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1 INTRODUCTION

1.1 Background

Considerable mineral resources have been discovered in the oceans during the past decades. Several technical-economical studies have been performed in the last 15 years. Norwegian marine industry represented by the Norwegian Deep Seabed Mining Group has developed a technological know-how and has the required experience for the development of an ocean mining system. Norwegian companies have contributed to studies since the early 1980's including a comprehensive project co-operation with India. This report analyses the marine mining industry status in order to identify possible business opportunities for Norwegian industry. The following possibilities has been identified and analysed in this report:

Cook Islands has enormous mineral resources within their own EEZ, but has very limited financial resources. Cook Islands wants to co-operate with Norway and Norwegian industry.

India may still be interested in Norwegian technology for their project.
China/Korea is performing mapping surveys and are interested in technology co-operation with Norwegian industry

There is a growing interest in exploration and mining of so-called hydrothermal sulphide deposits.

Any of these deep-sea mining operations will depend upon the following factors:

- Quality of exploration and prospecting
- The size and grade of the ore body
- The rate of mining
- The metallurgical recovery
- The selling price of the product
- Capital costs
- Operating costs
- Legal, political and physical parameters

These factors will all be considered in this report.

1.2 Norwegian Deep Seabed Mining Group

The following organisations are included in the Norwegian Deep Seabed Mining Group:

- ABB Offshore Systems AS (ABB)

- Aker Technology AS (AT)
- Fugro-Geoteam AS (FG)
- Kristian Gerhard Jebsens Skipsrederi AS (KGJS)
- Kongsberg Simrad AS (KS)
- Faculty of marine technology; NTNU

Steering committee:	ABB: Rune Strømquist; chairman AT: Odd Arvid Olsen KS: Kåre Sunnarvik FG: Stein Åsheim KGJS: Gunnar Jacobsen NTNU: Fredrik Søreide
Partner:	Fridtjof Nansen Institute: Jan Magne Markussen
Project management and co-ordination:	Aker Technology: Trygve Lund
Project execution:	Norwegian Deep Seabed Mining Group and Fridtjof Nansen Institute
Project financing:	50% by NDSMG 25 % by NFR and SND each

1.3 Why is deep-sea mineral mining interesting for Norwegian industry?

Marine mining would represent:

- New markets for the Norwegian maritime industry; i.e. equipment, transport services and construction activities.
- New market for “world-class” Norwegian mapping technology; i.e. deep water mapping and survey equipment, instrumentation, data handling and interpretation.
- New market for advanced Norwegian offshore technology; i.e. underwater technology, risers, control systems, remotely operated maintenance etc.
- New market for Norwegian shipping companies and their transport services.
- Norwegian industry has a reputation for building advanced ships; i.e. research-/mapping ships for Korea.
- Deep ocean mineral mining will involve new industrial development.
- Norwegian management of own petroleum resources is an example for other countries.
- Norway is a politically acceptable player internationally.

1.4 International Laws and Regulations

1.4.1 The 1982 UN Convention on the Law of the Sea and the 1994 New York Agreement

The 1982 United Nations Convention on the Law of the Sea was the result of nine years of negotiations. The Convention consists of 18 parts. There was universal agreement on 17 of the 18 parts. Part XI – the deep sea minerals part – was the problematic one. The industrial countries – lead by the United States, Great Britain and Germany – refused to sign the Convention because of Part XI. They felt that the deep sea part of the Convention was not good enough with regard to the interests of private companies. They also argued that Part XI could lead to a considerable UN bureaucracy.

59 countries had ratified the Convention on the 13th of October 1993. The Convention would enter into force one year after it had been ratified by 60 nations. No industrial country, with the exception of Iceland, had ratified. There was thus a real possibility that the Convention could enter into force – without ratification from any of the major industrial countries. A situation like that would be unfortunate both for developing countries as well as for industrial countries. Informal consultations were therefore initiated in order to try to solve the problem. The situation was regarded as very serious and the Secretary General of the United Nations involved himself personally in the informal negotiations.

The Secretary General had a list of eight so-called ”hard core issues”. The list consisted originally of nine issue areas. ”Environmental Considerations of Deep Seabed Mining” was, however, removed from the list during the autumn of 1993 because the countries agreed that the environmental problem areas would be ”manageable”. The remaining problem areas were as follows: the Enterprise, decision making process, revision of the regime, production policy, and economic and financial arrangements.

The informal consultations resulted in the so-called 1994 New York Agreement (Agreement Relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982, July 28, 1994), which everyone could agree to.

1.4.2 Comparison between the two regimes

The original Part XI of the 1982 UN Convention and the 1994 New York Agreement represent the ”old” and the ”new” regimes for the management of deep seabed minerals beyond national jurisdiction.

The relationship between the two regimes is regulated through two basic principles. A country is not allowed to accept only one of the regimes, and reject the other. The country must thus accept both the New York Agreement and the UN Convention.

Secondly, the two regimes shall be interpreted and used as one instrument. If there are inconsistencies between the two regimes, it will be the New York Agreement that will be the valid one.

1.4.3 The common heritage of mankind

The UN Convention defines the seabed and the resources on the seabed as the Common Heritage of Mankind. The New York Agreement does not change this principle.

Article 134 in Part XI defines the areas that constitute the Common Heritage of Mankind as ”the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction”.

Article 136 defines the resources that are to be regarded as the common Heritage of Mankind as ”all solid, liquid or gaseous mineral resources in situ in the area at or beneath the seabed, including the polymetallic nodules”.

1.4.4 The UN Convention versus National Legislation

The Cook Islands nodule deposits lie within the country’s Exclusive Economic Zone. The exploitation of these resources will therefore be regulated according to national legislation and not the UN Convention.

Many regards this as a great advantage as it will be easier to relate to national legislation than to the UN Convention and the International Seabed Authority. The International Seabed Authority is also regarded as bureaucratic and slow working.

As we shall see in Chapter 6, the Cook Islands does not, however, have any national legislation regulating the exploitation of their nodule deposits today. Such regulations will have to be formulated and institutions will have to be built. The Government of the Cook Islands would like to have a regime that ensures that the country will get a fair share of the revenues that the project generates - and a regime that can protect the environment. The Government of the Cook Islands regards the way Norway has been able to manage its petroleum resources as a model for the management of their deep-sea minerals. They hope that Norwegian authorities will assist them in formulating the necessary legislation.

The project group has therefore submitted an application to the Ministry of Foreign Affairs asking for the necessary funds to do this job (see Appendix 4).

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2 MARINE MINERAL RESOURCES

2.1 Introduction

The extraction of marine mineral resources already represents a two billion-dollar per year industry world-wide at the present time. There are approximately a dozen general types of marine minerals (depending on how one wishes to classify). Those being extracted include marine aggregates and placer deposits, such as sand, diamonds, tin and gold. Deposits that have generated continuing interest but are not presently mined include manganese nodules, crusts, sulphides, phosphorites and methane hydrates. A more detailed description of these resources will be given in the following sections.

2.2 Marine aggregates

Marine aggregates are deposits of non-metallic detrital minerals and calcium carbonate. The deposits consist of sands, gravels, shells or coral debris. Commercially interesting examples tend to be preferentially located near-shore in the inner portions of the continental margins or on beaches. Most marine aggregates have been concentrated into their present occurrences by seafloor hydrodynamic processes, although their deposition often is by some other mechanism such as erosion, rivers or glaciers. Aggregates are principally used in the construction industry (for cement), but are increasingly also dredged and placed back on beaches in replenishment programs. Quantitatively they are the most important marine mineral deposits being extracted at the present time.

2.3 Placers

Placers are metallic minerals or gems that have been transported to their sites of deposition in the form of solid particles. Placer deposits are generally found in EEZs, on beaches and near-shore areas. Most placers are resistant minerals that have been made available on breakdown of their parent rock as a result of chemical and mechanical weathering. The rocks are usually igneous in origin, but metamorphic and sedimentary rocks can sometimes also liberate placer minerals. Chemical weathering is much more important than mechanical, and placer deposits are therefore more common in mid- and low latitude areas where chemical weathering is pre-dominant (Cronan, 1992).

The placers are transported to the coast by glaciers, rivers or wind and typically settle in sinks or traps. The minerals are separated relative to their differences in specific gravity, grain size and density. The continual action of the waves and tides helps to concentrate the minerals in deposits known as placers. Lighter density minerals cannot be concentrated by this effect but can be concentrated by the huge panning system of sandy beaches that sorts and concentrates various minerals.

Placer minerals are therefore typically classified according to their specific gravity. So-called heavy placer minerals include gold, platinum and the important tin bearing placer, cassiterite (Yim, 2000). Heavy placer minerals have been recovered from several coastal and near-shore environments. One of the most recent gold placer mining operations took place in the 1980s in Nome, Alaska (Garnett, 2000).

Lighter placer minerals comprise the resistant accessory minerals of igneous rocks, including zircon (for zirkonium), ilmenite (for iron and titanium) and rutile (for titanium) etc. The most important gem placer mineral is diamonds. Diamonds are currently being recovered offshore in southwest Africa (Garnett, 2000). Diamonds are also thought to occur in Venezuela, India, China and northern Australia.

It is very difficult to generalise on the resource potential of placer deposits because they are so variable in nature and so scattered in distribution. Local circumstances therefore play a large part in determining the economic viability of a deposit.

2.4 Manganese nodules

Manganese nodules are relatively small and circular deposits of iron and manganese oxides that contain small amounts of up to 76 metal elements. The ferromanganese oxides normally accrete around a nucleus, which can be a piece of volcanic rock, organic remains, a fragment of a pre-existing nodule or some other solid object on the seafloor. This growth results in the formation of a nodule (Figure 2.1).

Figure 2.1. Bottom photograph showing a dense coverage of nodules

Nickel, cobalt and copper are the metals of greatest economic interest in the nodules. These metals reach concentrations of up to approximately 2%, but not in the same nodules. Nickel and copper co-vary with each other, and both vary negatively with cobalt. This means that a nickel and copper-rich nodule is generally low in cobalt, and conversely a cobalt-rich nodule is generally low in nickel and copper.

The sources of metals in the manganese nodules are either diagenetic or hydrogenetic. With so-called diagenetic processes, the nodules receive the metals from the interstitial waters of the sediments. With so-called hydrogenetic processes nodules receive the bulk of the metals from the seawater. Most nodules contain a mixture of hydrogenetic and diagenetic phases (Figure 2.2).

Manganese nodules vary in shape from spherical to oblate and even flattened. The shape is partly determined by the shape of the nucleus and partly determined by the growth history. The common "hamburger" nodules have flattened tops and rounded undersides, reflecting a variable supply of metals from both above and below. Typical Pacific nodules have a mean long axis length of 5.5 cm, short axis length of 4.4 cm, a thickness of 3.4 cm and a weight of 95.7 g. A diameter of less than 3 cm is considered small while a diameter of more than 6 cm is considered large.

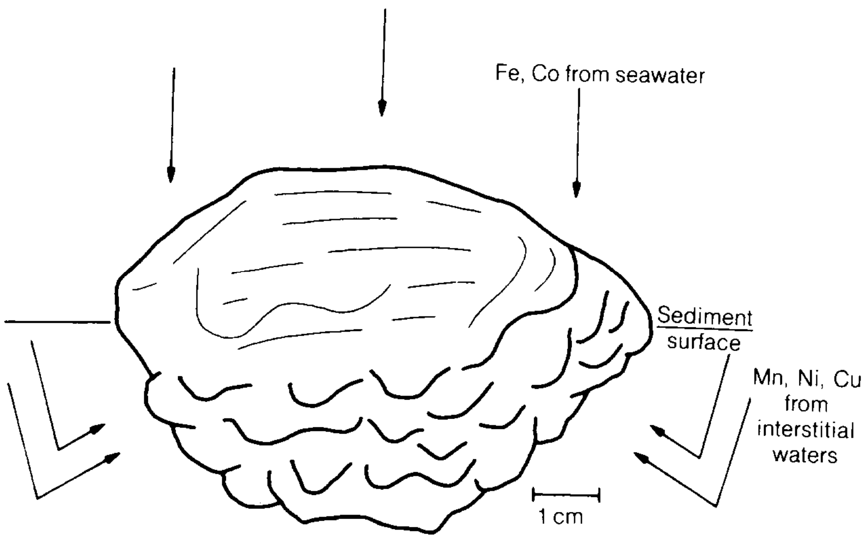

Figure 2.2. Nodule formation with morphological and compositional differences between the top and bottom

The internal structure of nodules reflects their growth history and is characterised by growth rings or internal banding. Growth rates can be determined by dating the nucleus, and also by measuring age differences between the different layers. These techniques have indicated that most nodules grow slowly in the order of a few millimetres per million years, although some grow faster in situations where there is a rapid local supply of nodule forming metals.

While occurring in greatest concentrations at the sediment surface, nodules also occur buried within sediments. Various estimates conclude that they are about half as abundant within the upper first meter of sediments as they are in the surface layer (Cronan, 1992).

2.4.1 Regional settings and resource estimates

The highest concentrations of potentially economic metals occur in general in nodules from the Pacific Ocean with intermediate concentrations in the Indian Ocean nodules, and lowest concentrations in those from the Atlantic, probably due to the relatively high sedimentation rates, which restrict nodule formation. In the Pacific Ocean nodules are quite abundant, and many areas contain more than 10 kg/m^2. In the Indian Ocean, nodules are most abundant to the south of the equator, in the basins to the east and west of the 90E ridge. The seafloor is, however, not uniformly covered with nodules and even in areas with a high average nodule density, the local abundance can vary from zero to more than 50% coverage of the seafloor over short distances (Figure 2.3).

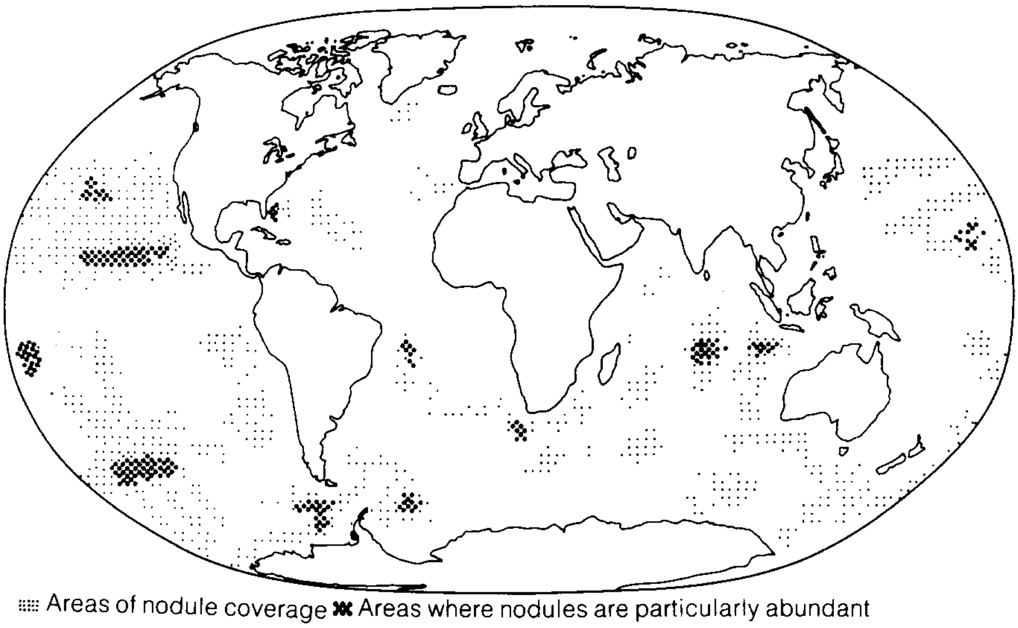

Figure 2.3. Distribution of manganese nodules in the oceans

The nodule abundance appears to be related to small-scale variations in topography. Nodules are more common on abyssal plains and seamounts than on ridges, continental slopes and on shelves. This is probably influenced by currents, sedimentation rates, sediment redistribution and erosion.

Nodules from different environments and water depths also show considerable compositional differences. Differences are typically found between nodules from the continental borderlands and seamounts, and the abyssal seafloor. Nodules found on the abyssal seafloor are highest in nickel and copper, while seamount deposits often are high in cobalt. This local variability will have important implications when it comes to actually mining nodules.

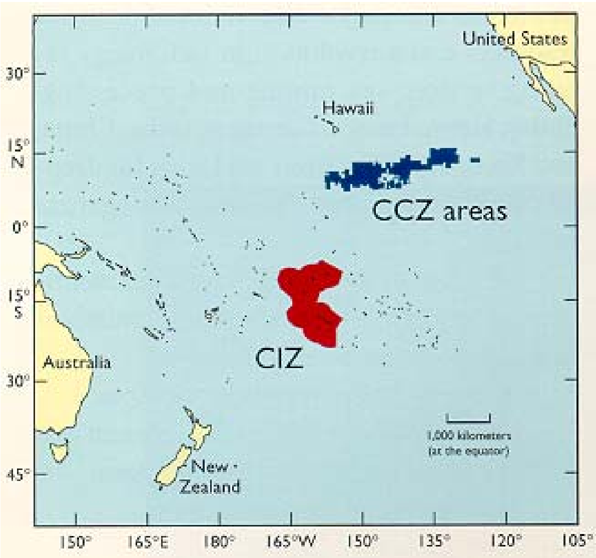

Figure 2.4. Location of the Cook Islands EEZ (CIZ) and Clarion-Clipperton area (CCZ)

Pacific Ocean Nodule Deposits

Five areas that contain abundant nodules have been identified in the Pacific Ocean. These are:

1. Clarion-Clipperton area
2. Northeast-Pacific Musicians Seamount area
3. Central Southwestern Pacific Basin
4. Southern Ocean around 60°S
5. Northern Peru Basin

The Clarion-Clipperton area was for many years considered the most promising location, and the obvious starting point for commercial projects.

The Clarion-Clipperton Zone (CCZ) is located just north of the equator in the Pacific Ocean, and is characterised by gently rolling abyssal hills (Figure 2.4). The CCZ area covers 9 million square kilometres and holds 34 million metric tons of manganese nodules. Specific estimates of metal resources include 7500 million metric tonnes Mn, 340 million metric tonnes Ni, 265 million metric tonnes Cu and 78 million metric tonnes Co (Morgan, 2000). The CCZ nodules have an average metal content of 0.74% Cu, 0.96% Ni and 0.16% Co. This estimate is based on publicly available data assembled by the US National Geophysical Data Center as well as information from a controlled-access database collected by the Ocean Minerals Company. More than 8000 individual sample collection sites are included in the aggregate database (Morgan, 2000):

	Unit	Min.	Max.	Mean
Abundance	kg/m^2	0.9	11.6	3.8
Cobalt	wt.%	0.01	0.63	0.16
Copper	wt.%	0.27	1.31	0.74
Nickel	wt.%	0.49	1.48	0.96
Manganese	wt.%	11.2	31.9	21.6

Indian Ocean Nodule Deposit

In the Indian Ocean more than 4 million square kilometres have been explored, and more than 10,000 locations have been sampled for nodules with sampling devices such as free-fall grabs, corers etc. Deep tow photographic surveys have recently also been conducted on pre-selected tracks to obtain visual observations and confirm the techniques for resource estimation. Based on these data, two areas of 150,000 square km each were identified with identical quantities of nodule resources.

Based on these surveys it has been concluded that India's prime area consists of 750 million tons manganese nodules, and combined Cu-Ni-Co resources amounting to 14.5 million tons. The prime area has water depths of 4000-6000 m and is located far away from any coastline (>1500nm). The cost of logistical support is therefore expected to be very high.

Based on observations from over 2000 locations the pioneer area in the central Indian ocean basin has an average nodule abundance of 4.39 kg/m^2 (with maximum values exceeding 20 kg/m^2) and an average grade of 1.12% Ni, 1.04% Cu and 0.14% Co (Jauhari & Pattan, 2000). The variations are:

	Unit	Min.	Max.	Mean
Cobalt	wt.%	0.07	0.43	0.14
Copper	wt.%	0.13	2.73	1.04
Nickel	wt.%	0.18	2.21	1.12
Manganese	wt.%	6.50	48.6	24.4

Cook Islands Nodule Deposit

In the early 1990s the non-profit research organisation the East-West Center in Hawaii carried out the first comprehensive resource assessment of the resource distribution and development potential of the nodules in the Cook Islands, on the request of the Cook Islands Government and SOPAC (Clark et.al, 1993; 1995).

The basic data was provided by SOPAC and the Metal Mining Agency of Japan and included the results of eleven cruises conducted by the Metal Mining Agency of Japan, France, United States, Germany and New Zealand since 1974. The survey data included bathymetry, seismic reflection profiles, samples, and analyses of the samples. Cook Islands' total EEZ is 2.5 mill. km^2. Most of the basic data collected in the surveys have a grid spacing of 21.2, 42.4, and 60 nm. It should therefore be emphasized that these surveys only have been reconnaissance grid surveys.

