only from the sea floor but also from reflectors below the sea bed. Echoes from deeper horizons arrive later than the echoes from the shallower horizons.

For intertidal areas the sound impulse is derived from small explosives, charges, either as Geoflex ribbon or dynamite set in shallow drill holes. For these techniques the echoes are received on geophones arranged on the ground surface.

The shallow seismic reflection techniques described above is often call "subbottom profiling".

Seismic refraction uses a higher energy sound source than the reflection method. To achieve higher energy sounds, explosives are set off at regular intervals. A second ship (or floating hydrophones), away from the point of explosion records the refracted arrival time of the sound waves travelling along the seafloor and along the various refracting surfaces below the seafloor.

Seismic refraction is not in common use because of the improved capabilities and lower costs of seismic reflection and because the use of explosives at sea can damage the marine environment.

Magnetic measurements

Magnetic measurements are used to detect magnetic minerals (e.g. iron-rich minerals) on or beneath the seafloor. They measure the thickness of sediments over magnetic basement rocks. Magnetic intensity measurements can be made with a total intensity magnetometer towed from a ship or airplane. Computer techniques are used to process the data and obtain information such as the thickness of sediments above rocks with comparatively high magnetic properties. Magnetometers can also be used to detect wrecks, cables and pipelines on the seabed.

Gravity measurements

Minor distortions in the earth's gravity may indicate the presence of orebodies which have specific gravities exceeding those of common rock. In the past the instruments used for the measurement of the variation of the gravitational field strength at sea included pendulums and gravity meters. At the present time gravity meters are used almost exclusively. These instruments use a delicate spring mechanism to balance the gravitational force on a small mass. The accuracy of marine gravity measurements is considerably less than the accuracy of land based gravity measurements.

Other methods

Techniques used in onshore exploration such as heat-flow measurements, electrical measurements and measurements of natural radioactivity, have potential for offshore exploration but have not been practised or fully demonstrated in the offshore environment. Airborne radiometric surveys are routinely flown concurrently with airborne magnetic surveys.

GEOLOGICAL METHODS

The aim of geological methods of exploration is to prove the presence of a mineral deposit by physical sampling. Sampling is undertaken for several purposes: for assay, basic scientific data, determination of engineering properties, pilot processing, and site evaluation. A sampling program must be properly designed to yield the desired information. The usual methods of sampling are surface grabs, shallow coring, dredging and deep drilling.

Surface sampling

A sample is scooped from the seafloor by a mechanical grab which picks up only the top few inches. The method is suitable for unconsolidated sediment and there are various types of grabs available.

A draft sampler resembling a dustpan can be used to obtain a sample over a larger area. Its disadvantage is that the sample becomes homogenised thereby diminishing the site specificity or naturalness of the sample.

Dredging

A frame dredge or a pipe dredge is used to obtain larger samples. A frame dredge is a network of chains which is dragged along the seabed; the size of the mesh and mouth can be regulated to pick up material of a certain size. A pipe dredge is a section of large pipe similarly dragged.

Shallow coring

A core sample of the seabed is taken to determine the thickness of mineralization or thickness of an overburden layer such as sand and gravel over the underlying mineral deposit. Coring may also be used to obtain stratigraphic information to help interpret the geological processes that formed the seabed.

There are several devices available, generally consisting of a core barrel, which is a tube several centimetres in diameter and several metres long, plus a device for driving it into the seabed:

- the *impulse corer* uses gravitational impact or an explosive mechanism, but its depth of penetration is not great.

  the *percussion corer* uses repeated impulse loadings to achieve penetration of up to 10 metres.

- the *box corer* is an impulse corer with a large cross-sectional area designed to obtain relatively undisturbed samples, but penetration is only about one metre.

- the *vibratory corer* is driven by acoustic or mechanical vibration at a frequency close to the natural frequency of the material to be penetrated, so that depths of up to 12 metres can be obtained.

- the *water injection* corer uses a water jet to advance a casing and an internal percussion corer is used to take the sample. Penetration of up to 15 metres can be achieved.

- the *suction corer* is used in unconsolidated muds to obtain bulk samples below the seabed. The slurry is pumped to the surface and screened and the large diameter core barrel advances downwards under its own weight or with mechanical assistance.

Drilling

Drilling allows penetration into consolidated deposits of minerals or to a greater depth than is possible with coring. Offshore drilling is performed from "jack-up" drilling rigs, semi-submersible drilling platforms and drill ships.

GEOCHEMICAL METHODS

Geochemistry is used to analyse constituents in sediments and rocks for traces of ore bodies. Geochemical methods can be divided into:

- *laboratory analysis* techniques which are used to subject samples to a variety of tests either onshore or aboard ship;

- *in situ analysis* techniques are at an early stage of development. Most of the research has centred around the application of neutron activation analysis, using a towed source and detector or a submersible. Neutron activation techniques create artificially generated radioactive isotopes and measure the decay radiation, but they leave a trail of radio-isotopes on the seafloor and may be environmentally undesirable methods of exploration.

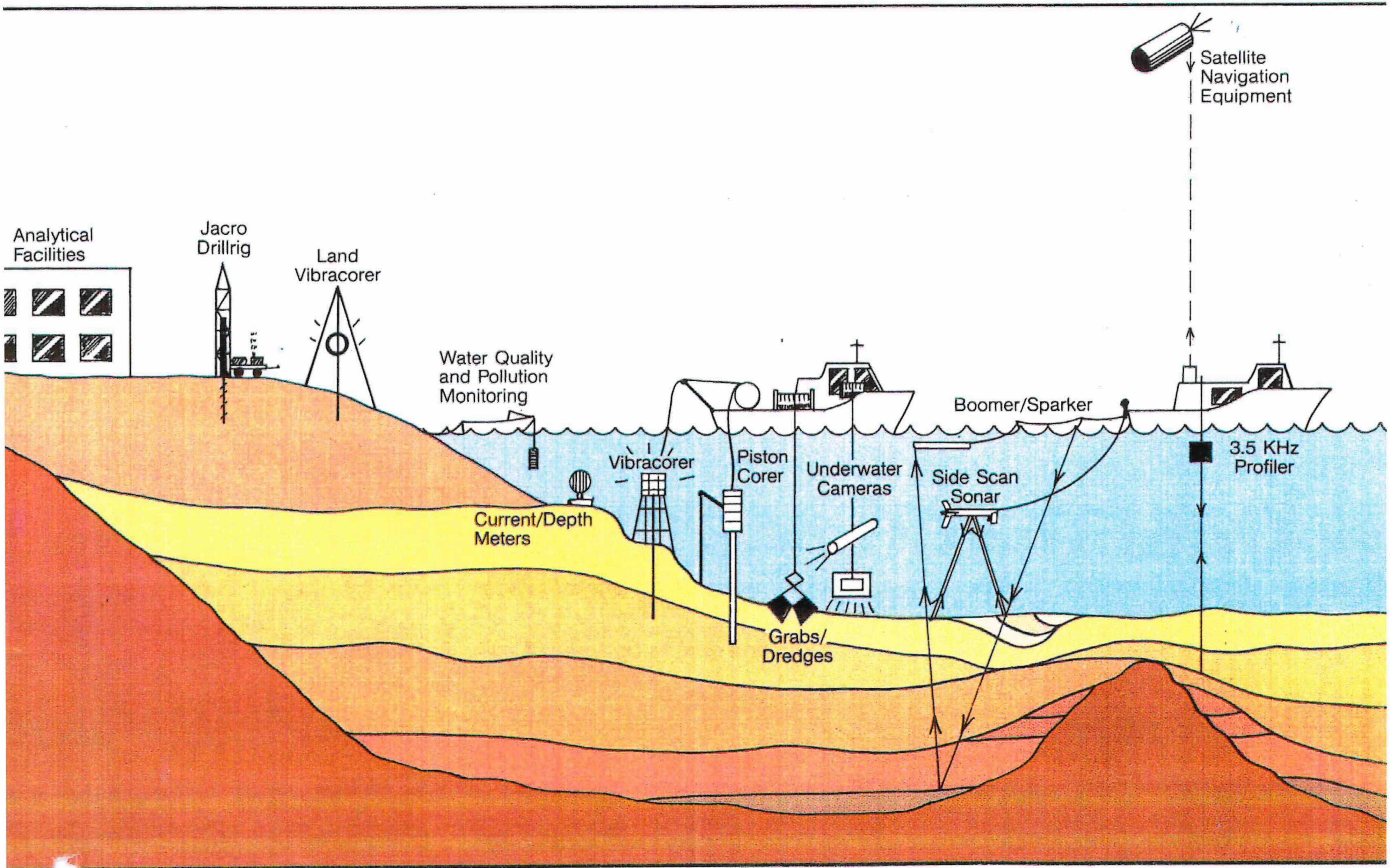
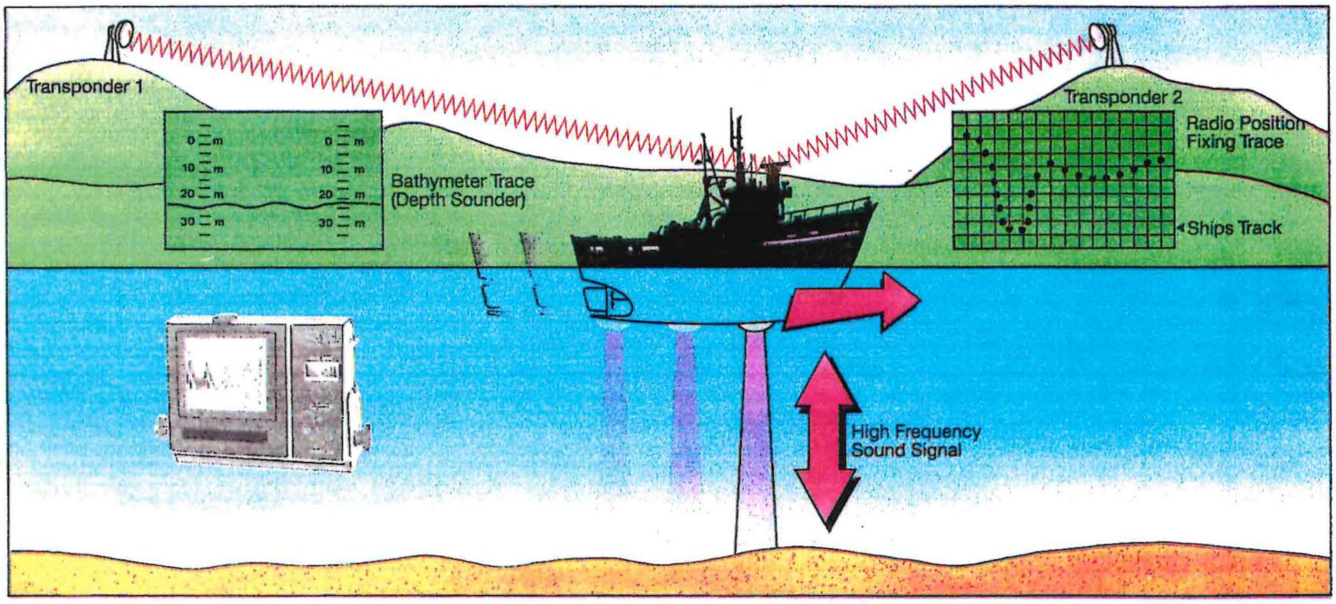