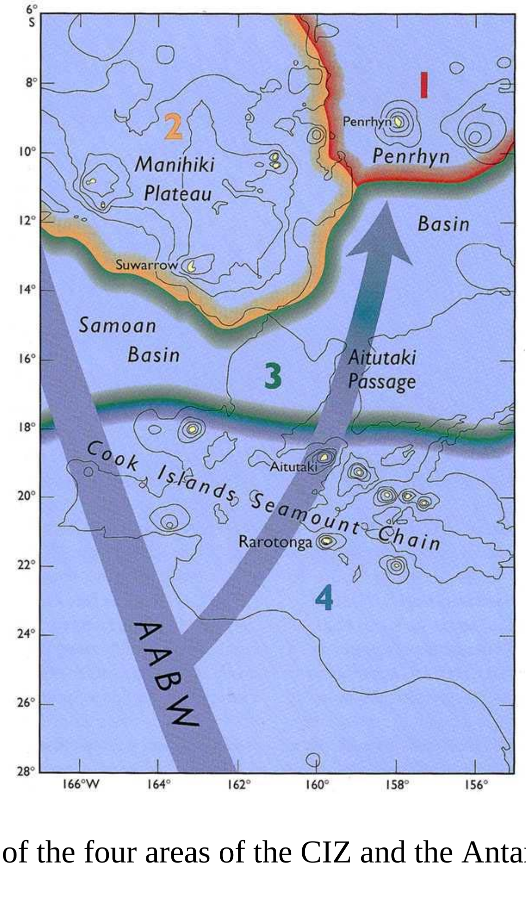

Fig. 2.5. Map of the four areas of the CIZ and the Antarctic Bottom Current

The Cook Islands Zone (CIZ) has been divided into four distinct regions based on submarine topographic characteristics:

- The southern Penrhyn Basin in the northeast
- The Manihiki Plateau in the northwest
- The Aitutaki Passage in the center
- The Cook Islands seamount line in the south

Each region is characterised by its seafloor topography, subsurface geological structure, and ocean current activity, which in turn affect the abundance and metal content of the nodules in the CIZ. The nodule abundance is higher in the southern regions than in the northern regions, due to these effects, especially sedimentation and current. The cobalt content is highest in the southern and central regions, while the copper and nickel contents are highest in the northern region. This is a result of an oxygen rich bottom current in the south that creates an oxidizing environment, which favours cobalt.

The Aitutaki Passage in the eastern central region has the most abundant manganese nodule concentration in the CIZ. Particularly high abundance of 80-105 kg/m^2 was found in an area between 14-18°S latitude and 157-161°W longitude. The highest nodule concentrations were found in 5000-5400 m depth. Four different categories of nodule abundance were established showing:

Abundance (kg/m^2)	Area (km^2)
>20	57,901
15-20	91,248
10-15	144,001
5-10	359,073

The CIZ contain on average 0.19% Cu (1.25% max), 0.32% Ni (1.7% max) and 0.45% Co (0.8% max). Based on a selected cut-off grade of 5 kg/m^2, the CIZ resource therefore consists of an estimated 7474 million tons of nodules with 32 million tons cobalt, 24 million tons nickel and 14 million tons copper.

If we compare the CCZ with the CIZ it seems clear that the CIZ has a 2.5 times enrichment in cobalt. This is probably caused by differences in geology and ocean environment between the two zones. The CIZ nodules are generally smaller, smoother in surface and more symmetrical than the CCZ nodules, which are characterised by flatter bottom sides. The CCZ nodules have probably been formed mainly as a result of diagenetic processes while CIZ nodules have been formed as a result of hydrogenetic processes.

The CIZ also has a much higher nodule density than the CCZ nodules and the average nodule abundance and composition of the CIZ nodules are also much more uniform than in the CCZ.

Since both the cobalt content and the abundance are higher in the CIZ, it seems clear that the CIZ has a greater potential for economic development than CCZ, and should be the first area to be mined.

2.5 Ferromanganese crusts

Ferromanganese crusts cover most hard substrates on seafloor edifices. Up until the late 1970s crusts were usually not distinguished from nodules. If a distinction was made, the crusts were called seamount nodules. There are however some important differences. Crusts are more of a continuous incrustation, with a thickness that ranges from 1 cm to 25 cm. Average thickness is 2.5 cm. Crusts also have a different mineralogical and chemical composition than nodules, and are not dependent on a nucleus to grow. Crusts can have a knotty or smooth texture, and occurs on a number of substrate rocks.

Formation of crust is by hydrogenetic processes. The growth rate varies from 2.7 mm/million years to 4.8 mm/million years (Hein et.al, 2000). Crusts have up to 8 distinct growth layers. The slower the growth rate, the higher the cobalt content. Crusts usually form at water depths of about 400-4000 m, with the thickest and most cobalt-rich crust occurring at depths of about 800-2400 meters. Hein et.al (1988) have developed eleven criteria for the location and possible exploitation of ferromanganese crusts. Exploration criteria include:

- Large volcanic edifices shallower than 2400 m
- Substrates older than 20 million years
- Areas with strong currents (to avoid sedimentation)
- Volcanic structures not capped by large modern atolls or reefs (to avoid debris)
- A shallow and well developed oxygen zone
- Slope stability
- Absence of local volcanism
- Areas isolated from input of abundant fluvial and eolian debris

In the 1980s crusts were recognised as an important potential economic source for cobalt. In the Pacific Ocean, cobalt has been found in maximum concentrations of up to 2.3%. Recent interest has also focused on the significantly enriched platinum concentrations of up to 3ppm. Nickel is present in concentrations up to 1%. Scientists seem to agree that crusts must have a cobalt content equal to or greater than 0.8% and an average crust thickness equal to or greater than 4 cm to be a potential target for mining.

Most of our knowledge on the nature and occurrence of crust is from the Pacific. There is a clear increase in crust abundance as the equatorial zone is approached. Areas that have been discovered to date with the highest economic potential are

Marshall Islands, Johnston Island, Kiribati, Federated States of Micronesia and French Polynesia. Ferromanganese crusts have also been discovered in the Atlantic and Indian Ocean, but the cobalt concentrations are not comparable to the central Pacific area.

2.6 Hydrothermal sulphide deposits

Hydrothermal deposits are precipitates of principally iron, copper and zinc sulphides formed as a result of submarine volcanic activity. The hydrothermal deposits form when pressurised hydrothermal waters are vented from the seafloor in relatively deep water. These deposits are often also referred to as seafloor massive sulphides (SMS) deposits. New sea floor is created in many areas with submarine volcanic activity including mid-ocean ridge spreading centres, intra-plate hotspots and at convergent plate margins (Figure 2.6).

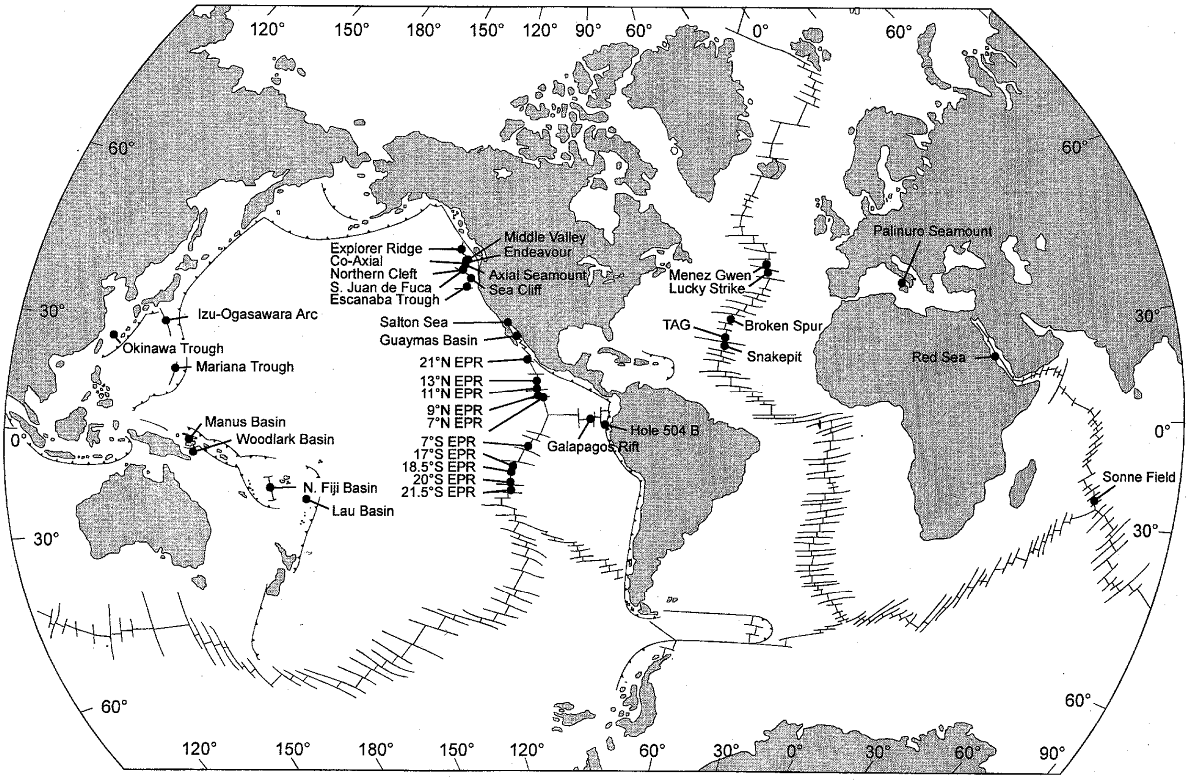

Figure 2.6. Location of hydrothermal systems on the seafloor

As the new seafloor moves away, seawater enters cracks and fissures in the hot and recently formed rocks, becomes heated, and engages in chemical reactions with the rocks. This leads to leaching of iron, copper, zinc, gold etc out of the rocks and reduction of seawater sulphate to suplphide. Research indicates that the seawater may interact with volcanic rocks down to depths of several kilometres below the seafloor. After reacting with the newly formed ocean floor rocks the hydrothermal solutions ascend to the seafloor to precipitate at least a fraction of the metals they have obtained as sulphide minerals and metalliferous sediments which are rich in copper, zinc, iron etc (Figure 2.7). If the hydrothermal solutions cool sufficiently below the seafloor, major sub-seafloor precipitation of hydrothermal minerals can also take place.

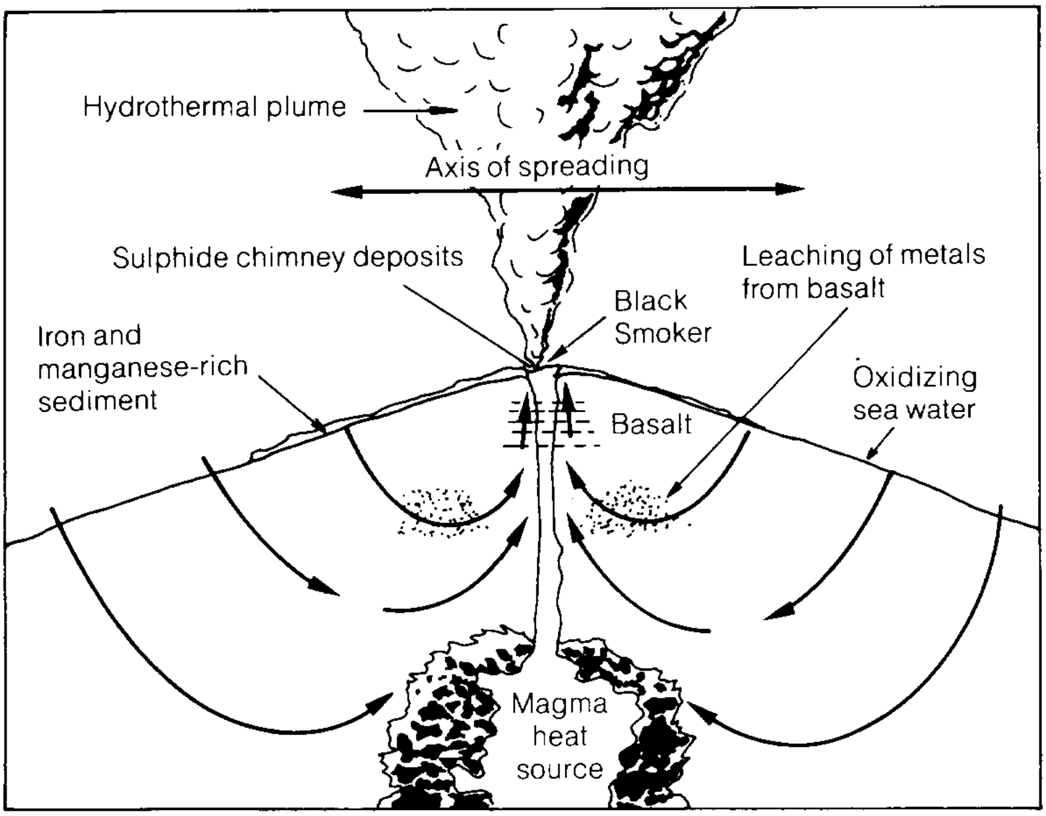

Figure 2.7. Sub-seafloor leaching processes and formation of hydrothermal deposits

The average water depths of the hydrothermal deposits located to date is 1500-2000 meters, while the average metal contents are:

Element	Intraoceanic Back-Arc Ridges	Intracontinental Back-Arc Ridges	Mid-Ocean Ridges
Pb (wt.%)	1.2	11.5	0.2
Fe	13.3	7.0	23.6
Zn	15.1	18.4	11.7
Cu	5.1	2.0	4.3
Ba	13.0	7.2	1.7
As (ppm)	1,000	15,000	300
Sb	100	3,000	100
Ag	195	2,766	140
Au	2.9	3.8	1.2
(N)	317	28	890

The discharge point of the hydrothermal solutions is referred to as a vent or a smoker. Black smokers are high temperature vents with a temperature of up to 400°C, while white smokers have lower temperatures. The precipitation of the hydrothermal solutions leads to the growth of sulphide rich chimneys on the seafloor. The deposits are surrounded by a halo of iron-rich sediments, and a plume of iron and manganese rich particulates can develop in the overlying seawater which can extend and precipitate oxides for many kilometres away from the source, depending on the current. This plume can be used to detect active vent sites, mainly through the elevated concentration of methane and manganese.

Flow rates of between 3.5 and 14 1/s from a chimney with a diameter of 3 cm is typical, and the total precipitated mass of metalliferous deposits from a chimney could therefore be 100 kg/day. Prolonged hydrothermal activity will therefore develop massive sulphide ore bodies. The chimneys can grow to heights of as much as 20 m or more after which they topple over to form a mound of broken chimney rubble. These mounds can be many meters high and several hundred meters in diameter. These are often capped by active and inactive chimney structures up to a further 5 m high.

The majority of the seafloor mounds that have been located to date contain around 1000 tons of sulphides, although some deposits are believed to contain up to 9 mill. tonnes. By analogy some fossilised SMS deposits found and mined on land, contains over 100 million tonnes. It is likely that similar sites can also be found in the oceans. However, the various estimates of deposit size and metal content have so far been based on surface sampling, and more detailed three-dimensional sampling must be carried out to confirm these estimates before mining can commence.

The Ocean Drilling Program (ODP) is a 15-year-old international partnership established to explore the world below the seafloor. It is managed by the Joint Oceanographic Institutions and funded in part by the National Science Foundation.

ODP has exposed some elements of the internal structure and growth patterns of some SMS deposits in the Atlantic (Humphries et.al, 1995). In one of the hydrothermal mounds the drill intersected more than 90 meters of massive sulphides. The deposit had undergone multiple stages of development, and 4 zones could be distinguished. The drilling also indicated that 2.7 million tons of massive sulphides are present above the seafloor, while 1.7 million tonnes are present below the ocean floor in the up-flow zone. This means that the mound contains for instance 30-60,000 tons of copper.

Different site conditions including sediments and rock conditions can lead to a considerable diversity of hydrothermal deposit types. Whereas the composition of mid-ocean ridge rocks is predominantly basaltic, a much greater variety of rock type occurs at the convergent plate margins. This can potentially give rise to a much greater variety of solution composition by rock-water interactions. The bulk composition of a sulphide deposit is mainly a reflection of the bulk composition of the underlying rocks from which the materials are leached. Detailed studies have confirmed that back-arc environments at convergent plate margins are probably the closest analogy of ancient volcanogenic massive sulphides that are currently being mined on land for Cu, Pb, Zn, Ag and Au.

This highly localised nature of the deposits, coupled with a high degree of variability in their composition means that each SMS deposit must be evaluated on its own merits, and that few generalisations will be possible. Approximately 140 occurrences of hydrothermal activity on the ocean floor are known to date. High-temperature hydrothermal activity is known at fewer than 25 sites (Herzig and Hannington, 2000). The majority of the sites discovered so far have been located in the Pacific Ocean. Only one deposit area has been found in the Central Indian Ocean (Halbach and Münch, 2000) at a water depth of 2850 meters. This area has samples of extremely high values of Cu (up to 32 wt.%), and combined Cu, Fe and Zn concentrations of 50-60 wt.%. Zinc, copper and gold rich deposits have also been discovered in the Norwegian EEZ, off Jan Mayen.

2.7 Phosphorites

Phosporites are authigenic minerals formed in situ on the seafloor. Phosporites tend to occur on the middle and outer parts of the (western) continental shelves and seamounts, rather than in nearshore areas. The formation of phosporites is probably associated with an upwelling of cold, nutrient-rich water (with phosphorus) from intermediate depths to the ocean surface, in combination with biological activity (Cronan, 1992).

Phosporites typically contains up to 14% elemental phosphorus in addition to minor elements of vanadium, uranium, fluorine and rare earth elements that can be obtained from them as by-products. Phosphorites are primarily utilised in fertilizer production, but also in the chemical industry to manufacture elemental phosphorus and phosphoric acid. There are, however, still large quantities of phosphorites on land, and it does not seem likely that this resource will be extracted in the near future, unless access to the land sites becomes restricted. Since many of the terrestrial phosphorite sources are situated far away from the customers, a more localised marine production could, however, be viable for some countries like India and New Zealand. New Zealand has for instance conducted studies that point to marine production if the prices rise and the agricultural economy appreciates.

2.8 Hydrates

Naturally occurring gas hydrates forming in the seafloor sediments have ever since the 1970s been heralded as the next century’s viable energy source. Methane hydrates are solid ice-like substances composed of water and natural gas (methane). The gas hydrates occur naturally in ocean sediments where methane and water can form at appropriate temperature and pressure conditions.

The presence of hydrates in the sediments has usually been inferred from bottom simulating reflectors (BSR) on seismic profiles. BSRs have been interpreted as the boundary between acoustically high-velocity “gas-hydrate-cemented” sediments located within the gas hydrate stability zone (GHSZ) above, and a “reservoir” of acoustically low-velocity free gas below the BSR, which act as a gas trap (Hovland, 2000).

Based on assumptions and geophysical models, the promise of enormous volumes of buried gas hydrates has been promoted during the past 10 years. Several countries have established extensive research programs. Japan has a USD 60 million research program focusing on gas hydrates and ways to commercially extract the hydrates. Also the United States (Amato et.al, 2000), India etc have similar programs.

The findings so far from The Ocean Drilling Program’s legs 141, 146 and 164 have however been rather discouraging with respect to the in situ amount of both gas hydrates and free gas. In the sediments drilled on Leg 146, in the eastern Pacific Ocean, the average amount of gas hydrates above a prominent BSR was estimated at 1-2 percent by sediment volume. The first visible evidence of gas hydrates came in the form of 5 mm white pellets and up to 3 cm long clear nodules of gas hydrates located in soft clay within the first 19m below the seafloor. The free gas amount below the BSR was only 3-4 percent by sediment volume. On Leg 164 in the western Atlantic Ocean (Blake Plateau), slightly higher amounts, averaging up to 5-7 percent by volume of sediment were found (Hovland, 2000).

Another prominent BSR off the coast of Norway was recently investigated by drilling. No gas hydrates were found, and only very little methane occurred in the pore waters below the BSR (Østmo et.al., 1998). Obviously, these percentages are far too low for commercial extraction. The gas hydrate resource picture may not, however, be completely pessimistic. Features that could concentrate gas hydrates on the ocean floor such as mud volcanoes, diapiric ridges and surfacing faults, could create potential reservoirs. The most likely method to be employed for exploitation will however probably not be drilling, but excavation, similar to open pit mining of ores on land.

An improved understanding and resource characterisation is necessary to develop hydrates as a resource. It is also likely that considerably higher prices must be achieved for hydrocarbons. However, just compiling an inventory of hydrate formations around the world will take many decades and huge technical and environmental obstacles also remain to be solved. Methane is the cleanest-burning fossil fuel, but when released unburned into the atmosphere it is a potent greenhouse gas with far-reaching implications for global climate. Another problem is possible destabilization of continental margins, which could trigger undersea landslides and potentially cataclysmic tsunami waves.

2.9 Marine resources vs. terrestrial resources

Potential seabed mineral resources must be viewed in relation to both conventional and more speculative rival mineral resources on land. Current land based resources of the metals found in marine deposits are probably sufficient to support both near and intermediate future world demand. However, the terrestrial mining industry is now being forced to change its operating procedures as a result of a number of forces. The most important of these, at least in the short term, is the need to reduce the extent of damage to the environment. The industry is under an increasing pressure to limit the release of toxic gases such as sulphur dioxide, and also to store waste products as safely as possible.

A second major problem faced by the mining industry is that of decreasing ore grades. It is a universal experience that the average grade of ore in terrestrial mines is falling continuously. The recovered gold grades have for instance fallen from a figure of 2.56 g gold per ton of ore mined in March 1987 to a figure of 1.86 g per ton in March 1996. Even though the data show that from time to time, the grades increase sharply as a significant new gold source comes on stream, this only delays the general downward trend on a temporary basis.

Average land based deposits contain 30-35% Mn, 1.25% Ni, 0.7% Cu and 0.15% Co. Cobalt enrichments to levels greater than 0.1% are confined to only a few major land deposits, such as those in the copper belt of central Africa. These large African copper deposits have cobalt as a minor constituent, with concentrations of up to 0.4%. Deposits from Cuba and Australia typically have values nearer 0.1%. About 80 percent of all the copper mined today is derived from low-grade ores containing 2 percent or less of the element. Ores are removed either by open-pit or by underground mining. An ore containing as little as 0.4% copper can be mined profitably in open-pit mining, while underground mining is profitable only if an ore contains at least 0.7% copper.

Manganese nodules, hydrothermal deposits and ferromanganese crusts are probably the most interesting marine deposits. These deposits have a metal content that potentially can rival the content found in terrestrial mines. Marine mining will probably also enjoy lower exploration costs and environmental advantages. However, before mining of the ocean can start for real it will be necessary to prove that marine mining can be done economically. This will be studied in more detail in this report.

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3 METAL MARKET

3.1 Introduction

Marine mineral resources contain only a few metals which are considered to be of any economic interest. Most manganese nodule mining scenarios envisage either a three or four metal operation, i.e. nickel, copper, cobalt and possibly manganese. SMS deposits contain mainly copper, gold, lead, zinc and silver. Prices for the primary base metals nickel, copper, lead, zinc and silver are based largely by reference to prices established on the London Metal Exchange (LME), while other terminal markets determine the prices of cobalt, manganese and gold.

Prices are clearly affected by fundamental supply and demand factors and have varied significantly over the past decades. Over the long term, metal prices may be expected to fluctuate around the long-run marginal cost, but prices will clearly be influenced by supply or demand disruptions. These fluctuations can have significant effects on profitability, on the ability to undertake large capital expenditures, and to sustain mines with relatively low ore grades and/or high operating costs.

Although often regarded as a necessary evil, metal price forecasts undoubtedly play a key role in business studies within the mining industry. By its very nature, price forecasting is not an exact science and is subject to the interaction of many variables. Nevertheless, forecasting prices of the metals that will be extracted is one of the most critical assumptions in this study. Thus the most important metal markets will be further analysed in the following sections.

3.2 Cobalt

Cobalt is used in many diverse industrial and military applications. It is for instance used for a variety of purposes in the electrical, communications, aerospace and mechanical industry. The main use of cobalt, which accounts for two thirds of its use, is as a base for various alloys. Cobalt is used in hard magnet alloys and as a major constituent of superalloys used principally in high temperature components for gas turbines and jet engines. Other applications are for soft magnet alloys, for metallurgical and glass making furnaces, for cutting and wear resistant alloys, for hard facing alloy consumables, for dental and bone surgery materials, for alloys with special thermal expansion characteristics and as a material for stainless, constant rate springs. Cobalt also forms a base for permanent magnet alloys, sometimes alloyed with iron. In most of its alloying applications, cobalt gives essential qualities such as heat resistance, high strength, wear resistance, and excellent magnetic properties. Cobalt is therefore considered a strategic metal, and most developed countries keep a stock of cobalt.

The chemical industry also consumes a large amount of cobalt for use as a catalyst in petroleum and chemical processing, drying agents for paints and inks, and pigments for ceramics, paints and plastics. Its radioisotope is used in modern diagnostic and therapeutic medicine. An emerging market for cobalt oxide is in lithium ion and cobalt rechargeable batteries, now in growing use in laptop computers and camcorders.

Growth has traditionally been led by the superalloys industry on the back of a healthy aerospace sector and increased orders for jet engines. Commercial jet production is expected to grow at an average annual rate of 7%. The outlook for growth in demand for cobalt in catalysts is also good. In hydroprocessing the market for catalysts is forecast to grow at an average of 4% per year. The batteries sector will be the fastest growing area of demand for cobalt in the next 5 years. Consumption of cobalt in batteries was estimated at between 800t and 1,000t in 1996, but could reach over 4,000t in 2000, an average annual growth rate of 40% per year. The future prospects for cobalt demand is therefore good, as these high-tech uses should enable the world market for cobalt to grow at an estimated 5-8% a year from the present level of approximately 25,000t per year.

Cobalt is usually mined as a co-product of either nickel, copper, or other more abundant metals. The mined ore often contains only 0.1% elemental cobalt. Most cobalt production is therefore ultimately dependent on the production of copper and nickel, and cobalt metal pricing directly affects the cost of its derivatives. Important cobalt producers include Russia, Finland, Canada, Norway, Zambia and Zaire. A significant amount of the world’s supply of cobalt has traditionally been produced in Africa. The social and political systems and economies of some of these producers are frequently unstable and have lead to supply disruptions. Consequently, metal prices have varied greatly. Historically, cobalt has had the most volatile pricing of all trace minerals. Average cobalt metal prices have ranged from US$ 4-30/lb over a 20-year period. Spot prices have reached US$ 50/lb.

In the 1990s there was a significant increase in interest in the cobalt market, as prices rose from an average of US$ 10/lb in the late 1980s/early 1990s to peaks of US$ 30/lb. Prices were pushed to record highs by strong demand for cobalt after the recession of the early 1990s, combined with a drop in supply of material, particularly from the traditionally dominant producers in Zaire and Zambia.

However, world production of refined cobalt increased by over 40% between 1993 and 1996 as all of the major producing countries increased output, with Finland (24% per year) and Zaire (23% per year) showing the greatest growth since 1993. As a result, cobalt prices dropped steadily throughout 1996, reaching a low point of around US$ 18-19/lb in early 1997. However, the changeover of power that took place in Zaire in May 1997 and a declining performance of cobalt producing assets in Africa and Russia renewed market worries about cobalt supplies, and cobalt market prices rose again to US$ 25/lb.

These prices encouraged the development of a number of new cobalt-producing projects, and this new supply has brought lower cobalt prices and greater stability with a current price level of around US$ 10-15/lb. However, if too many large projects come on line, then the price of cobalt could go down even further. A major deposit is now under development at Voisey's Bay in Labrador by the International Nickel Company (INCO). If this deposit comes on line as expected later in this decade it will dominate both the nickel and cobalt markets. Initial estimates are that control of this one deposit will increase INCO's share of the world nickel market to 40%. Several major new cobalt deposits (laterites) are also rapidly being developed in Australia. This is shifting the balance of the cobalt mining industry from Zambia and Zaire to Australia and Canada. This will likely bring some price stability to the market with prices almost certainly lower for cobalt than those experienced in the 1990s, probably in the region of US$ 10/lb.

A low price level will play a major role in the future of cobalt consumption, particularly in newer applications such as batteries where there are alternative materials. Uncertainty regarding the cobalt supply has caused industry to look for alternatives. The possibility of substitution of other materials for cobalt in for instance batteries could become quite prevalent if the cobalt price level is high. In addition is the cell size getting smaller and the amount of cobalt per cell is also declining. If nickel and manganese anodes are adopted in lithium ion cells, the prospects for overall growth in cobalt will be severely dented. On the other hand, if substantial alternative sources of cobalt should emerge, for instance from marine deposits, there could be a greater incentive to reintroduce it back into products and expand the market.

3.3 Nickel

Two-thirds of the world's primary nickel is currently consumed in the manufacture of stainless steel. This proportion has risen substantially in the last 15 years and will continue to rise, albeit much more slowly, to reach around 70% by 2005. Alloys and electroplating constitute the other principal end uses of nickel, with consumption in rechargeable batteries a small but growing demand sector. Nickel alloys improve the strength and corrosion resistance of other metals, such as chemical reaction vessels and pump parts. Pure nickel is used in electron tubes and in the galvanic plating industry, where many objects must be coated with nickel before they can be chrome plated. Nickel is also used in chemical plants, petroleum refineries, electrical appliances, motor vehicles, dyes, pigments, insecticides, and as bonding agents.

Overall, global primary nickel demand has increased by an average compound annual rate of 3.4% over the past 40 years, and similar annual average growth rates of between 2.7% and 3.7% are forecast for the future.

World mine production of nickel totalled 1.1 million tonnes in 1998, the highest output ever recorded. In addition, recovery of secondary nickel amounted to between 0.5 and 0.6 Mt/year. The principal producing countries were Russia (22%), Canada (19%), New Caledonia (13%) and Australia (12%). Russia has been the largest producer since 1982. Some 123,000 tonnes of new capacity will have been initiated between 1999 and 2001, including new projects in Australia, Indonesia, Columbia and Venezuela. Two major producers dominate production of refined primary nickel. Norilsk in Russia and INCO in Canada and the UK, account for approximately one third of world output.

Nickel mining capacity increased year-on-year by from 3.6% to 4.9% between 1994 and 1998, mainly through expansions to existing operations. An increase of 3.5% in 1999 was principally due to the start-up of three new projects in Western Australia. However, most of these increases were partially offset by mine closures or suspensions in Brazil, Finland and Australia and the continuing rationalisation of capacity at INCO’s Ontario division in Canada, leaving the supply-side in a slight deficit.

The latest technological development in the recovery of nickel is likely to produce significant changes in the industry. The adoption of PAL technology (pressure-acid leach) to recover nickel from Australia’s dry laterite ores, is probably the most important development in the last few years in the nickel industry. This technology has the potential to recover nickel from all types of laterite ores at significantly lower costs than those previously incurred by mining companies processing both sulphide and laterite ores using pyrometallurgy. In the short and medium term, PAL technology could lead to substantial cost cutting by the longer established producers. In longer term, lower and less volatile nickel prices could make the use of nickel more attractive in both existing and new end-uses, thus leading to an expansion of the nickel market. However, the Australian PAL producers have yet to show that they can recover nickel at less than US$ 2/lb on an ongoing commercial basis, and full aggregate production is not now expected until 2001 due to commissioning difficulties. Thus the nickel-copper-PGM sulphide deposits, such as those found in Canada and Russia, still remain the essential sources of nickel.

Industry analysts estimate that the nickel market will remain in deficit in 2000 before returning to an expected rough balance by the end of 2001 and then again move into surplus as the added capacity comes on line. From 2002 and beyond, new capacity is expected from the Australian PAL operations and eventually from INCO’s currently stalled sulphide prospect at Voisey’s Bay. Other projects elsewhere have also recently obtained financing and are scheduled to be in production within a few years. While the future market demand for nickel is expected to be strong, the market cannot support unlimited sources of new supply. As has been borne out in the past, a large increase in the nickel supply beyond that which is required to meet increases in demand will likely result in a significant reduction in nickel prices, in which case the economic viability of new projects could be significantly affected. In the long term, nickel prices are expected to stabilise in a new and structurally lower band than the current price level of US$ 3-4/lb.

3.4 Copper

Copper is widely used in industry both as a pure metal and as an alloying material. Copper is an excellent conductor of electricity and is celebrated for its corrosion resistance. It is used in a broad range of alloys, and is the basis for brass and bronze.

Copper is mined in many parts of the world; some of the largest producers are Chile, Peru, the United States, Zaire and Zambia. The copper supply has increased a lot in the past few years, and producing countries also include: Indonesia, Canada, Australia, Russia, China, Poland, Mexico, Zimbabwe, Japan and Kazakhstan.

World refined copper production exceeded consumption between mid-1996 and early 2000. This was the direct result of a rapid expansion of capacity that followed a price spike in 1995. During this period mine production grew at an annual rate of 5.6% compared with consumption growth of 3.2%. Large market surpluses developed by mid-1997 and coincided with a flattening of demand from Asia. By late 1997 prices were below long-term trend levels, bottoming at US 56¢/lb in April 1999. The reason for this was that in 1998 and 1999 world copper production had reached new highs with new production coming from Chile, Southeast Asia and Africa. This new production ended up in warehouses, which further depressed prices. The economic troubles in Asia also reduced demand, and therefore prices, as construction in that part of the world slowed considerably. Most analysts point to the fact that the major producers of copper, such as BHP, Phelps Dodge, Codelco, and Rio Tinto had themselves to blame for the glut in copper and the low prices, since they failed to reduce production levels.

However, beginning in mid 1999 these companies announced mine and smelter closures and production cuts at their less profitable mines. Phelps Dodge recently announced further cuts in production at some of its high-cost mines due to increased fuel costs. This supply side move was desperately needed to reduce the high levels of copper available. The copper producers are now seeing the results of these production cuts with supply declining and prices increasing. The copper market has moved into deficit and refined metal stocks at commodity exchanges have begun falling. At the beginning of 2000 the copper supplies stored in warehouses were at a record high of about 825,000 tons of metal waiting for buyers. At the end of July copper inventories were dropping like a rock with the inventory listed at 500,000 tons.

However, most industry analysts conclude that the copper market will now remain delicately balanced between 2000 and 2005, and that neither supply nor demand issues are currently powerful enough to provide a clear direction. In this environment copper prices are forecast to appreciate to between US 90¢/lb and US 100¢/lb, a level consistent with long-term price trends and somewhat higher than the current price level of US 80-90¢/lb. These analysts forecast that short-term supply disruptions, demand surprises, and the timing for restarts of idled capacity will create volatility. These marginal factors will strongly influence spot market copper pricing.

Some analysts believe that the copper price will appreciate more. They argue that the positive global economic performance is fuelling a strong demand growth that is expected to last until 2003. Especially if the Asian economies recover, strong demand could be experienced, and global copper consumption could rise at an average annual rate in excess of 4% (compared to the average forecast of 3.4% per annum). Demand growth would then be outstripping new mine supply, which is being constrained, in the short-term, by industry rationalisation and the impacts of high energy costs.

These analysts predict that the price will level off well above US$ 1/lb in 2001/2002. In this scenario, the economic cycle will have run its course beyond 2003, and copper demand will flatten in mature, developed Western economies. This leaves the market delicately poised, and copper producers will largely be determining their own destinies when deciding the timing of commitment to new projects. It is also important to notice that with a price level well above US$ 1/lb, the threat of substitution by other materials becomes a real concern. As a general rule the long-term average price will therefore most likely fluctuate around US$ 1/lb.

3.5 Manganese

Manganese is the cheapest of the metallic elements used to alloy with iron and is one of the more abundant elements in the earth’s crust. Manganese ore is mainly used in the production of manganese ferro- and silico-alloys, manganese metal, manganese dioxide, and manganese chemicals. Manganese ore is differentiated as manganese ore (containing 35% or more Mn) or manganiferrous ore (containing <35% Mn >5%) and within the latter ferrugenous manganese ore (containing 10-35% Mn) and manganiferrous ore (containing 5-10% Mn). Manganese ore is considered metallurgical, chemical or battery grade when the Mn content is higher than 35%.

More than 80 percent of the world’s manganese resources come from South Africa and the former Soviet Union with other producers in Brazil, Australia, Gabon, China and India. South Africa has the largest known deposits in the world of metallurgical-grade manganese ore that can be mined profitably using current techniques. The world reserve base of manganese is an estimated 5,100Mt, 80% of which are in South Africa and 10% in Ukraine. One important trend is that China has become a major market for high-grade metallurgical ore, and a major source of exports of ferro-silico-manganese and manganese metal to Japan and elsewhere.

Apparent consumption of manganese ore declined from 23.3Mt (gross weight) in 1996 to 17.3Mt in 1998. Most ore is consumed in countries with large manganese-ferro-alloy industries. World production of manganese-ferro-alloys declined from 7.3Mt in 1997 to 6.8Mt in 1998. Reductions in output occurred in most of the principal producing countries, in response to poor market conditions. In contrast, manganese metal output is thought to have increased during the 1990s, from about 100,000t per year to 140,000t per year.

As manganese is present in virtually all types of steel, production of crude steel is the single most important factor in the demand for manganese. Manganese improves the rolling and forging qualities, strength, toughness, stiffness, wear resistance, hardness, and hardenability of steel. Currently the steel industry accounts for approximately 90% of world demand for manganese. Carbon steel is the principal market, accounting for between 65% and 70%, or more than 4Mt/year of the total manganese consumption. Crude steel production reached 784Mt in 1999, and is forecast to increase by an average of 1.8% per year up to 2005. Growth in manganese demand is expected to reflect this trend, albeit at a slightly slower rate.

Besides steel production, manganese is also used in batteries and chemicals, as well as an oxidation agent in the reduction of zinc and uranium ore. The market for EMD (electrolytic manganese dioxide) in batteries grew by between 5% and 6% per year during the 1990s, whereas demand for NMD (natural manganese dioxide) declined.

Two significant trends characterised the manganese industry during the 1990s: consolidation and integration. In 1998/99, Samancor acquired the manganese interests of BHP in Australia, and Eramet purchased the manganese assets of Elkem in Norway and the USA. Consequently, approximately 74% of manganese mining and 48% of manganese-ferro-alloy production in the Western World are under the control of four groups: Samancor, Eramet, CVRD and Assmang. Within these principal groups, further integration of mining and ferro-alloy production has occurred.

The manganese industry is a stable one. The consolidation and integration within the industry means that producers are able to respond to fluctuations in demand by either taking capacity on or off stream. Furthermore, no major new applications are likely to emerge which will significantly alter the supply and demand balance. As a result of these two factors, there is little volatility in either supply or prices. Manganese prices are therefore expected to continue to reflect the economic health of the steel industry, and thus the overall economic activity. Metallurgical manganese ore has been stable at US$ 2.50 per tonne for the past five years.

3.6 Gold

Gold is one of the most valuable and certainly one of the most versatile precious metals. Gold is the most popular metal for jewellery and ornaments in virtually every culture across the globe. But the fact that gold does not tarnish or corrode makes it useful also in a number of additional applications, from electronic circuit boards in high-speed computers to protective shields for the space shuttle. It is mined on every continent except Antarctica, with some of the larger gold deposits located many hundred feet below the earth's surface. South Africa is the leading gold producer followed by the United States, Australia, Canada and Russia.

Gold no longer seems to be a metal that is used to hedge against inflation and as an international backing for a country's currency. The metal now responds more like a supply and demand commodity. A significant driving factor in this current environment is the Central Banks and IMF selling their reserves. An example is the more recent decision by Great Britain to sell half of its gold reserves. The price of gold dropped to a new 20-year low of US$ 256 per ounce, as more metal became available to the buying public. This low price is fuelling large consumption in India and several other nations that value gold as a symbol of wealth. Further, high cost mining operations in South Africa and in other producing countries are closing mines and reducing production. This is good news for companies with quality assets that can be produced inexpensively.

Industry analysts think that the overall fundamentals of gold have been altered significantly by Central Banks and Government policies, and that the current price range of US$ 250 to 300 per ounce will remain with us for the intermediate future.

3.7 Silver

Demand for silver throughout the world during 1999 increased by 5%. Demand for silver in 1999 had reached 877.4 million ounces with supply at 888.2 million ounces. Silver has traded in the US$ 5 to 6 per ounce range for the last seven years. A recent report notes that demand is outstripping supply and inventories are approaching low levels. A slightly stronger silver price may be the outcome of this scenario.

3.8 Lead and Zinc

World lead and zinc markets are being heavily influenced by the current dramatic growth in Chinese production of these two metals and the associated flood of lead and zinc exports. In 1999 and early 2000, lead prices declined as production growth and Chinese exports outstripped world demand growth putting the market in surplus. The price peaks of the late 1980s-early 1990s will not be revisited in the near future due to this flood of Chinese exports.