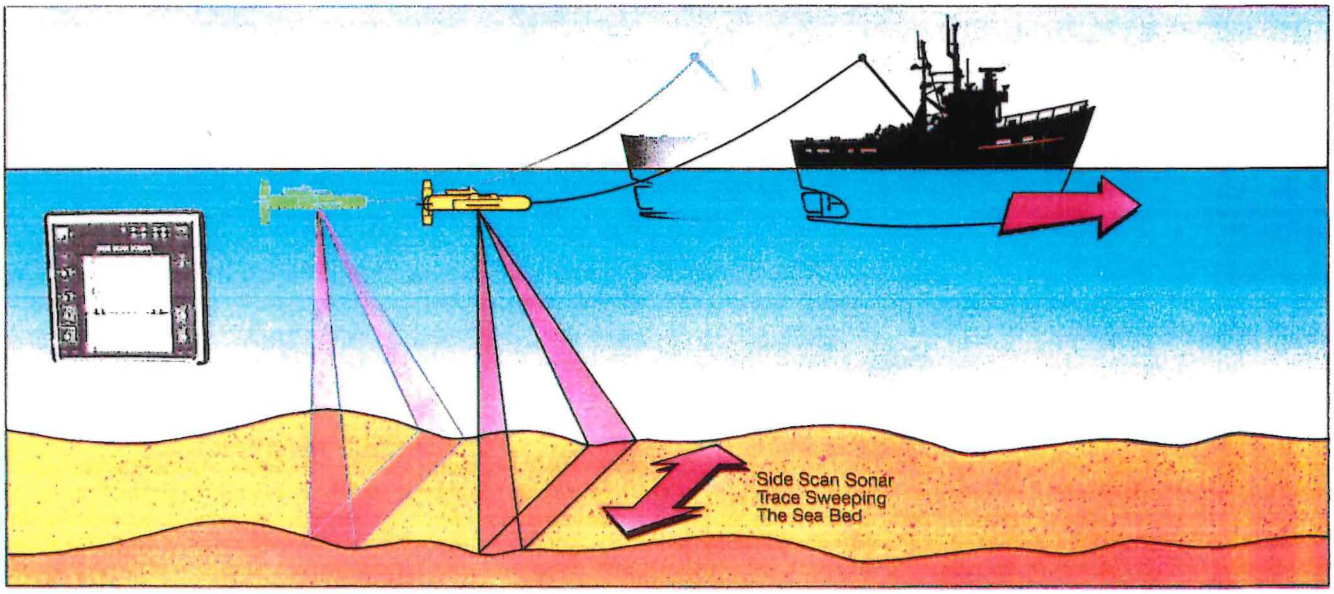