Thus, between 2001 and 2005, the zinc price is forecast to decline from the current price level of around US 50¢/lb, consistent with a long-term trend evident since the mid-1970s. World zinc demand growth of 3.7% per year over the six years to 1999 was driven by increased use of galvanizing in motor vehicles. Galvanizing is zinc's dominant use with construction and transport the two main end-use sectors. Additional continuous galvanizing capacity being installed in the US, Europe, South America and Asia will underpin a zinc demand growth of 2.7% per year to 2005.

Because lead metal production is increasingly from secondary materials, lead mine output declined through the 1990s and mine developments are predominantly for zinc. The current price of lead is approximately US 20¢/lb.

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4 MARINE MINING PROJECT STATUS

4.1 Introduction

Deep seabed minerals were first discovered by the British *Challenger* oceanographic expedition between 1873 and 1876. Almost a hundred years would pass before the nodule deposits were ”rediscovered”. In 1965, John Mero published his book *The Mineral Resources of the Sea*. In this book he presented preliminary results from exploration work carried out in the Clarion-Clipperton zone in the Pacific Ocean – between Hawaii and the US West Coast. Mero concluded that the metal content in the nodule deposits in this area was comparable to some of the best mines on land.

The 1960s and the beginning of the 1970s were characterised by optimism, economic growth and rapid technological development. Four internationally composed industrial groups were established between 1974 and 1978 in order to explore the deposits and develop the technology to exploit the resources. In addition to these industrial groups, a separate French group was also established. Each of the industrial groups invested between 50 million and 120 million USD until 1980. Ocean Mining Associates (OMA), Ocean Management Incorporated (OMI), and Ocean Minerals Company (OMCO) carried out tests of integrated mining systems on a scale of 1:10 in the Clarion-Clipperton Area, and brought up nodules from 5500 meters. The two other groups, Kennecott Consortium and the French AFERNOD Group, carried out tests of parts of their mining systems. All five groups carried out similar scale tests with the processing technology, in addition to extensive exploration work. Early in the 1980s it became evident that the groups had underestimated the technological challenges and over-evaluated the profitability of the projects. In addition, the groups were highly dissatisfied with Part XI of the United Nations Law of the Sea Convention. By 1985, a majority of the groups had decided to ”freeze” their further R&D activities.

The early 1980s saw a change of actors. Industrial groups with private investors were replaced by national programs, where governmental authorities financed the main part of the R&D work. These actors could afford to think long-term and had political motives such as supply considerations and industrial opportunities as the main motives for their involvement. India and Japan both established their national programs in 1981. France, the Soviet Union and West Germany also established programs and at the end of the 1980s South Korea and China also joined ”the deep sea club”. An important motive for India’s involvement was ”not to miss the industrial revolution a second time”.

A new major change occurred early in the 1990s. Further exploration of the deposits and development of technology were characterised by a higher degree of regional and international co-operation, and the research on the environmental consequences of deep seabed mining was established in a serious way. The countries and the industrial groups had developed more or less the same type of technology. Technological as well as economical factors thus justified international co-operation.

Developments in international politics also enabled such co-operation. India was the pioneer when it came to establishing international co-operation. It was in the early 1980s that India established the co-operation with Norwegian Deep Seabed Mining Group. It should also be mentioned that in 1991 the United Nations asked Norway and the Fridtjof Nansen Institute to finance and carry out the first comprehensive international report on environmental consequences and regulations for deep-sea mining.

Research organisations from North America, Asia and Europe furthermore discovered massive sulphide deposits in the oceans. This has initiated new private investment in the marine mining sector. At the end of the 1990s, two companies, one in Australia and one in the US were established to explore and initiate commercial mining of sulphide deposits (Section 4.5).

Until 1997 everyone expected that the first generation commercial nodule project would be based on the nodule deposits in the Clarion-Clipperton area in the Pacific and the Central Indian Basin in the Indian Ocean. The discovery of the nodule deposits within the Cook Islands' Exclusive Economic Zone changed this. The Cook Islands nodules are richer than the Clarion-Clipperton nodules both with regard to metal content and density. The first commercial nodule project based on nodules in the Pacific will therefore most likely be located outside the Cook Islands. The Cook Islands project is presented in Chapter 6 and 11.

4.2 Current status - India

India has carried out comprehensive exploration of the nodule deposits in the Central Indian Basin. India was the first country in the world to achieve status as a Pioneer Investor in accordance with the United Nations Convention on the Law of the Sea. India plans to carry out tests of an integrated mining system in 2002-2003. India bought a self-propelled collector unit from a German company in 1999. This unit will also be used during the planned test mining. The Indian deep-sea program is organised by the Department of Ocean Development (DOD) in New Delhi. DOD has a very special political position in India in the sense that it is the Prime Minister that is also the minister of DOD. The staff of DOD is regarded as highly competent and the Department is known to be run extremely efficiently. Indian companies, such as Engineers India Ltd., and research organisations, e.g. Indian Institute of Technology in Madras - participate in the program.

Norwegian companies have been India's main co-operative partner for exploration of the Indian Ocean nodule deposits. The co-operation was expanded in 1997 also to include mining technology. The Indians together with Norwegian companies started joint development of an integrated mining system. The Indo-Norwegian deep-sea co-operation was, however, stopped in May 1998 by the Norwegian Government because of India's nuclear testing program. German companies took over the role of the Norwegian companies as India's main co-operative partner – and soon got a contract for delivery of a collector unit worth NOK 100 million.

Fugro Geoteam, together with NTNU, assisted the National Institute of Oceanography (NIO) in Goa in developing the Indian exploration competence in the early 1980s. A Norwegian ship, *Skandi Surveyor*, was chartered for five years, and India also bought equipment from Norwegian companies. It is important to underline that the DOD and NIO were in charge of the development program all the time. The role of the Norwegian partners was that of assisting the Indians. NIO is today regarded as one of the leading oceanographic institutions in Asia.

DOD characterises the Indo-Norwegian exploration co-operation as the most successful co-operation project they have ever had with a foreign partner – not least because the Indians felt it was a co-operation between "equal" partners. The Norwegian partners did not, according to DOD, try to dominate the co-operation. They did a good job when transferring technology and knowledge and also showed respect towards the highly educated Indian scientists. Indian authorities therefore signalled, at the end of the 1980s, that they wanted to expand the exploration co-operation with the Norwegian companies. Norwegian authorities also actively supported these efforts. Early in the 1990s the Indian Government further informed the Norwegian Government that they would like to give preference to deep seabed mining in the bilateral co-operation between the two countries. In 1994 a report by Fixdal, Gopalakrishnan, Majumder and Markussen, *Deep Seabed Mining – Potential for Indo-Norwegian Cooperation*, was published. The report was financed by NORAD and presented possible joint projects both when it comes to exploration activities, studies of environmental consequences, and development of mining and processing technology.

When the joint Indo-Norwegian development of the integrated mining system started in 1997 it was well prepared. The Central Mechanical Engineering Research Institute (CMERI) in Durgapur had carried out extensive initial studies of the alternative mining systems. Two special R&D groups had been established at CMERI – one focusing on the mining technology and one on the collector unit. A prototype of a collector unit had been developed and built – and tested in a shallow water basin at CMERI. A separate test plant for the mining system had also been built in Durgapur. DOD stated that there were several reasons why they wanted to co-operate with Norwegian companies. Firstly, they felt that Norwegian offshore technology could increase the efficiency of the total system, and make the system more environmentally friendly. They felt that the Norwegian competence supplemented the basic competence and knowledge that they had built up themselves.

Secondly, they had as mentioned very good experience from co-operating with Norwegian companies.

When the co-operative project was initiated on November 1 1997, three project groups were established. Both Indians and Norwegians participated in all three groups. The three groups – Collector Unit Group, Riser Group and Exploration Group – co-operated closely. The purpose was to design a system that could later be built and tested. The system would consist of a self-propelled collector unit, a flexible link to a buffer storage unit, a riser and a mining ship (see Figure 4.1).

4.3 Current status Korea/China

India has also established deep-sea co-operation with Korea and China. These two countries established separate deep seabed mining programs at the end of the 1980s. Both countries have separate mine sites in the Clarion-Clipperton area.

There are clear similarities between the two countries' programs, both when it comes to technological concepts and to time aspects for test mining. Both countries – like India – are developing a mining system consisting of a self-propelled collector unit, a buffer storage unit and a riser. Korea has formulated plans to carry out tests of an integrated mining system in the scale of 1 to 5 between 2004 and 2007.

This Korean program consists of three phases:

The First Phase (1994-2003) involves exploration work and R&D work for conceptual design of the technology needed to mine, transport and process the nodules. USD 11 million is to be used during this first phase.

The Second Phase (2004-2007) is estimated to cost USD 140 million and contains the following sub-projects: 1) delineate mining tracks for commercial mining; 2) examine the components and subsystems of the ocean mining system leading to a one fifth scale test of the system; 3) carry out pilot plant testing of the chosen metallurgical process in the scale 1 to 10; 4) update cost estimates to be used in the economic model; 5) prepare contract plans and specifications for the commercial mining facilities, processing system and transportation system; 6) review the legal requirements of being Pioneer Investor; and 7) carry out a comprehensive cost model of the operation.

The Third Phase (2008-2013) begins when the decision is made to invest in the facilities and equipment required for a full-scale project. The commercial production phase of the project is estimated to start in 2014.

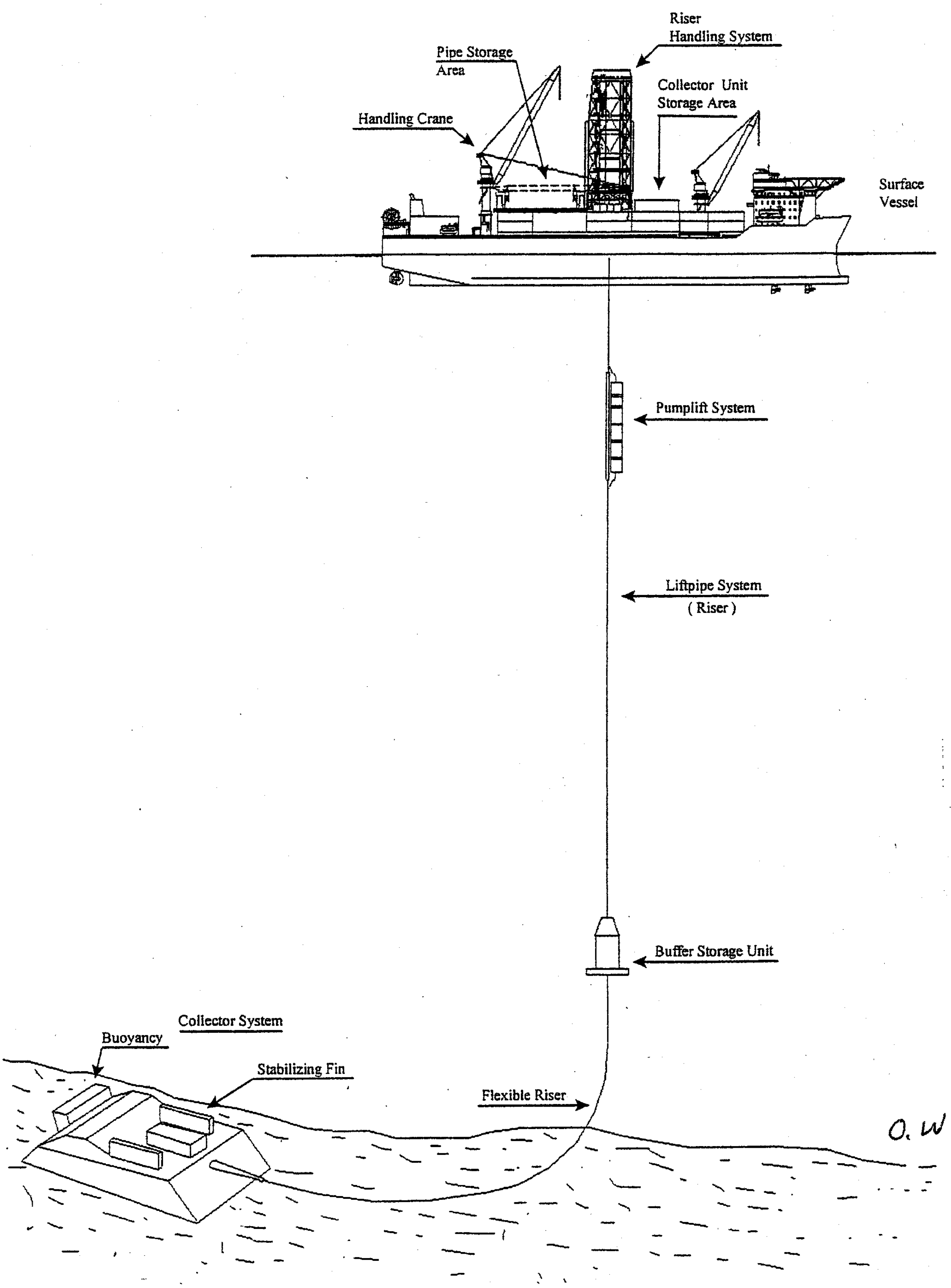

Figure 4.1. The mining system developed during the Indo-Norwegian co-operation

The Korean deep seabed mining project is financed by the Ministry of Science and Technology (MOST) and the Ministry of Maritime Affairs and Fisheries (MOMAF). Korea, like India, co-operates with Germany to develop the collector unit.

China has, as mentioned, a similar national program, headed by the governmental deep-sea organisation COMRA.

4.4 Current project status other countries

The Japanese deep seabed mining group *Technology Research Association of Manganese Nodules Mining System* tested an integrated mining system in the Pacific Ocean in 1997/1998. Twenty Japanese companies participate in the group – among them the big industrial groups Hitachi, IHI, Mitsubishi, Mitsui, Nippon Kokan and Sumitmo. The Japanese mine site is also located in the Clarion-Clipperton area. The Japanese Government has, however, expressed interest in discussing a possible co-operation with the Cook Islands. The Metal Mining Agency of Japan, which is a governmental organisation, started in April 2000 exploration in exclusive economic zones of neighbouring countries to the Cook Islands, in an attempt to find similar deposits characterised by high metal content and density.

Deep-sea activities are also carried out in the United States, Canada, Germany, France, and Russia.

4.5 Industry status

After the manganese nodule boom of the 1970-80s, the national programs continued without any serious industry interest. Industry was rather attracted to shallow water aggregates and placers (sand, gravel, diamonds etc.), which are the most important marine mineral resources being recovered today. In the mid 1990s the new discoveries of seabed sulphide hydrothermal deposits spurred new interest in ocean mining, with new companies being set up.

4.5.1 The marine diamond industry

Diamonds were first discovered on the coast of Namibia in 1908. They had been transported to the southern Atlantic after their erosion from kimberlites hundreds of kilometres inland. Alongshore currents, combined with high-energy wave action during periods of considerable sea level changes concentrated the diamonds in trap sites on paleo coastlines and other marine geological features, mixed with sediments.

Large scale marine diamond mining started a decade ago after years of exploration work, and is now by far the most advanced marine mining operation in depths beyond 80m. Operations in water depths down to 200m have necessitated the successful development of new survey and mining systems. The principal diamond producer in South Africa is De Beers Marine. The principal diamond producer in Namibia is Namdeb, which is a joint venture between the Namibian authorities and De Beers Marine. Namdeb and De Beers Marine holds almost all of the preferred deep-water licenses.

The two main competitors are NAMCO (Namibian Minerals Corporation) and TransHex which are also involved in smaller scale marine diamond operations. In total these three companies produce close to a million carat per year. Marine operations are more capital intensive with higher unit costs than similar land based activities, but the grades and thus value are higher, approaching USD 200/ct. In addition there is little or no overburden. The marine diamonds have a total value of USD 200 million, and a market value of more than 1 billion. By comparison world production from terrestrial sources is more than 100 million carat with values averaging USD 70/ct.

De Beers Marine was formed in 1983 but it was not until 1990 that the first diamonds were recovered. The company now operates eight advanced vessels for exploration and mining. The company utilises bathymetric and geophysical technologies to produce high resolution images of the seafloor in order to locate seabed features favourable for the accumulation of diamondiferous sediments. This work is aided by sophisticated modelling techniques where information is extracted to identify mineral and gem-rich areas based on the geology and physical morphology of the seafloor.

This work is followed by remote observations and sampling. Recognised features are then studied further with more detailed mapping and evaluation, including sub-bottom profiling equipment and evaluation sampling on a 50x50 meter grid. This is sometimes followed by confirmatory bulk sampling. This dense sampling is necessary as diamonds are extremely irregularly distributed. De Beers Marine spent more than USD 50 million on exploration alone in the period 1991-1994.

The selection of an appropriate diamond mining system requires full knowledge of the seabed geomorphology, and a quantified understanding of the nature and composition of the seabed sediments. Mining is carried out with a Wirth drill or subsea crawler. A Wirth drill excavates a 7 meter wide and 5 meter deep hole in 10-15 minutes and each mine ship is able to excavate an area of 2000 m^2 per day. The remotely controlled tracked vehicle is lowered to the seabed by hoist cables and guided via an umbilical to the surface. The crawler then advances down specific lanes according to a mapped grid, mining gravel and mechanically transporting it onto a screen where oversize is discarded. The rest is transported via flexible slurry hoses to the ship's treatment plant. A cutting device and water jets attached to the front of the crawler softens the sediments and sucks it into suction boxes. The crawler can theoretically cover an area of 5000 m^2 per day at an estimated cost of USD 30/m^2. In order to minimise the damage from the mining activity, De Beers Marine has an ongoing research program to understand and protect the marine environment better. It recently achieved ISO 14001 certification for Environmental Management.

The offshore diamond industry now operates to 200m depth with leases extending to 1000m. At a meeting with De Beers Marine in Cape Town in April 2000 the company expressed an interest in co-operation with the Norwegian group. Based on their unique experience from deep-water mining, a strategic alliance should be seriously considered. For a more detailed analysis of the marine mining industry see Garnett (2000).

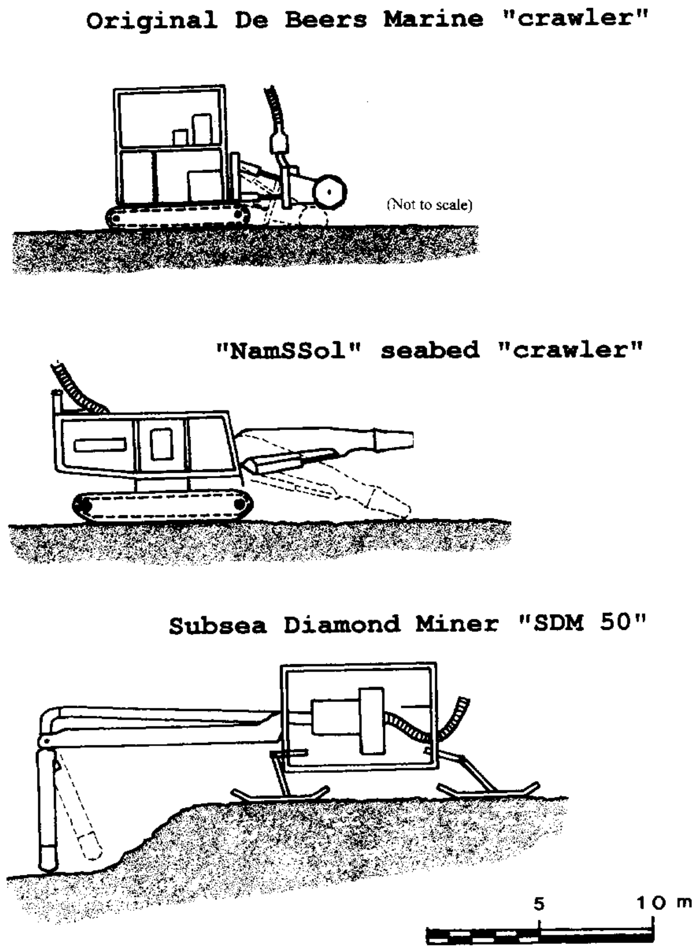

Fig 4.2. Subsea crawlers used by the marine diamond mining industry

4.5.2 Hydrothermal deposits in the Red Sea

The Red Sea hydrothermal deposits have been extensively investigated during the past 40 years (Scholten et.al, 2000). Hydrothermal activity in the Red Sea is linked to the divergent movement of the African and Arabian continental plates and the subsequent formation of new oceanic crust. The formation of the deposits in the Red Sea is further facilitated by the fact that the activity takes place in relatively small areas which act as a trap for the discharging hydrothermal fluids and prevent their distribution over large areas. In addition saline brines fill about 25 deeps in the Red Sea, creating an environment with low or no oxygen content. This environment further favours the formation and preservation of hydrothermal deposits.