Satellite
Navigation
Equipment
Analytical
Facilities
Jacro
Drillrig
Land
Vibracorer
Water Quality
and Pollution
Monitoring
Boomer/Sparker
3.5 KHz
Profiler
Vibracorer
Piston
Corer
Underwater
Cameras
Side Scan
Sonar
Current/Depth
Meters
Grabs/
Dredges

Fig 1



RADIO POSITIONING AND BATHYMETRIC SOUNDING



SIDE SCAN SONAR PROFILING

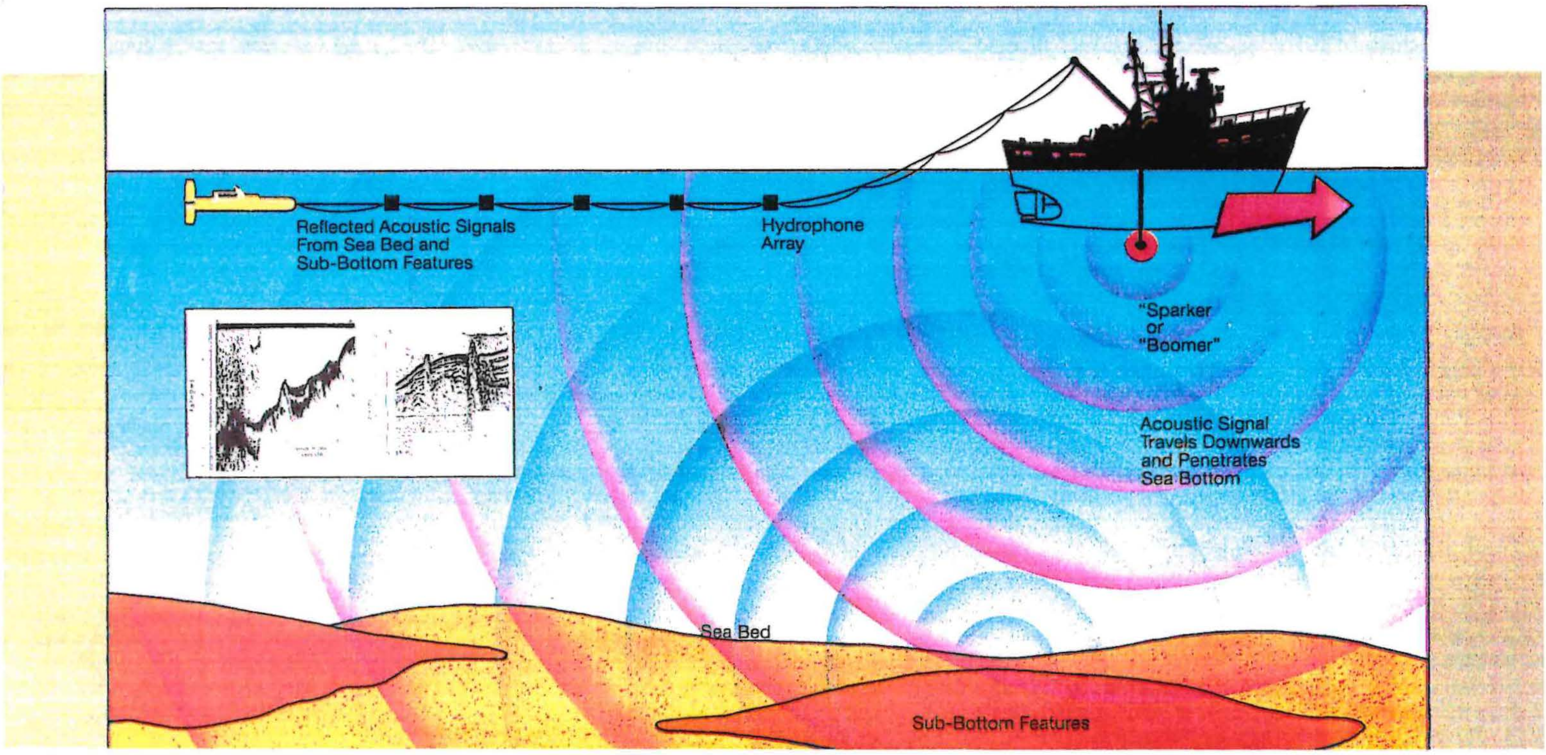


Fig 2

OFFSHORE MINERALS

MARINE MINING TECHNOLOGIES

INTRODUCTION

This paper examines the existing techniques and recent innovations for marine mining in shallow and deep water environments with examples taken from overseas operations. Information is presented in three parts: dredging, new dredge designs and deep sea mining technologies.

DREDGING

Hydraulic and mechanical dredging provides an efficient means of recovering underwater deposits of precious metals and minerals, sand and gravel. Figures 1&2 illustrates dredge designs currently in use.

Hydraulic dredging techniques

Pipeline cutterhead dredges incorporate a centrifugal pump and a mechanical rotating cutter suction device installed at the end of a movable ladder adjoining a suction pipe. The rotating cutter loosens the seabed materials which are then sucked into a dredging pump and conveyed by a suction pipe up to a disposal point on the dredge. Some dredges are equipped with screening or separation plants and material is pumped to barges for transport to shore-based processing facilities for recovery. An example is given in Figure 4.
Current applications include excavation for compacted materials such as clay and consolidated gravel.

Self -propelled Hopper Dredges are fitted with suction pipes that suck up materials and water which are conveyed to a pump(s) on board. The material is carried via discharge pipes to hoppers in the ship hull for subsequent transport to a disposal site. Applications for soft materials such as sand.

Dustpan dredges have high pressure jets of water fitted to the rim of the suction pipe head which breaks the soil substrate and loose material is sucked into the dredging pump and conveyed via pipes to disposal areas.
Applications for light flowing materials such as sand and gravel.

Jet-ejector dredges consists of two types of jet nozzles one for dredging, the other for enlarging the dredging well fitted to a long nozzle pipe on the ejector. Seabed materials are sucked up by the ejector and discharged into hopper barges for shipment or delivered through floating pipelines.
Suitable for sand and gravel extraction at depths up to 70m.

Jet-assist dredges have a conventional dredging pump and a high pressure jet pump in series. This allows deep dredging by delivering water under high pressure through the suction pipes into jet nozzles at the base of the cutting head. Increased water velocity through the jet nozzles creates a suction which draws up sand. The conventional pump creates the vacuum needed to draw up materials pumped up by the jet pump.

Mechanical Dredging Techniques

Mechanical dredges function as well as hydraulic systems but require barges to transport dredged materials to a disposal site.

Dipper dredges consist of a dipper stick and an excavating dipper. The dipper scoops up material and, once filled, the material is loaded onto barges and transported to shore-based facilities for treatment and disposal. Operational at depths of up to15m. Suitable for hard, compact and oversized materials such as rock.

Clamshell dredges comprise a clamshell bucket which is supported by a cable from a mobile boom extending from the bow of the dredge. An operating control console enables greater movability of the boom for more effective barge loading operations. Applications for oversize gravel and blasted rock formations.

Bucket -ladder dredges consist of a cutting ladder carrying a series of buckets on an endless chain moving continously from the seabed to the hull for gravity discharge of the dredged materials to a recovery plant on board the dredge or nearby barges for transport to shore. Suitable for excavations up to 30m.
Uses of this technique include mining of various ores, rare earths and precious metals such as gold and aggregate recovery.

Dredge type and type of excavated material is summarised in Table 1.

TABLE 1 - DREDGE TECHNIQUE AND APPLICATION

DREDGE TYPE	*MATERIAL*	*DEPTH (METRES)*
Pipeline cutterhead	*clay and consolidated gravel*	*0-25*
Self propelled Hopper	*soft materials:-sand*	*0-25*
Dustpan	*light flowing materials:- sand and gravel*	*0-25*
Jet-ejector	*sand and gravel*	*70*
Jet-assist	*sand*	*0-25*
Dipper	*hard, compact materials:- rock*	*15*
Clamshell	*oversize gravel and blasted rock*	*0-25*
Bucket-ladder	*tin ore, rare earths, precious metals and aggregate*	*30*

NEW DREDGE DESIGNS

Technical advances are making possible increasing uses in aggregate recovery and mining.

Submarine Capsules - These capsules having cutterhead dredging equipment will be suspended under the water by supporting platforms 20-30m above water level.

Deeper Digging Depths - Improvement in both the bucket-ladder and the clamshell designs will make possible mining in depths of up to100m and excavation of hard materials such as blasted rock.

New Pump Designs - Advances in pump design will allow for larger quanities of materials to be pumped through more efficient systems.

Compressed air dredges - a pumping head comprised of cylindrical chambers for dredging, a compressed air distribution system and air compressor units. This system delivers compressed air to the dredging cylinders which pump up sand, slurry and mud. The material is then fed to a common discharge line for disposal.
Dredging depths of up to 60m are achievable.

DEEP SEA MINING TECHNOLOGIES

The deep ocean floor has a vast reservoir of rich minerals including manganese, cobalt, copper and nickel deposited in nodules having commercial value which have not been fully explored. There is also potential for mining of diamond and other commodities. Commodities presently being mined in the ocean are shown in Table 2.

Nodule Collectors are vacuum cleaner like harvesters moving on caterpillar tracks sweeping the ocean floor for nodules which is connected to the surface vessel by a pipe string. This machine also has potential for sulphide extraction with the addition of a device to shatter hard brittle sulphide deposits. It is envisaged that the system may become operational to depths of 6km with technical design modifications. See figure 3.

Remote controlled seabed crawlers/tramrods & Large diameter wirth drills pump diamondiferous gravels for diamond recovery. Commercial diamond production off the coast of Nambia, SW Africa utilising the seabed crawler technique will commence in 1995.
A comparison of the seabed crawler/tramrod technique with current shallow water operations is highlighted in Table 3.

TABLE 2 - MARINE MINING INDUSTRY

COMMODITY	***COUNTRY***
SAND & GRAVEL	*UK, JAPAN, DENMARK, HOLLAND, SWEDEN, U.S.*
TIN (in concentrates)	*INDONESIA, THAILAND*
CALCIUM CARBONATE	*U.S., FRANCE, ICELAND, FIJI, BAHAMAS* → (W.A)
SULPHUR	*U.S.*
PRECIOUS CORAL	*TAIWAN*
BARYTES	*U.S.*
IRON SANDS (as concentrates)	*JAPAN*
DIAMONDS	*SW AFRICA*
Gold	*U.S.*

(Source: Mining Magazine v130 n3 Mar 1974)

TABLE 3. MINING TECHNIQUES IN SOUTH AFRICA (1994)

SHALLOW WATER MINING OPERATIONS	***DEEP WATER MINING OPERATIONS***
Technique:- Divers with air lift pumps	*Technique:- Sea-bed crawler/tramrod or Wirth drill*
Small scale operations	*Large scale operations*
Labour intensive	*Capital intensive*
Heavily dependent on weather/swell conditions	*Less dependent on weather/swell conditions*
50-700 tonne vessels	*3000+ tonne vessels*
Operational days:- +/- 100/year	*Operational days:- +/- 225/year*
HMS feed/day:- +/- 7 tonnes	*HMS feed/day:- +/- 600 tonnes*
HMS feed/year:- 700 tonnes	*HMS feed/year:- 135,000 tonnes*
HMS on shore	*HMS on board*
Water depths:- 0-25metres	*Water depths:- 25-200 metres*
Typical ore grades:- 50-200 carats/100 tonnes	*Typical ore grades:- 5-30 carats/100 tonnes*
Typical output:- 300-2,000 carats/year	*Typical output:- 70,000-200,000 carats/year*

Note: HMS refers to the Heavy Media separation plant which is capable of recovering heavy minerals, including diamonds from coarse sea-bed sediments. This follows a screening process to remove oversized gravels and undersized sands. Estimates of 0.01-0.10% of pumped sea floor materials emerges from the HMS plant for diamond recovery in X-ray Sortex machines.