These Red Sea deposits are a potential ore body for zinc and copper, with gold, silver and cobalt as important subsidiary metals. The best deposits have been found in the brine filled Atlantis II deep, which is an elongated basin with a maximum water depth of 2200 meters. The Atlantis II deep covers a total area of approximately 57 km^2, with a sediment thickness from 2 to 25 meters. This deposit rivals the largest deposits found on land. The estimated value of the deposit is USD 5 billion in 1985 prices. The Atlantis II deposit alone contains 2,000,000-3,000,000 tons of zinc, 500,000-1,000,000 tons of copper, 3750 tons of silver, 50 tons of gold and 5000 tons of cobalt. However, the metal grades of the wet sediments are on average very low (0.5% for Zn, 0.07% for Cu, 0.5ppm gold).

Because of the high economic value of the deposit, a pre-pilot mining test was carried out in 1979 by the German company Preussag on behalf of a group representing countries bordering the Red Sea. This was the first time that hydrothermal deposits were recovered for economic purposes. About 15,000m^3 of metalliferous mud was pumped through a 2200 meter long pipe string and subjected to separation on board. This showed that it would be possible to recover the deposits in a period of about 16 years. Rumours are that an Arab-Asian consortium is re-evaluating the possibility of mining the Atlantis II Deep, but this has not been confirmed during the study.

4.5.3 Nautilus Minerals Corporation and Sea-X

Nautilus Minerals Corporation Limited is a Papua New Guinean company with its registered office in Port Moresby and international shareholdings. As a foreign-controlled company in PNG, Nautilus has approval from the Investment Promotion Authority to carry out mineral exploration and development activities in PNG.

Enfin Group Limited is a Vanuatu corporation of independent investors. Enfin operates the wholly-owned registered business named Sea-X. The main external function of Sea-X is to act as an international umbrella company. It will generate other companies like Nautilus to explore for minerals and secure title in other countries. For example, Sea-X is the applicant for a special prospecting licence in

North Fiji Basin areas in Fiji's EEZ. It is the current and future owner of all intellectual property, designs, patents and know-how resulting from the group's work in the exploration of and mining for SMS deposits.

Sea-X Australia Pty Limited (ACN 081 833 285) is an Australian service company with the purpose of operating the group's Sydney office and supplying various services to the group. To preserve freedom with regard to corporate structuring decisions, particular care has been taken to maintain flexibility in the corporate structure. Accordingly the three entities do not own each other in a 'tree structure' but are instead each owned by a common group of main shareholders (in roughly similar proportions).

The core business objective is to develop marine exploration and mining opportunities for so-called 'seafloor massive sulphides' (SMS) deposits. Nautilus sees SMS deposits as offering revolutionary mineral economics and represent a rich frontier of unclaimed mineral deposits. Nautilus was the first pioneer in this new field. Since the beginning in 1994, the company has developed a unique experience base.

Sea-X intends to become an international group of companies that holds rights to different regions and different elements of the enterprise. One set of companies will own the titles and applications to minerals, and the second will own intellectual property and a service contract to develop and supply exploration and mining technology and services to the first set. Both types of companies have a large potential, but at this stage they each attract different players. Some see the minerals as the place to be and others see the technology and know-how as the key. This strategy will bring income from both own deposits as well as deposits developed by others where the group can offer technology and services.

The founder of the project is Julian Malnic. He is a geologist with extensive international experience in mineral exploration, company building, resource journalism and technical communication. Other participants include Russell Debney, a seasoned commercial lawyer with 13 years in building an offshore petroleum-engineering firm. Sir Anthony Siaguru is a Papua New Guinea lawyer and statesman represented on the boards of major PNG resource companies.

Dr Richard Garnett is a geologist and mining engineer with experience in marine mining on the continental shelf. Dr Ray Binns discovered the PNG deposits. Dr Tim McConachy is an experienced explorer specialising in SMS deposits. He is a technical adviser to Nautilus but is currently working under contract to CSIRO. Dr Peter Halbach from Berlin's Freie Universitat is the discoverer of the North Fiji Basin deposits and an expert in the prediction and location of SMS deposits.

Nautilus' exploration leases in PNG cover some unusually high grade SMS deposits which were discovered by an international research team lead by Australia's premier, state-owned scientific unit, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Dr Ray Binns. The finds were made while searching for analogues of terrestrial deposits. In November 1997, Nautilus signed a research agreement with the CSIRO. A significant proportion of the USD 1.0m Nautilus has invested to date has been paid to the CSIRO as a research/exploration contractor. The information so generated has become an asset of the company and has been supplemented with data gathered from other workers such as Korea and Japan.

Description of leases

On November 28, 1997 Nautilus Minerals Corporation was granted two Exploration Licences covering more than 2500 km^2 in the Manus Basin of the Bismarck Sea south of Papua New Guinea. These titles are the only ones of their type anywhere in the world covering this type of deposit and are 100% owned by Nautilus. The leases were issued under the conventional mining laws of Papua New Guinea. Although they are about 150 miles from shore, they lie within the archipelagic boundary of that nation and are included within its territorial waters.

EL 1196 covers the PACMANUS and SuSu Fields; EL 1205 covers the Vienna Woods Field. ELA 1265 covers a large epithermal gold system at Conical Seamount 10 km south of Lihir Island in 1050m of water. The area is characterised by an absence of cyclones and extremely quiet ocean conditions. Average water depths of 1600-1750m must be considered relatively shallow by current standards.

Nautilus' licences were lodged with and accepted by the Papua New Guinea Department of Mineral Resources. Renewals are awaiting ministerial approval. If the Department does not approve of the licenses, subject to any rights that the company has to appeal the decision, the licences will be terminated.

The SMS deposits discovered in these waters covers an area of approximately 1800 km^2, and contains at least three high-temperature smoker sites with Cu and Au rich massive sulphide deposits. The prime economic targets are gold and silver; zinc, lead and copper are possible secondary targets. The studies of economic potential look promising. The specific geological environment in the area is believed to result in extremely high grade where contained metal values routinely exceed USD 500/t. The high grades have however only been established by surface sampling and a drilling program is therefore needed to confirm these estimates (Binns and Dekker, 1998). SMS deposits routinely exceed the grade of onshore mines by a factor of 10 and it is necessary to obtain sufficient information about true tonnage and grade to make an economic decision to mine. The Ocean Drilling Program is now drilling in the area to test various research proposals, but is not equipped to study the near-surface SMS mineralisation.

If the metal grades are proven by drilling to be sustainable in the three dimensions of the SMS mound, the mining industry will get access to new mine sites with grades not seen on land in decades. SMS mining operations will have gold-bearing zinc and copper concentrates as their main products. They will closely resemble terrestrial base metal operations, with gold being sold off to the smelters in copper and zinc concentrate streams. The gold grades encountered of 15-21 grams per tonne are a multiple of those mined in typical terrestrial mines.

The first dredge sample assays show that at current prices, some deposits contain more than USD 600 a tonne of copper, gold, zinc and silver. The Roman Ruins deposit in the Manus Basin area has averaged 3.4% zinc, 15.3% copper, 15g/t gold and 200g/t silver. 59 samples from the PACMANUS area shows an average of: 9.9% Cu, 25.6% Zn, 14.7% Fe, 1.5% Pb, 15ppm Au, 200ppm Ag (Malnic, 2000).

SMS deposits tend to be bi-modal with either high copper or high zinc. Copper grades can locally exceed 35% and a one tonne sample recovered from EL 1196 in April 2000 graded 51% zinc.

Nautilus also has an application for an exploration licence pending over Conical Seamount, a gold-mineralised, 1050m deep seamount lying 10 km south of the island of Lihir. On land, Lihir Gold Ltd has a USD 760m gold mine that processes a type of gold-pyrite mineralisation similar to that sampled at Conical Seamount by its discoverer, Professor Peter Herzig. One sample set assays 20-30 g/t Au. These high grades could make Conical Seamount a starting point in the development of systems to mine in the 1300m to 1900m range which Nautilus expect to be typical for its SMS mining operations.

Sea-X is researching and exploring many other areas, and also has an application in the 200 nautical mile Exclusive Economic Zone of Fiji. The discoverer of the Fiji deposits, Dr Peter Halbach, estimates several million tonnes of high-grade mineralisation is present, provided a thickness of 5m prevails.

Two major deposits also exist at Izena (7Mt) and Myojin Knolls (9Mt) in the waters of Japan. Discussions with representatives of Japanese agencies confirm these could be farm-in targets for the group when it completes the development of the SMS mining system. The Japanese and Bismarck Sea deposits are the most extensively explored deposits in the world. USD 100-150m have been spent in the Bismarck Sea alone, almost entirely within Nautilus’ licence areas.

Description of Nautilus business idea

About 140 known areas with hydrothermal deposits have been located so far. About half of these are deposits of copper, zinc, lead, silver and gold in variable amounts, not unlike the deposits being mined on land. Indeed, the land-based mines originally formed in primordial oceans. Approximately 10 of the deposits appear to be of sufficient size (a few million tons) and metal content to be possible candidates for economic recovery.

The known deposits represent more than 20Mt of mineralisation located mainly within EEZs and close to land and ports. The economic potential of SMS mineralisation is great and has largely gone unnoticed by the terrestrial mining industry because of its unfamiliarity with the marine environment. The major mining companies are however expected to follow as soon as the benefits are more widely realised. Nautilus intends to be the first to develop a major SMS marine mining company.

It is now more than 20 years since the petroleum industry, similarly led by the discoveries of new types of deposits, moved offshore. Nautilus believes this history is an important analogy for what is to follow in the minerals sector. With more than two decades of marine resource experience and technological development in oil and gas production, and with significant contributions from the telecommunications and military industries, the company is prepared to meet the technical challenges of SMS mining on the titles it has been granted in Papua New Guinea.

In Nautilus' analysis marine mining operations for SMS will face competitive advantages relative to terrestrial operations in virtually all areas. The list presented below summarises the main arguments as to why SMS mining will out-compete terrestrial mines at least in the production of zinc, copper and gold.

The Key Economic Benefits:

- Discovery is rapid and relatively low cost
- Sampling can be quickly scaled up from surface grabs to trial mining; the feasibility cycle is short
- Drilling and early production is hastened by absence of overburden
- The 'mine facility' can be efficiently constructed in a shipyard
- The 'mine infrastructure and plant' is mobile, leasable and not subject to the normal 'mine life' writedowns
- Materials handling and grinding costs are low because of soft ore and high grades
- Mining can be market responsive between high-zinc and high-copper deposits
- Deposits can be aggregated without infrastructure or cost penalties
- Landowner risks and compensation is reduced
- Pit-to-port infrastructure is eliminated
- Unsaleable waste production is limited
- The general logistical efficiency of working in the marine environment is high

SMS mining offers scope for a highly compressed development cycle. Time between first identifying a plume and tracking down a deposit, and the time of mining the deposit at its source, could be very short. With a mobile production vessel, test mining can be conducted within a matter of weeks of a discovery. On land, definition drilling required to justify the cost of a test shaft will typically take two years, and then the test shaft will take additional time. With this part of the development cycle shortened, the feasibility study costs are also expected to be significantly lower than for terrestrial mines. Nautilus has estimated that the cumulative net cash flow draw down could be less than one third of a terrestrial mine with equivalent production.

The infrastructure for the mining facility at sea, although expensive, is entirely reusable. This should be contrasted with today's estimated USD 200 million to find and develop a typical 1 to 3 million ton deposit of this type on land. Most of the capital infrastructure costs for a mine on land (roads, power lines, perhaps mine buildings and accommodation, shaft, underground development) are left behind when the mine closes. A marine production unit is reusable and extremely transportable for deployment at the next site that may be far away. The ore can also be transported directly from the mine site by ship.

The mobility of marine plants also means discontinuous deposits may be mined sequentially and in response to prevailing metal prices. The flexibility of the process might even allow mining that is more responsive to fluctuations in metal prices. For example, if tests showed that a deposit was particularly rich in copper, and the price of copper was rising, a mining company could concentrate on that deposit rather than others. Logistics at terrestrial mines normally cannot accommodate such nimble planning.

Today, the two most serious threats faced by terrestrial mining are land access problems due to indigenous peoples issues and increasing population pressures, and increasing constraints on tailings and mine waste disposal. On both points marine mining will be clearly favourable since the high grades mean little tailings will be produced at the site, and can alternatively be returned to the site on the seafloor. The high grades are also favourable for processing, since less crushing, grinding and processing is needed.

Description of the planned work program

Nautilus is currently drafting an exploration and development program and funding studies into the best methods for exploring at sea. It is also funding research into possible mining technologies. It has contracted Sea-X Australia Pty Ltd to plan, implement and manage its exploration and development efforts. The focus of the development program is to use and improve existing technology, and is basically a low cost approach.

The company has drafted the following two-year pre-feasibility work program:

- Global exploration philosophy
- Secure additional leases in other areas
- Complete bathymetry and deposit definition (AUV technology)
- Geophysics research and development
- Development of RES, (Rapid Exploration System) and instrumentation for RES
- Environmental base studies
- Biogenic resource assessment
- Mining methods including drilling technology, mining tool, cutter head for a production program of 800-2000 t/day
- Riser/lifting system
- Mineral processing/marketing
- Mill layout including evaluation of a floating refinery
- Information and communications program
- Economic and financial modelling

The estimated cost of this program is USD 5-8 mill.

Nautilus' exploration for SMS deposits will be based on detailed proprietary knowledge of the host geological environments and on specialised predictive methods for finding and defining them. However, most of these tasks are being done for the first time and the outcome is less predictable. It is, for example, very difficult to predict how much ship time will be required to explore 5000 km^2 of the sea to a satisfactory reconnaissance level or how good the drill core recoveries will be. Strategic advantages will, however, be gained by developing know-how, patenting the appropriate elements and being able to offer systems and services commercially within and/or outside the group.

The first task is related to finding and defining deposits. It is important to develop improved methods to locate and define sites. SMS deposits are located by tracing a ‘plume’ of ‘smoky’ particulate-laden water back to the hydrothermal source. Active sites can be discovered by an increase in particulates, manganese, methane and temperature (0.1°C) in the water column. Nautilus has a preliminary design for a proprietary Rapid Exploration System (RES). Its primary purpose is rapid and low cost reconnaissance exploration to identify plumes, and will be used to survey large areas to locate new SMS deposits.

Locating plumes is a very reliable method for locating the deposits. Low cost digital video and 35mm cameras can then be suspended to the seafloor to observe the plume source, which is often the site of SMS build-up. Surface sampling of the mound can be carried out with a cable-drawn dredge. Sidescan sonar is being developed as a routine method for creating 3D images of the deposits.

Estimations of the shape of the mineralised body and suitable drill sites can be made from the sidescan sonar images. Drillholes can be drilled by a conventional drilling ship or a PROD-type, bottom-deployed, carousel-drilling module. Pattern drilling is the proposed method for measuring SMS resources.

Nautilus expects to announce shortly the finalisation of an agreement with British offshore marine contractor Seacore Limited for the development of a mining system to a pilot stage and then to commercialisation. This will lead to an actual system being built, tested and offered for service.

Seacore has a capable core of engineers with extensive skills in marine operations and marine mining. Seacore is currently designing and building marine diamond mining systems for use in up to 150m, and has a strong mining skill base. The Seacore-Nautilus technical alliance is for an initial period of 10 years and is expected to be initiated early 2001.

In brief, the conceptual design involves breaking the porous SMS mineralisation with counter-rotating pick heads or hydraulic jaw mechanisms, reducing the size of broken ore by crushing it at the seafloor before feeding it to a surge bin. The crushed ore will then be pumped to the production vessel overhead through a suspended pipe or riser. Vision will be with light and sonar, control will be remote and the unmanned mining cutter head will be retractable through the production vessel’s moonpool. The design of the mining system will of course seek high efficiency and low costs, and will be comprised of a range of proven integrated technologies.

The largest capital item will be the topside production plant, the ore shuttling vessels and the refinery (if any). Nautilus intends to modify and use existing ‘ships of opportunity’. Nautilus is conscious of the advantage it has in having the first titles granted under a mining act, and would like to initiate the work fast. The development of the necessary technologies is seen as simply an extension of what is already being done in the deep sea environment by the oil and gas, military and communications sectors.

Basic flotation tests, the preferred concentrating method in terrestrial mines, have returned very positive results for SMS mineralisation. Tests on samples from various deposits, ranging from high-zinc to high-copper, successfully recovered more than 90% of the elemental metals to concentrates. Penalty elements were present in acceptably low concentrations and further testing will demonstrate likely concentrate compositions that can be readily sold on world markets for up to 50% of the contained metal value. Nautilus is also evaluating new leach processing methods (see Chapter 9).

4.5.4 Deep Sea Minerals, Inc.

Deep Sea Minerals, Inc. (DSM) is a Delaware corporation dedicated to the mining of seabed mineral deposits. DSM was formed 3 years ago. It is a private company but intends to go public in the near future.

DSM is the main competitor of Nautilus. The company is currently engaged in a world-wide leasing program to acquire exclusive rights in specific EEZs that DSM's marine geologists have identified as prospective targets for seabed mines of copper, zinc, gold and silver. DSM is also developing a program of world-wide exploration for seabed mineral deposits. Of primary concern for commercial development of these marine deposits are two related objectives:

(1) the acquisition of exclusive rights to prospective areas on the seabed for exploration and potential mining, and
(2) an assessment and minimisation of the potential environmental impacts which may accompany such development.

Scientific Vision:

- establish a world leading organisation for exploring, evaluating and recovering seafloor deposits of base and precious metals

Scientific Mission:

- identify, map and sample ocean floor deposits capable of being recovered at a profit
- evaluate the economic viability of deposits for mining
- determine the environmental consequences of ocean mining and their amelioration
- develop mining and mineral processing systems for seafloor mining

In the last two years, the corporation has assembled an international team including some of the world's leading marine research scientists and engineers. The scientific advisory board now consists of:

Dr. Steven Scott, Chief Scientist. Dr. Scott is a Professor and Director of Scotiabank Marine Geology Research Laboratory, University of Toronto, Canada. He has twenty-seven years of research experience on polymetallic sulphide deposits on land. He is also the co-discoverer of several seafloor hydrothermal sites.

Principal Scientists and Engineers:

- Dr. Graeme Cairns, research geophysicist, CNRS France and logging technician, Ocean Drilling Program. He is currently developing marine electromagnetic surveying systems and is also responsible for other geophysical technologies.
- Dr. Michael Cruickshank, marine mining engineer. Thirty-eight years experience from the marine minerals industry, government and academe. He is currently affiliated with the Marine Minerals Technology Center, University of Mississippi.
- Dr. James Franklin, consultant, Canada. Recently retired from the Geological Survey of Canada as its Chief Scientist.
- Dr. Peter Herzig, Professor and department chair, Freiberg University of Mining Tech., Germany. Fifteen years of experience in massive sulphide and precious metal deposits on land and on the seafloor.
- Dr. Richard Hutchinson, Emeritus Fogarty Professor, Colorado School of Mines.
- Dr. Charles Morgan. Current member of the Legal and Technical Commission of the International Seabed Authority. Ten years with Lockheed Advanced Marine Systems, followed by several years with Ocean Minerals Company working on their deep seabed mining claim for manganese nodules and on related technologies.

Associated Scientists:

The following government employees are prohibited from working within Deep Sea Minerals but have agreed to participate in company's activities as outside experts:

- Dr. Yves Fouquet, senior scientist, Institute Français pour la Recherche et l'Exploitation de la Mer (IFREMER), France. Seventeen years of marine experience during which time he has been responsible for the discovery of several significant seafloor sulphide deposits.
- Dr. Mark Hannington, research scientist, Geological Survey of Canada.
- Dr. Roger Hekinian, senior scientist, Institute Français pour la Recherche et l'Exploitation de la Mer (IFREMER), France. Thirty-one years experience. Co-discoverer of several seafloor polymetallic sulphide sites. Retires in 2000 at which time he will become a Principal Scientist.

The company claims that the scientific material available from these and other researchers affiliated with the company represents a value of approximately USD 100 mill.

DSM's business is international in nature and requires an international infrastructure. The individual countries in which DSM will be conducting business will require corresponding individual DSM subsidiaries. To facilitate these subsidiaries DSM is creating an offshore holding company in Bermuda. This holding company structure enables DSM to conduct international business in a tax favourable environment.

Deep Sea Minerals has recently purchased Neptune Resources, a marine mineral-exploration company headquartered in Sydney. This company has an application pending for obtaining exploration leases north-east of New Zealand (Colville Ridge). This company will become Deep Sea Minerals (Australia).