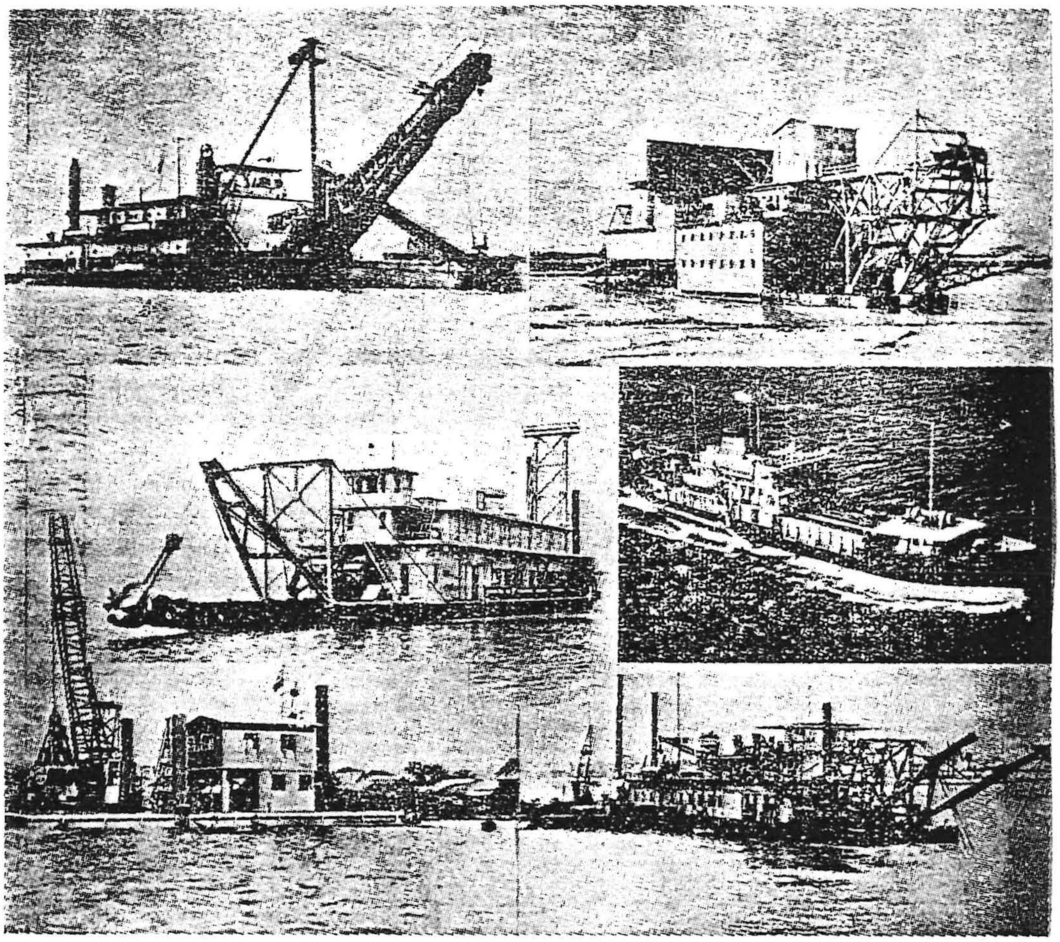


Fig. 1 Six basic types of dredges:
Top left—Dipper dredge; right—Bucket ladder dredge.
Centre left—Hydraulic pipeline cutterhead dredge; right—Hopper dredge.
Bottom left—Clamshell dredge; right—Dustpan dredge.

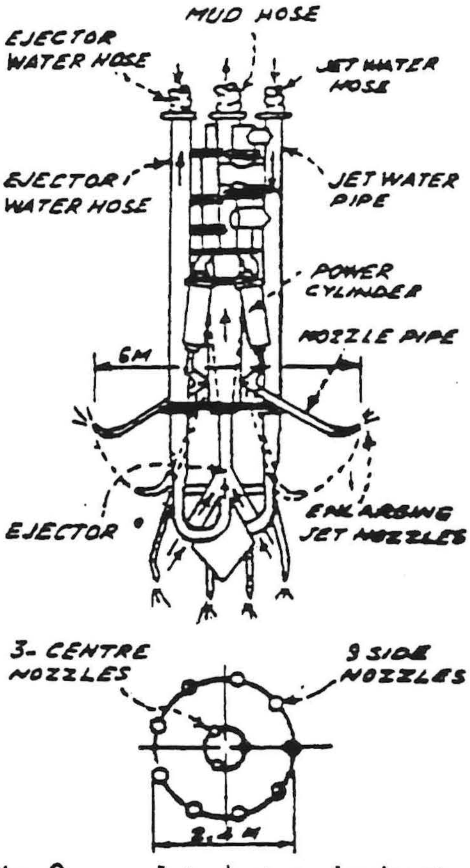


Fig. 2 Jet-ejector dredger: Digging nozzles pierce silt and clay layer on the seabed, enlarging nozzles breakdown the sand and gravel layer and the ejector completes the excavation process by sucking the mud mixture to the surface.

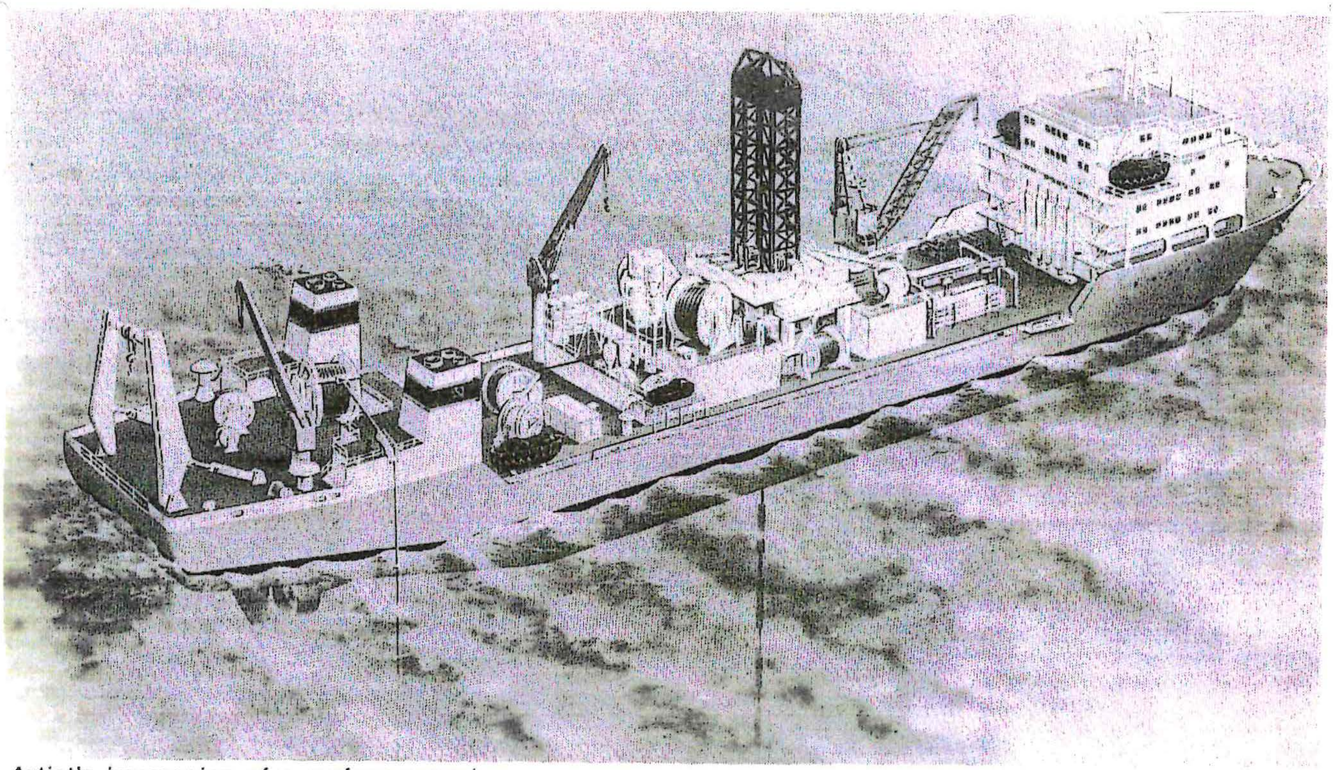
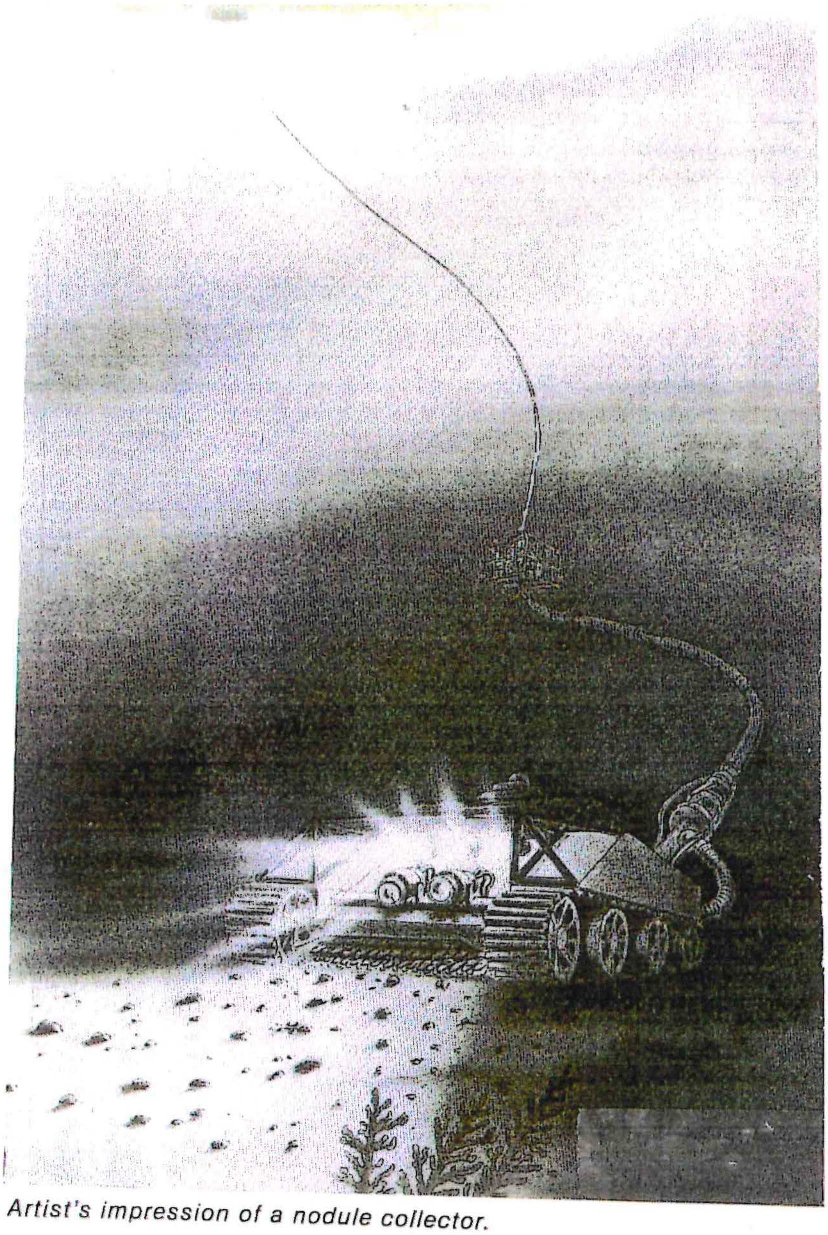
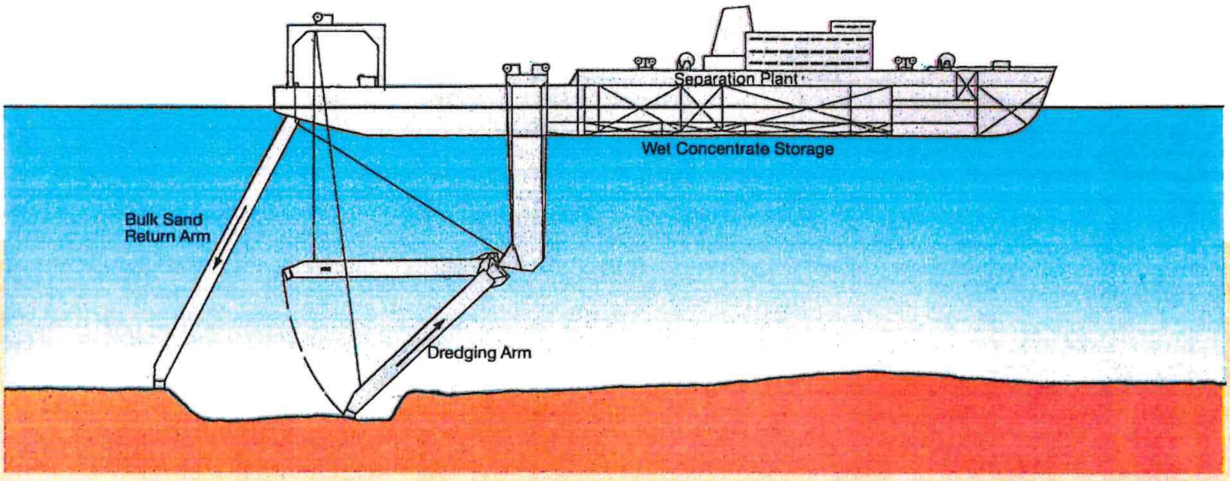
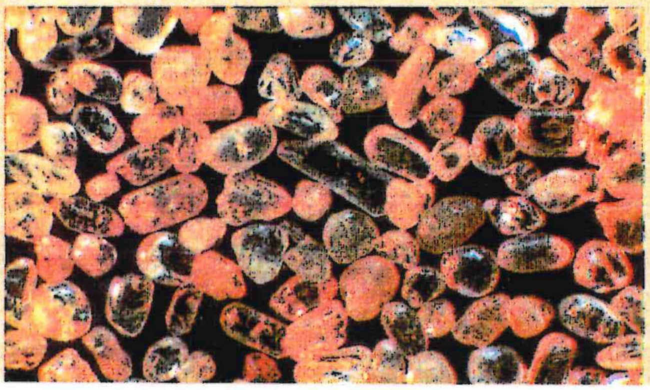

Artist's impression of a surface vessel.

Fig. 3


Artist's impression of a nodule collector.



MINING PLANT CONCEPT



ZIRCON

Figure 4 shows an example of an offshore heavy mineral sands operation utilising a self propelled pipeline cutterhead dredge. Wet concentrate is extracted in a separation plant on the dredge and tranferred to barges for transport to processing facility on shore for rutile and zircon recovery. This dredging technique is designed to return unused bulk sand to the cut area immediately following dredging. Operational depths of up to 70 m are achievable.

This technique is similar to that used in the North Sea sand extraction industry and is proposed for heavy mineral sand extraction off the coast of NSW.