DSM has created a strategic partnership with Phelps Dodge Exploration, Phoenix, Arizona. Phelps Dodge Exploration (PDX) is a subsidiary of Phelps Dodge Corporation, one of the world's leading natural resource and industrial manufacturing companies, founded in 1834. Phelps Dodge is the world's second largest copper producer, and produce an estimated 1.1 mill. mt. The company is involved in all aspects of copper production from exploration and prospecting to mining and production of copper wire and cable. The rising cost of mineral exploration and mining, in addition to environmental concerns about terrestrial mining, has forced Phelps Dodge to look for alternative sources of metal. This initiated the collaboration with DSM to investigate marine mineral resources.

Deep Sea Minerals is operated by an Executive Management Committee. The committee has equal representation from PDX and DSM. This arrangement permits DSM to draw on the extensive experience and capabilities related to exploration, metallurgy, process design and mining that are available at PDX while at the same time focussing on marine operations. The strategic partnership means:

- PDX has a 10% ownership in DSM; both classes of stock (voting & common shares)
- PDX has the right to purchase up to an additional 20% of both classes of stock
- For additional ownership of DSM, PDX must receive DSM board approval
- PDX has the exclusive right to market the mineral production of DSM
- PDX will provide expertise in exploration, mining & technology, metallurgy, strategy & development and business analysis & planning
- PDX will have three seats on DSM's board
- PDX will compose 50% of DSM's management committee

DSM operations are further divided into eight technical focus groups that address the essential functions of the venture. In practice, the groups interact on many of the important operational decisions that must be made. Also critical to the success of DSM are independent industrial groups which are affiliated with DSM through joint ventures, contracts or other arrangements, and which provide the needed capabilities to address the many technical challenges that arise.

Strategic alliances

DSM has used Haliburton SubSea to develop the necessary exploration and mining systems from proven commercial components. Haliburton SubSea is the designer and producer of the remotely operated NamSSOL mining device, which is used for diamond mining in South Africa. Haliburton has recently designed a new autonomous subsea drill for DSM that can drill 100 meters in 20 hours.

Another important industrial affiliate is the Canadian scientific submersible facility who owns and operates the Remotely Operated Platform for Ocean Sciences (ROPOS). ROPOS is a 40 horsepower hydraulic ROV, fully operational to 5000m. DSM intends to use this and other ROVs for its marine operations, and minimise the requirements for internal staffing.

DSM is also trying to develop strategic partnerships with leading governmental and research institutions world-wide. The company has initiated talks with IFREMER, the French Institute of Research and Exploitation of the Sea. IFREMER can potentially provide very significant general scientific and logistical support. In areas of mutual interest to DSM and IFREMER it is also anticipated that co-sponsored and co-funded cruises can be conducted, thus effecting considerable cost-savings.

The German oceanographic institute, the German Federal Ministry of Education & Research (BMBF) is also prepared to co-sponsor and co-fund cruises in areas of mutual interest. BMBF will provide extensive scientific and logistical resources to DSM.

Affiliations on a global basis with other leading research institutes and commercial companies will also be considered. The company is for instance trying to access the US Office of Naval Research database on black smokers.

Description of DSM's business idea

The company has spent the last few years collecting information about known hydrothermal deposits in EEZ's around the world. The scientific advisory board has classified the known deposits, and the company will eventually try to secure leases in the most promising areas:

- Several sites in the Pacific, including sites in Papua New Guinea, New Zealand, Fiji, Tonga (Lau Basin)
- Japan (the Japanese deposits are some of the largest know to date. The Japanese has, however, recently refused a proposal from DSM to investigate these further)
- Italy (southern Tyrrhenian Sea)
- Greece (Anatolian Trough, northern Aegean Sea)
- Caribbean back-arc
- The Galapagos rift region
- Mid-Atlantic Ridge, central and south Atlantic spreading ridges
- Atlantis II Deep and others, Red Sea
- Andaman Sea, western Indian Ocean and Indian Ocean mid-ocean spreading ridges

The choice of sites among the 140 discovered to date is based on a variety of factors including how well the size of a deposit is known and its anticipated metal grade and accessibility (both logistical and political). If successful in obtaining leases in some of these areas, two types of surveys will be conducted:

(1) High resolution mapping of individual sulphide mounds or clusters of closely spaced mounds for the purpose of selecting suitable sites for drill set-ups and providing the mining engineers with data on the shape of the deposit. The thickness of the deposit and its metal content will be obtained by drilling.

(2) Reconnaissance or regional exploration mapping of larger areas on the order of several tens of km long by a few km wide chosen on the basis of their favourable geology for sulphide deposits.

So far, all of the known deposits have been found as a result of academic research. DSM believes that a concerted well-funded effort with the prime objective of finding large, rich deposits should do better. DSM is especially targeting so-called "giant" targets. A deposit is termed "giant" if it contains more than 100 million tons of ore. The 94 million ton Atlantis II Deep deposit in the Red Sea comes close to a giant massive deposit.

Because of potential environmental concerns and also due to the technical challenges posed by super-heated water, DSM will only mine inactive sites, where large deposits occur near active vent sites, but where active venting has ceased.

DSM has drafted a pre-feasibility work program and is now trying to secure funding for the following activities:

- Land acquisitions
- Further exploration with a complete survey of 3-5 sites
- Developing marine mining technology
- Metallurgy
- Environmental baseline studies
- Strategy and business development
- Further economical analysis

In addition to lease acquisition and the survey program, drilling of targets in order to verify the content and ultimately value of hydrothermal deposits is considered the most important. Deposit delineation of high priority targets will be necessary before any large-scale system engineering can begin in earnest. To date most deposits have been characterised only in two dimensions at most.

Another fundamental aspect of DSM's development strategy is the development of multiple deposit sites concurrently. The company thinks that this approach, although more expensive than the development of a single high priority site, is essential to minimise the risk of failure due to inadequate reserves or ore grade, or to unacceptable conditions for mining or permit acquisition.

4.5.5 Other companies

A few other companies have also been established recently in the US and Canada to pursue opportunities in marine mining. A Canadian company is supposedly trying to secure offshore mineral claims from the Canadian government. Another American company consists of two airline pilots who are interested in investing in ocean mining.

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5 VARIOUS OPTIONS FOR NORWEGIAN COMPANIES

5.1 Presentation of the Norwegian Deep Seabed Mining Group

The Norwegian Deep Seabed Mining Group consists of six organisations, primarily involved in the marine industry. The six organisations are:

- *ABB (www.abb.com)*
- *Aker Maritime (www.akermar.com)*
- Kongsberg Simrad *(www.kongsberg-simrad.com)*
- *Fugro Geoteam (www.fugro.geoteam.no)*
- *Kristian Gerhard Jebsen Skipsrederi (www.kgjs.no)*
- *Faculty of Marine Technology, the Norwegian University of Science and Technology (www.marin.ntnu.no)*

The Group also co-operates closely with the *Fridtjof Nansen Institute*, which has been working with research related to deep-sea minerals and the law of the sea for more than 25 years.

5.2 Norway's Options in Deep Seabed Mining

These Norwegian companies and organisations have several options in deep seabed mining; as suppliers of products, technology and competence, as investors in mining projects, and as advisors to governments such as the Cook Islands and to the United Nations. Their interest in deep-ocean mining is, however, primarily related to finding new areas of applications for their marine technology. The individual companies' interests can be summarised as follows:

ABB is interested in developing and delivering the collector unit on the seabed together with the electrical distribution and control system.

Aker Maritime is interested in developing and delivering the surface vessel and the riser system.

Fugro Geoteam is interested in mapping the seabed and the underlying geology.

Kongsberg Simrad is interested in delivering instruments for the mapping together with equipment for positioning and control systems

Kristian Gerhard Jebsen Skipsrederi is interested in operating the mining and transport vessels and is a possible investor in the mining operating company.

Marine mining represents a possible future growth area for Norwegian industry and shipping companies. Norwegian companies hold a very strong international position when it comes to shipping, offshore oil and gas activities and fisheries. Ocean mining could become a fourth marine area for Norway as an ocean nation.

Norway's offshore technology has many synergies with deep seabed mining. Norwegian companies have for instance become world leaders in deep seabed mapping technology. The total competence that exists within Norway's maritime sector is an important factor in this respect. Marine mining is of interest for Norwegian companies for the following reasons:

- New markets for the Norwegian maritime industry; i.e. equipment, transport services and construction activities.
- New market for "world-class" Norwegian mapping technology; i.e. deep-water mapping and survey equipment, instrumentation, data handling and interpretation.
- New market for advanced Norwegian offshore technology; i.e. underwater technology, risers, control systems, remotely operated equipment etc.
- New market for Norwegian shipping companies and their transport services.
- Norwegian industry has a reputation for building advanced ships; i.e. research and mapping ships for Korea.
- Deep-ocean mining will represent new industrial development.
- Development of deep-sea mining technology could have positive effects for the oil and gas industry.

Several countries have expressed an interest in co-operation with Norway in deep-sea mining. The Government of the Cook Islands wants the Norwegian Group to develop their project industrially. The leaders of the Indian Ocean mining program have expressed interest in resuming co-operation with the Norwegian Group. South Korea and China are also potential markets. This is a reflection of the fact that Norwegian management of own petroleum resources is an example for other countries and that Norway is a politically acceptable player internationally. Figure 5.1 illustrates the roles the Group believes that it and other Norwegian organisations can play in regard to the Cook Islands nodule project.

During this study the project group have submitted an application to the Norwegian Ministry of Foreign Affairs for funds to support the Cook Islands government in developing laws, regulations and model contracts for marine mining of nodules in the Cook Island EEZ. A copy of the application is included in Appendix 4.

The Group has also recently been invited to become partners in Deep Sea Minerals, Inc and Nautilus Minerals Corporation, two commercial marine mining companies that are involved in exploration and mining of SMS deposits. Co-operation with these and other companies is one alternative. Another solution is to create a

Norwegian marine mining company. The many options available to the Norwegian Deep Seabed Mining Group represent an interesting new business opportunity.

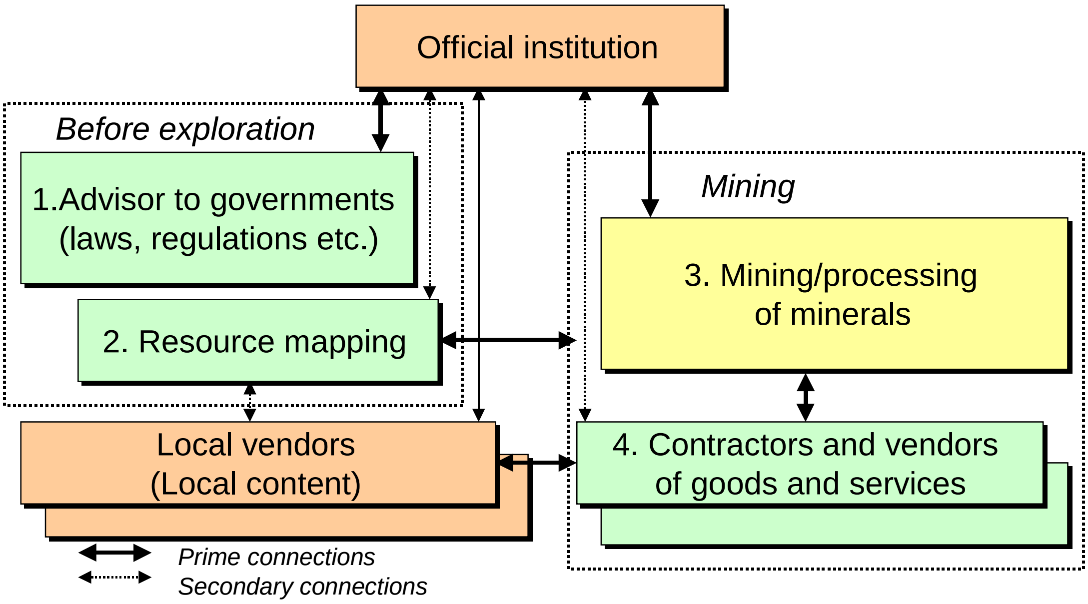

Fig 5.1. Possible roles for Norwegian industry

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6 THE COOK ISLANDS NODULE PROJECT

6.1 Brief presentation of the Cook Islands nodule project

Until 1997 it was, as previously mentioned, generally agreed that first generation commercial nodule projects would take place in the Clarion Clipperton area in the Pacific Ocean or in the Central Indian Basin in the Indian Ocean. That year, however, it became known that the Bechtel Corporation had carried out a comprehensive technical-economical pre-feasibility study of the nodule deposits in the Cook Islands EEZ. The San Francisco-based Bechtel Corporation is the world's largest engineering company. The nodule density was claimed to be over 20 kg/m^2, which is twice as much as the nodule density in the Clarion-Clipperton Area and the Central Indian Basin. The content of cobalt was also claimed to be twice as high. The Bechtel report concluded that the Cook-deposit might supply the world with cobalt for more than five hundred years.

6.2 A summary of Bechtel's pre-feasibility study

The Bechtel Corporation had carried out a comprehensive pre-feasibility study of commercial mining of the nodule deposits in the Cook Islands. Economic, technological, environmental, legal and political issues were analysed in the study: *Cook Islands – Deep Sea Nodule Mining Prefeasibility Study*. The company also formulated detailed plans for test mining and an environmental impact study: *Deep Sea Nodule Mining Study – Pilot Ocean Mining Program, Design Development Plan*. Bechtel concluded that it would be possible to start commercial mining of the Cook Islands nodules 3 years after the Government of the Cook Islands had granted production permission (see Figure 6.1).

The project will, if it is initiated, become the world's fifth biggest producer of cobalt, and will supply 10% of the world's annual consumption of this metal, equal to 2,652 tons. To produce this, 1,097,360 tons of wet nodules must be harvested annually.

Bechtel divided the project into four phases:

- Phase 1 consists of the pre-feasibility study.
- Phase 2 encompasses exploration work at the target harvesting site, recovery of bulk samples of nodules, bench testing and pilot-plant testing of the smelting and refining processes, plant site selection, designing of the trawl, outfitting a trawler and conducting test harvesting, and establishing the environmental baseline conditions in the harvest area.
- Phase 3 includes engineering, procurement and construction of the project and pre-operational testing of facilities.
- Phase 4 designates full-scale production.

Bechtel has finished phase 1- in addition to planning phase 2.

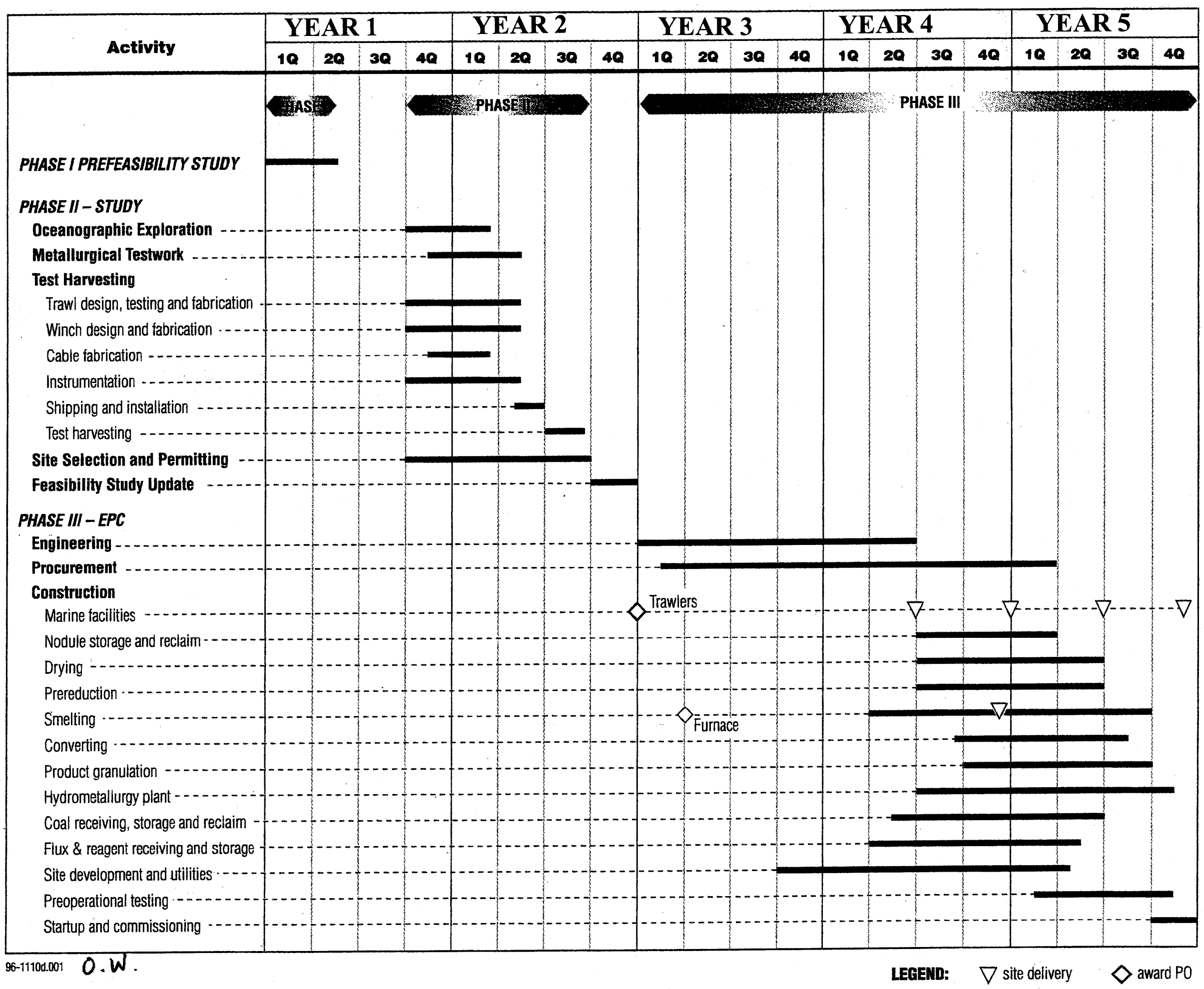


Fig 6.1. Summary of planned activities

Bechtel's preferred mining method is trawl harvesting in the Aitutaki Passage. 4 trawlers will be used for harvesting. Each trawler will transfer the nodules into 3 bulk carrier vessels of about 30,000 tons capacity for transportation to the processing plant located near Whangarei in New Zealand. The nodules will then be processed using a combination of pyrometallurgy and hydrometallurgy. The base of the harvesting operations will be at Rarotonga.

Bechtel also studied the environmental consequences of the suggested mining technology, and claims that the suggested trawling method will have an insignificant overall environmental impact. However, the company suggests that an environmental impact study should be carried out in connection with the pilot-mining operations.

Bechtel found the project to be technically and environmentally feasible. They carried out a comprehensive analysis of the profitability of the project. The expected internal rate of return is 21%. This Return on Investment (ROI) is independent of the financing structure and is regarded as the basic indicator for the profitability of the project. By adjusting for the suggested financial structure – 30% equity and 70% debt – the Return on Equity (ROE) is 29%. This is however based on a cobalt price equal to USD 25/lb and a project lifetime of 26 years. 90% of the revenues will come from the sale of cobalt.

The annual operating cost is calculated as follows:

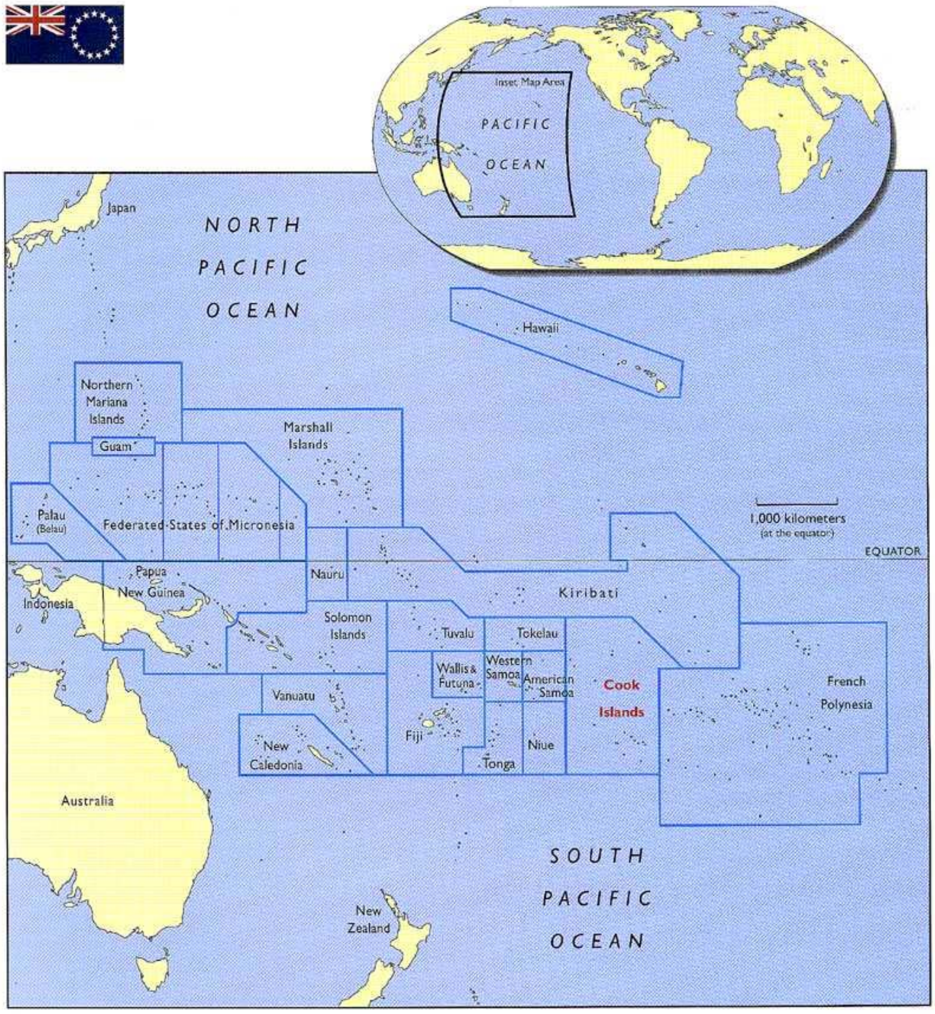
Marine Operations:		
Harvesting	7.707.000	
Transportation	9.914.000	
Subtotal		17.621.000
Smelting:		
Consumables	16.044.500	
Labour	2.522.000	
Subtotal		18.566.500
Refining:		
Consumables	3.517.410	
Labour	838.000	
Subtotal		4.355.410
Maintenance Labour		2.328.700
General and Administration		4.163.500
Total Operating Cost		47.035.110

The capital cost is calculated to USD 435,100,000. The capital cost summary is:

Plant Equipment	192.623.000	
Bulk Materials	43.109.000	
Subcontractor	5.100.000	
Installation Labour	53.798.000	
Total Direct Cost		294.630.000
Spare Parts	4.570.000	
Common Distributables	6.920.000	
Ocean Freight and Inland Freight	9.480.000	
PCEM Services	31.370.000	
Project Insurance	1.730.000	
Contingency	47.400.000	
Total Project Costs		396.100.000
Phase 2 Work		11.000.000
Development Costs		9.000.000
Owner's Costs		19.000.000
Total Capital Costs		435.100.000

Harry Hattyar, who was responsible for Bechtel's Cook Islands nodule project, mentioned to representatives of the Norwegian Deep Seabed Mining Group in a meeting in San Francisco in November 2000, that the cost estimates are very conservative – and that the cost figures therefore could be up to 20-30% higher than the actual cost. However, Bechtel also used a 3% escalation of the metal prices in their economy model. This is in our opinion wrong and resulted in a too high profitability of the project.

Harry Hattyar was also asked whether he believes that Bechtel could be interested in participating in further industrial development of the project. Provided that the project is commercially feasible, Hattyar said that he assumes that Bechtel could be willing to have a share of approximately 10-15%.



The location of the Cook Islands relative to other Pacific island nations. The blue lines do not constitute recognized territorial boundaries; they merely group islands under the same political jurisdiction.

Fig. 6.2. Location of the Cook Islands in the Pacific Ocean

6.3 The Cook Islands – regional conditions

The Cook Islands is a small island group in the Southern Pacific. The country consists of fifteen islands that are divided into a southern and a northern group. Rarotonga, Mangai, Atiu, Mitiaro, Mauke, Aitutaki, Manuae, Taktea and Palmerston constitute the southern group. Penrhyn, Manihiki, Pukapuka, Rakahanaga, Suwarrow and Nassau constitute the northern group. Rarotonga is the main island – with the capital Avarua.

The Cook Islands is a poor nation. A large portion of the population has emigrated to New Zealand and Australia. The young are leaving due to the lack of employment opportunities. Today there are 14,000 inhabitants left on the Cook Islands, while some 55,000 persons have left or emigrated. Tourism is the main source of income.

In addition, the country gets some revenue from the sale of fruit and vegetables, black pearls and from the fisheries within the country's EEZ.

The people of the Cook Islands, of Maori-origin, do not starve. There are fish in the lagoons and fruit and vegetables on land – and the climate is good. The school system and the health services are, however, very limited, due to lack of money. There are no qualified teachers on several of the outer islands in the north. There are only two hospitals among the fifteen islands – one in Rarotonga and one in Aitutaki. The hospital in Aitutaki is very modest. The hospital in Rarotonga is somewhat better and has enough capacity to carry out smaller operations, such as the removal of an appendix. If there is a need for larger operations, the patients must be flown to New Zealand. The flying time between Rarotonga and Auckland is four hours, and the flying time from the islands that have air connection with Rarotonga is also between one and four hours. The majority of the islands do not, however, have air connection with Rarotonga. If a person should suddenly become ill, there is thus only a small possibility to give assistance. However, the Cook Islands has a health insurance arrangement, which means that individuals do not have to pay for air transport and hospital themselves. The Cook Islands pays for the expenses.

6.4 Legal Arrangements

The nodule deposits are within the EEZ of the Cook Islands. The exploitation will thus be regulated in accordance with national legislation – and not in accordance with the United Nations Convention on the Law of the Sea.

The Cook Islands has no such legislation today. The deep-sea mining project is regarded as a 'national project'. This was emphasised several times when representatives of the Norwegian Deep Seabed Mining Group met with politicians from both government and opposition in November/December 2000 in Rarotonga. Cook Islands has a stable national legal regime, which of course will be very important for potential investors in the project.

Several companies from the United States, Japan, Germany, France and China have expressed interest in establishing deep-sea mining co-operation with the Cook Islands. The Cook Islands has a history of being exploited by foreign interests, and the Government of the Cook Islands therefore prefers to co-operate with Norway. They feel that the Norwegian Deep Seabed Mining Group will develop the project in the best possible way, and also hope that Norwegian authorities may assist them in formulating regulations and building of institutions that:

1) May ensure that the people of the Cook Islands get a fair share of the revenues from the project
2) Protect the environment

The management of the Norwegian petroleum resources is regarded as a possible model that could be a starting point for developing regulations for the Cook Islands. The project group has submitted an application to the Norwegian authorities (see Appendix 4)

There are no local lawyers on the Cook Islands today. There is one lawyer from the US and one from New Zealand working on the islands. The country is thus totally dependent on foreign assistance.

6.5 Advantages/disadvantages for Norwegian companies

There are, undoubtedly, only positive attitudes in the Cook Islands towards co-operation with Norway in deep seabed mining. The Cook Islands Government wants the Norwegian Deep Seabed Mining Group to develop the project industrially – provided that the Group considers the project commercially viable. Social, economical and historical matters explain this confidence in Norway. Cook Islands Consul General in Norway, Hallbjørn Hareide, is a key factor in this respect. He has systematically informed the Government of the Cook Islands about, for instance, how Norway is managing its petroleum resources.

The Government of the Cook Islands is extremely sceptical to establishing co-operation with other foreign companies. The country feels that it has been exploited by foreign companies within both fisheries and tourism, and is reluctant to enter into new projects where foreign companies keep the revenues, while the Cook Islands are left with nothing – or even debt.

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7 MAPPING AND SURVEYING

This chapter will present the current status of mapping and surveying technology and the way forward to develop the technology and operational level needed for a deep-sea mining project in the Cook Islands. A description of the anticipated costs is also included.

7.1 Selection of survey areas

Within the archipelago of the Cook Islands, between 7°S and the Tropic of Capricorn, and between 155 and 175°W, the exclusive economic zone covers an area of 2.5 million km^2. Assessments performed by various research institutions and exploration expeditions have concluded that the most abundant and cobalt-rich nodules are available in an area of 650,000 km^2. In order to limit the overall exploration costs we intend to limit the total survey work to 200,000 km^2 with a focus on areas where available information indicate high concentration of nodules.

The highest concentrations of nodules have to date been located in the Aitutaki Passage and in the area where the Passage enters the South Penrhyn Basin (see Figure 7.1). The Aitutaki Passage, leading northeast, is situated between 18 and 10°S. The area has the shape of an enormous deep-sea valley. The Passage or 'valley' is 1.300 km long and about 200-300 km wide. At 13°S the valley narrows to only 150 km. The Aitutaki Passage plays an important role for ocean currents in the southwestern part of the Pacific. The so-called Antarctic Bottom Water current, which consists of cold and mineral rich water, flows through the Passage. The speed of the current increases as it flows through the narrow part. The result is that the mineral rich water from Antarctica is spread like a fan into the South Penrhyn Basin.

In the Aitutaki Passage and in the area where the Passage enters the South Penrhyn Basin, the average nodule density is 20 kg/m^2. In some areas the density is between 80 and 150 kg/m^2. This exceptionally high density is found in the area 15-16°S and 159 and 160°W. The cobalt content in these deposits has a maximum value of 0,8%. In the Aitutaki Passage and in the area where the passage enters the South Penrhyn Basin the average cobalt content is 0,45%.

The Metal Mining Agency of Japan has recently started a new survey of the exclusive economic zones of the Cook Islands and some of its neighbouring countries. This survey will last for three years. Since the seabed conditions in parts of the southern Pacific are similar to those outside the Cook Islands, it is possible that new deposits characterised by high cobalt content and high nodule densities can be found.

However, until new information is available, the Aitutaki area will be given special attention in order to verify the public domain information. We intend to start both the large-scale mapping and the detailed mapping programme here.

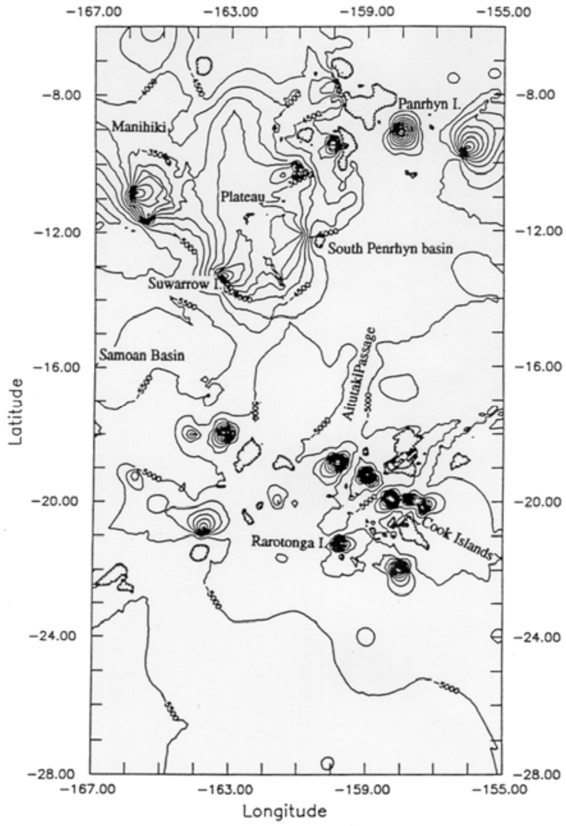


Figure 7.1. Potential mining areas in the Cook Islands

7.2 Large scale mapping

From a planning point of view, the best mining areas are poorly explored in spite of available data from the area. To have a realistic background for evaluating the nodule resources, large-scale mapping must be performed to find the areas with the best potential for mining activity, based on topography and location. Exploration reserves can then be estimated based on the size of the areas that fulfil the criteria for production, and the assumed nodule density. Large-scale mapping will be a multidisciplinary task that will be conducted prior to mining.

It is our proposal to carry out the large-scale mapping using one vessel with geophysical instrumentation.

Having an average water depth of 5,000 m in the survey area and given favourable field work operational conditions, it will be possible to cover an area of 3,500 km^2 per day using surface operated equipment. Theoretically it will be possible to complete the geophysical part of the large scale mapping in 60 days not including mobilisation, demobilisation and transit times, crew changes, weather down time and unforeseen technical challenges. Reality may, however, show that a time window in the order of 120 days is a more realistic figure, including all the marine operation elements. As a comparison, it is expected that we can achieve a maximum daily coverage of 25 km^2 during the detailed mapping phase.

When the large-scale mapping data have been converted to maps, the geophysical vessel can start the detailed mapping work, while a sampling vessel will start the regional bottom-sampling programme. The programme will be based on the results from the large-scale mapping. Favourable areas with expected high concentrations of nodules combined with suitable bottom elevation and topography for the harvester will be selected. A supplementary sampling programme will provide valuable additional information for understanding the collected geophysical data. These data together with laboratory analysis of the collected bottom samples and the geotechnical parameters that are found, will be major contributing elements for understanding the geology and estimating the resources. The objective is to focus on areas that can represent 10 to 15 possibly 25 years of nodule harvesting.

At a certain stage in the sampling programme, an ROV unit will be included as a part of the on-board instrumentation. It must also be stressed that the bottom sampling will not be done only to support the geophysical interpretation; representative quantities of nodules must also be recovered for metallurgical testing and analysis.

The large-scale mapping programme shall also include an oceanographic research programme to reveal the present status and long term fluctuations. This programme will be carried out from the sampling vessel.

7.3 Detailed mapping

Based on the large scale mapping results, favourable areas for mining will be selected for detailed mapping. These will be selected based on a detailed desk study of all available survey information of the areas of interest. Available general information will reveal area limitations in view of bottom elevation, outcrops and anticipated nodule distribution.

We propose to base the detailed mapping on a type of "free floating" system (AUV). ROVs can be used for sampling and point investigations, but will be too slow for area surveying. The “free floating” systems ought to be deployed a few meters (<50 m) above the seafloor. Given proper technology development it should be possible to have a daily data coverage of 25 km^2.

The aim of our production is to collect a quantity of 125 tons of wet nodules every hour. If the nodule concentration in the area is 50 kg/m^2, the harvester must cover an area of 5,000 m^2 to reach this goal, given that 50% of the available nodules are left behind to allow re-population. Given ideal working conditions of optimal harvesting patterns, and if basing the harvesting on a 300 day around the clock operation cycle, the annual harvested area will cover 36 km^2. If the nodule concentration is 25 kg/m^2, the annual harvest area will be 72 km^2.

In theory such areas can be fully covered by detailed geophysical mapping in 4 - 5 days when found, but the detailed bottom sampling, geotechnical testing and visual inspection will take much longer time. The detailed mapping shall provide bathymetry maps with one-meter contour lines, high-resolution images that identify seabed irregularities and maps showing nodule abundance.

In reality we will face a somewhat different situation, uneven nodule concentration, rock outcrops and sloping elevations will be major drawbacks, and due to these it may be necessary to relocate the survey work. In the southern basin the nodule density is assumed to be high, and the nodules covering the seafloor occur most often in areas of gently undulating relief, and usually they rest on red clay. In order to find suitable mining areas for 10 - 15 years of production, the minimum area for detailed mapping may prove to be more than 10 times the size of the predicted area.

The predicted area is 540 km^2 and may only require 23 days of on-site geophysical mapping. This may very well not be the true situation. The nodule density will vary, and in cases of varying density we have to cover 2,000 km^2 to fulfil our requirements, and the detailed mapping programme will increase to 80 days.

In addition to geophysical mapping there will be detailed bottom sampling and geotechnical programs consisting of an oceanographic programme and a biological programme. In order to find the areas that will fulfil commercial requirements for nodule harvesting, the sampling programme will have a rather high density of sampling points.

7.3.1 Selection of sites for data verification, pilot testing and test harvesting

A part of the large scale mapping work will also have to focus on finding suitable sites for equipment testing. Present deep-water mapping and survey equipment has not been designed to produce high-resolution data. As a result we need to test the equipment and analyse the reflected signals, i.e. recognisable signatures of reflected signals for geophysical data correlation. This will become a data interpretation tool. We will try to locate shallow nodule covered areas for this purpose. Seamounts may be an opportunity. Such sites with a preferred water depth between 2,500 and 3,000 meters may furthermore serve the purpose for deep-water pilot testing of the lifting system and the harvester.

If seamounts can be found, the flat summit will be a good site for testing. Previous surveys in the Pacific region have shown that nodules distributed on the summits are typically very rich, in places reaching a population density of up to 50 kg/m^2. On the seamount slopes and near their foots and top margins, the shape, size, population density and chemical composition are changing. Nodules previously found on seamount summits have been rich in cobalt (0.4 - 0.5%) and poor in nickel. The cobalt content is decreasing towards the base of the slope while the nickel concentration increases. We may also find that ferromanganese crusts occur at the surface of deep seamounts and covering rocky outcrops and reaching a thickness of up to 10 cm.

7.3.2 New areas

When the areas for detailed mapping have been sufficiently covered, new areas for detailed mapping may be selected for verification as possible future mine sites. Based on new geologic information resulting from the detailed mapping of the Aitutaki Passage and the South Penrhyn Basin, it will be easier to define new areas for detailed mapping. At present we cannot say if this phase will commence or not. It will depend on the progress of the mining project. If this phase will be initiated, the planning and execution of the new area survey will very much follow the previous operations, but with certain corrections and modifications based on the experience that has been gained.

7.4 State of the art; mapping and surveying

The mapping part of a deep-sea mining project can be divided into three main phases:

1. To get an overview of potential mining sites
2. To do detailed mapping/surveying for production area location
3. To do post-survey to document the state of the seabed after production

We will refer to these phases in the subsections of this chapter since the requirements will differ from one phase to another.

7.4.1 Geophysical equipment

There are two types of equipment that will be of interest, Multi-Beam Echo Sounder (MBE) and side-scan sonar (SSS). As an aid in interpretation of the data a sub-bottom profiler (SBP) should be run. Even if the instruments are the main challenge it should be mentioned that the survey vessel itself is also of main interest.

7.4.2 The survey vessel

There are many survey vessels that are equipped with the instruments needed for the overview surveying. One of the main features for vessels operating around the Cook Islands is the "endurance", or how long can they operate before they have to return to port for fuel or provisions. Normally, vessels stay at sea for 4 weeks, but in view of our operation, longer endurance (45-60 days) is preferred. Basic figures for a typical vessel will be an overall length of 85 meter, a beam of 15 meter, a draught of 5 meter and a tonnage of 3,500. The vessel should be able to accommodate 45 persons. The other aspect is the working environment onboard, especially considering the temperatures in the area. The vessel ought to have a suitable air-conditioning system. These factors will be important when choosing the survey vessel.

Figure 7.2. Multi-purpose vessel type

For the detailed surveying, ROV and geotechnical investigations, the survey program should define if it is most economical to operate from one vessel, which can do all of these operations, or from several specialised vessels. The multipurpose vessels are expensive per day, but the mobilisation cost at Cook Islands will be high. The combination of ROV and geotechnical work will probably be most efficient. AUV surveying and environmental/meteorological surveying will be less expensive with a normal survey vessel.

7.4.3 The overview surveying

The technology needed for the mapping/surveying is covered by today's technology. The only uncertainty is the operational requirements. The overview survey must be done with a MBE with a frequency that is suited for the expected depths. As a rule, 100kHz MBE reach to 1000m, 30kHz reach 4000m and for full ocean depths, 12kHz MBE should be used. Since the depths at Cook Islands are down to 6000 meters, a 12kHz system will be best suited for this depth range. Features with a diameter of

100 meters is the smallest target that can be seen on this distance, and the depth accuracy, which will be around 10-12 meters, is the best that can be achieved. In addition the terrain modelling will smooth the data somewhat so that “details” of this size might be difficult to detect. A realistic size of objects and terrain features on the seafloor that can be seen on the maps from these surveys will therefore have a diameter of 250 meters and a height of 20 meters. This is good enough to select areas with good potential for mining, but not for deciding if the area is suitable for the mining operation.

During this phase, a SSS will give additional information about the seabed. This information will be vital when selecting the best areas for detailed surveying. A SSS should thus be towed behind the vessel during the MBE survey, at a height above the seafloor which gives the same coverage (or somewhat more) than the MBE. The frequency of the SSS must be selected according to the ranges it shall operate on.

For the sake of better interpretation, a hull mounted SBP should be run. This will help the geologists to say something about the sediments of the seafloor, and together with seabed samples identify regions of different sediments.

7.4.4 The detailed surveying

When doing detailed surveying a technology development is probably needed. The detailed mapping must reveal local obstacles for the harvesting systems and prove that there are nodules on the seafloor. These detailed investigations will not be possible from the surface 5,000 meters above the seafloor. The only way to get good enough data is to operate the instruments closer to the seafloor.

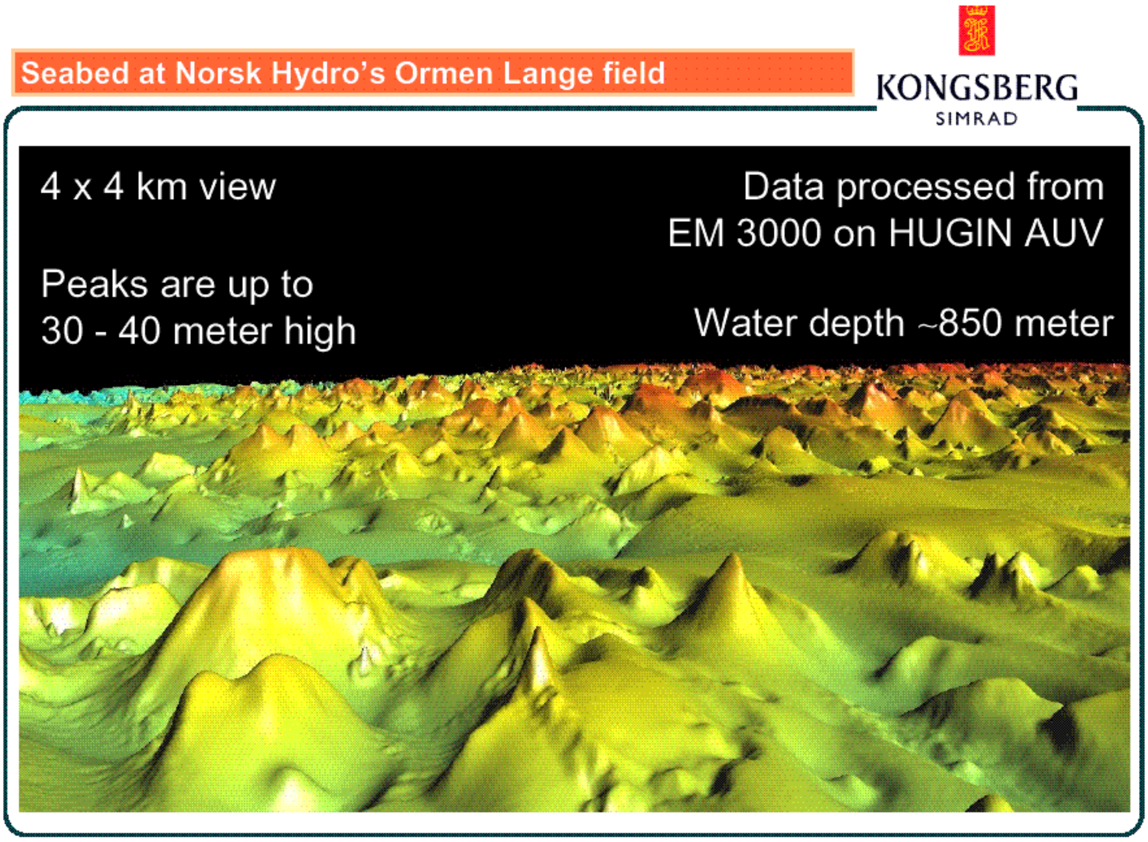


Figure 7.3. AUV data example

The instruments to be used are MBE and SSS. A SBP should also be run - if possible. There are two methods today that can be utilised:

A. The oldest one is to tow the sensors deep in the ocean, behind a survey vessel. This is the least expensive solution, but it involves positioning and steering problems and uncertainties. The survey speed also goes down (operation at 2-3 knots), resulting in long surveys. This method is well proven, but less accurate and quite time consuming.

B. The new method developing these days is the Autonomous Underwater Vehicle (AUV) or Untethered Underwater Vehicle (UUV). Such systems are launched from the survey vessel and operate by itself without any cable from the survey vessel. The AUV can be controlled from the survey vessel through acoustic communication but operates mainly autonomous. An AUV can carry the MBE and SSS equipment and maybe a SBP as well. The speed of the AUV is close to 5-8 knots. An AUV will be a very efficient tool. Turning times on line shifts is almost not existing compared to turns with a deep towed system, which has a long cable and low speed.

The AUV will probably be the best instrument in the coming years. Kongsberg Simrad has developed the HUGIN AUV and this unit is in commercial use already. Several other companies are close to launching their AUV solutions as well, for example the Fugro/Boeing AUV that will be available in 2001. The AUV instrumentation consists of standard units, but they will have to be improved to be operational in the depths down to 6,000 meters. Today the HUGIN AUV is rated at 3,000 meters, which is the deepest available.

Whatever method or system will be used for the detailed survey, it will have to carry a short range MBE (typically 300-500 kHz), and a high resolution SSS. A SBP is also preferred.

Figure 7.4. The Hugin AUV

7.4.5 Bottom sampling devices

The following equipment is relevant for geotechnical investigations in connection with the proposed deep-sea mining project:

7.4.5.1 Gravity core

This is the simplest equipment for taking samples of the seafloor. A cylinder is dropped into the sea and propagates by its own weight down to the seafloor where it penetrates the upper part of the seafloor due to its own gravity force. The cylinder with its content is then lifted onboard and analysed by geologists and geotechnical personnel. On depths like those around Cook Islands this technique is questionable, and probably not feasible at all. This option should therefore not be considered.

7.4.5.2 Grab samples

This is another simple method to gain information about the seabed. A grab is lowered from the vessel and takes a “bite” of the seafloor before being lifted to the vessel and the samples stored and analysed. This is also a method that would be difficult to use on these depths. The option is probably not realistic and should not be considered. An alternative is to use a free falling grab with underwater camera.

7.4.5.3 CPT

This technique is more sophisticated and requires a larger instrument (the Cone Penetration Testing) to be lowered to the seafloor and operated remotely from the vessel. There are several different types that can be used. This requires a dynamically positioned (DP) vessel. The sample of the seafloor is drilled by the CPT, and the requirements of the investigation will define the drilling depth and thus the instrument to be used.

Figure 7.5. Deepwater Seacraft seabed testing system

Figure 7.6. HPC Vibrocore seabed sampling.

7.4.5.4 GAMBAS refraction seismic

This is a Fugro developed instrument that can be used to investigate the conditions of the seafloor. A sledge with a seismic source is dragged along the seafloor, and the seismic reflections are collected by geophones/hydrophones in a cable behind the sledge. The data are recorded by the survey vessel and processed to find the detailed structure of the seabed. The depth rating of GAMBAS is not good enough yet, and a development is needed for this instrument to be used in a deep-sea mining project.

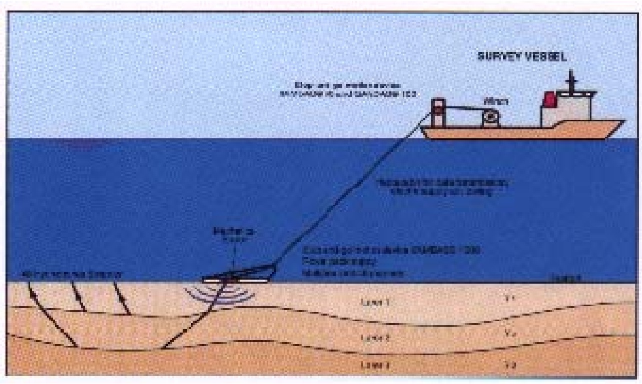


Figure 7.7. The GAMBAS principle

7.4.6 Geotechnical methods

In addition to the simple seabed samples, Fugro has developed the SEAROBIN, a 2 meter Cone Penetrometer Test (CPT) seabed system, to provide quantitative measurements of sediment type, stratification, density, and shear strength to 2,000m water depth. A depth extension must be provided to use this instrument at the depths around the Cook Islands.

Laboratory testing of soil and rock is an essential element of geotechnical analysis and foundation engineering. Two of the most important tasks for a geotechnical engineer are the development of a laboratory-testing program appropriate for the specific project and analysis of the results.

Figure 7.8. Soil sample testing

CPTs are performed at intervals, which vary with the nature of the seabed as revealed by the geophysical methods and in particular the GAMBAS® refraction technique. In areas where the stratification and soil properties are uniform CPT spacing can be increased to several kilometres. However where the soil conditions vary considerably over short distances CPT spacing should be closed up to identify the various soil properties. In addition to the 2m CPT, the SEAROBIN takes a 1m long push sample. Other types of sampling equipment available for seabed testing include a High Performance Vibrocorer and Piston Corers.

The SEAROBIN system and other geotechnical equipment can be operated from the geophysical survey vessel, or for accelerated data acquisition run in parallel from a second ship trailing the main survey spread. The geotechnical data is processed onboard and constantly reviewed with the geophysical data. This allows for total integration of data onboard the vessels so that the nature of the seabed can be revealed.

An example of processed and integrated data analysis is shown in Figure 7.9.

In order to place large and heavy constructions and robots on the seafloor, thorough investigations of the seabed must be done to make sure that the objects placed there will not fall over or sink into the mud. A full geotechnical program with deep samples and even drilling to take out real representative samples for analyses must be done. When the weight and other parameters are known for the collector and seabed installations a more precise description of the needed geotechnical program can be given. However, such a program will probably be comparable to programs in the oil and gas industry.

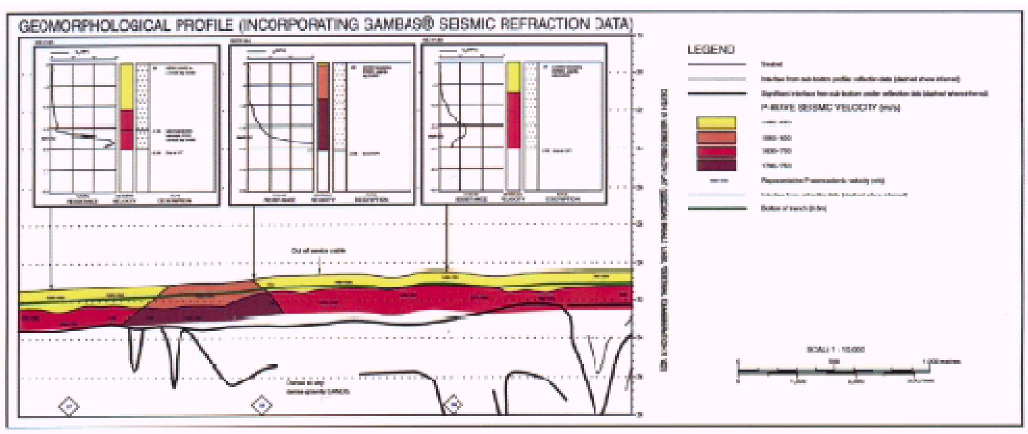


Figure 7.9. Geomorphological profile

7.4.7 Underwater photography and video

ROV (remotely operated vehicle) can be used for underwater photography, video recording, sampling and CPT measurements.

The ROV is operated from a surface vessel by means of an umbilical providing power to the thrusters (hydraulic or electric) and fiber-optic signals to and from various equipment fitted to the ROV, e.g. video-cameras, manipulators, sample box, search-lights, sonars, depth sensor, transponders for positioning etc. A multi-sample, frame-mounted CPT equipment is currently being developed.

ROV operation in water depths of 5-6,000m requires specialised equipment like the Jason II ROV vehicle. This ROV is rated to more than 6,000m.

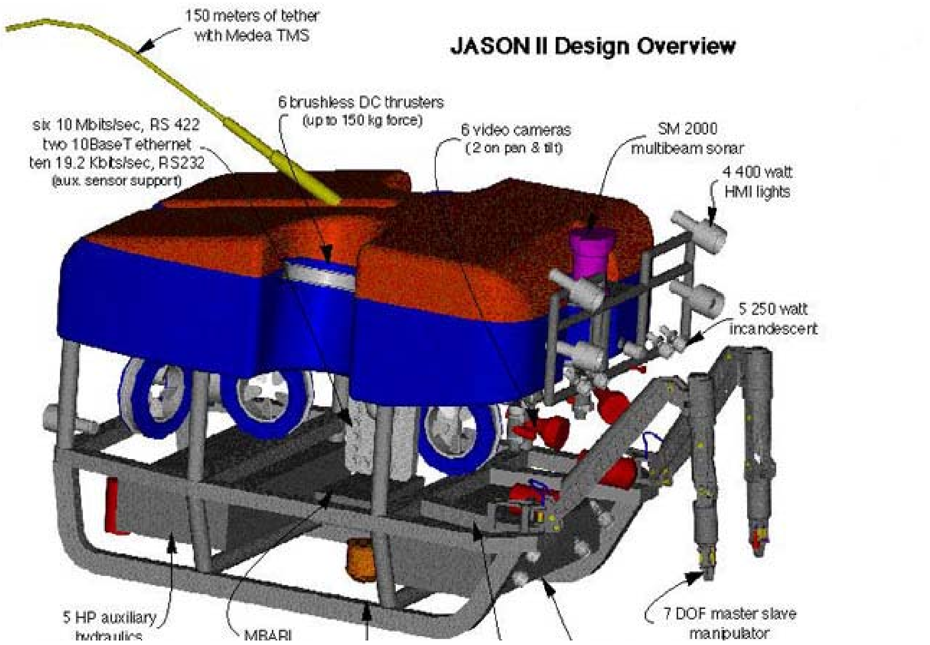


Figure 7.10. Deep sea ROV

Characteristic	Jason	Jason II
Mass (kg)	1,800	3,000
Depth Rating (meters)	6,000	6,500
Size (l x h x w, meters)	2.2 x 1.5 x 1.3	2.7 x 2 x 1.5
Power (kW)	9	16
Thrusters	5 @ .75kW 2 @ .25kW	6 @ 3.7kW
Speeds (forward) (vertical)	.75 knots 20 meters/min	1.5 knots 30 meters/min
Science Payload (kg, in water)	50	150
Dynamic Lift (kg)	40	170

Manipulators	One 6 DOF electric 15kg at 1M (rate control)	One 7 DOF hydraulic 55kg at 1.3M (master/slave) One 6 DOF hydraulic 45kg at 1.7m (rate control)

Lighting (Watts)	800 HMI 1,000 Quartz	1,200 HMI 1,250 Quartz
Hydraulic Power (l/min @ Bar)	2 @ 172	13.25 @ 207
Sample Storage Volume (M^3)	.05	.35
Tether Management	N/A	

7.4.8 Oceanographic data collection

An understanding of oceanographic and meteorological (metocean) conditions is essential for the design, construction, operational safety and efficiency of all coastal and offshore engineering projects. Information on the prevailing metocean regime is essential both for planning and for day-to-day operations offshore.

Deep-sea mining activities are likely to be confined to the abyssal plain. Here, the principal metocean conditions of concern are:

- Surface wind and wave conditions, which affect vessel motions
- Current conditions, which affect the riser system and associated operations

In the open ocean, measured wind and wave data are unlikely to be available. Therefore, reliance must be placed on information from satellite sensors and numerical models. These can be analysed to provide statistics for operational planning in advance of operations. In addition, meteorological and wave forecasting services would be needed during operations.

Currents in the deep ocean are largely confined to the uppermost 200 meters, above the permanent thermocline. Here, currents are a result of large-scale circulation and wind-induced surface current rather than tidal forcing. Below the permanent thermocline, the flow is very weak, <10cm per second, resulting from the slow drift of water masses.

Again, current measurements are unlikely to be available, although some information from drifting buoy studies may be available. Some information regarding large-scale circulation would be available from satellite sensors, which may give an indication of the magnitude of the currents that could be expected.

Current measurements could be obtained during operations using a real-time data acquisition system and Acoustic Doppler Current Profiler (ADCP). The 38 kHz phased array ADCP is able to measure currents over a range of ~1,000 m at a resolution of ~10 m. Fugro GEOS has deployed these routinely to support deepwater-drilling operations.

Wave data could be obtained in real-time using either a wave radar equipped with a Seatex MRU motion compensation system or possibly using WAMOS, a system which derives directional wave measurements from a standard ships' X-band radar. However, the latter requires on-site calibration for best results, and is more appropriate for a permanent installation.

It is mainly the wind, wave and current information that will be of interest to this project. These parameters influence the surface based operations and the forces that the sub-surface equipment has to cope with. From experience, the bottom currents at depths like 4,000-6,000 meters are small, and should not cause any major problems. However, the currents in the water column are of more interest, and especially to the riser system and other connections that will exist throughout the water column. Profilers, including some that measure sound velocity and microturbulence, can be dropped from a ship to free-fall to the seafloor, adjust ballast, and return to the surface for retrieval.

Equipment that can be used to measure ocean currents exists (i.e. RCM 11 from Aanderaa Instruments) which are rated down to 6,000 meters. However, the instruments are based on the Doppler effect technique and have therefore limited range of operation. To get the whole profile, the instrument must be run through the water column or several instruments must be placed on different depths to cover the whole water column.

On the surface wave side, there are several instruments available.

7.4.9 Meteorological monitoring

A collaborative effort of scientists from several oceanographic institutions aims to provide accurate measurements of the sea surface. Sensors being designed or upgraded for use either on research vessels or buoys include systems that measure surface temperature, air temperature, wind speed and direction, barometric pressure, solar and long-wave radiation, humidity, and precipitation. From these measurements, accurate estimates of air-sea fluxes can be made. The sensor package includes the capability to telemeter some data on a regular basis via satellite to a central data facility.

Instrumentation is no technical challenge, but co-operation or purchase of data from research organisations seems to be a better approach.

7.4.10 Environmental studies and fauna inventory

Current-measurements are also needed to get an idea of the possible distribution of pollution or waste from the seafloor production. There are numerical models that can be used to get an estimate of such current based transport of particles.

Profilers dropped from ships can provide data from both descent and ascent. Ship-wire-deployed and free-drifting water sampling and incubation instruments can measure plant nutrient uptake, bacterial incorporation of dissolved organic, and plankton feeding rates. Specially designed water bottles enclose a sample, and then dispense chemical labels useful for a variety of measurements.

Satellite-based instruments useful to oceanographers studying ocean circulation also include altimeters, which register variations in sea level slope that indicate current flow, and infrared sensors that show currents, eddies, and other circulation features.

7.4.11 Remote sensing

Remote sensing is useful as a supplement for the environmental part of the surveying. The remote sensing methods can give valuable extra information to the study of currents and waves in the area. The remote sensing will become a valuable tool to do surveillance of the area during mining and after, to make sure that no surface pollution is generated from the activity.

With respect to the mapping of depths and geology, the remote sensing is without interest.

Another area where satellites are of interest to projects like this is when oceanographic instruments (drifting on the sea surface) transmit their data. The data are then picked up by the satellites and transmitted to the earth for data collection

7.5 Navigation and positioning

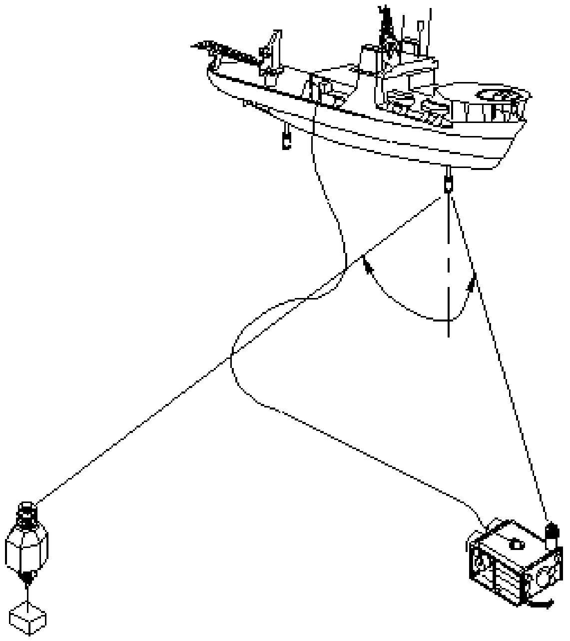
All aspects of the surveying are dependent on navigation and positioning. Different kind of techniques must be used on the various types of instruments and vehicles. This section describes the methods that will be of most interest to the project.

7.5.1 Survey vessel

The survey vessel should be fitted with traditional world-wide differential GPS (DGPS) systems like STARFIX-MN8 (Inmarsat) and STARFIX-SPOT (High power satellites). With these systems, dependent on the range to the reference stations, position accuracy better than 5 m can be achieved. The coverage of reference stations in the survey area is at the moment not too good, the closest stations at the moment are Honolulu (Hawaii) and Auckland (New Zealand) It is likely that investment in new reference stations close to the survey area is necessary to get the necessary accuracy. This applies to the detailed surveying requirements, but not to the overview type of surveying.

It is also expected that high precision GPS systems like STARFIX-HPS will be operational at the time the survey will start. STARFIX-HPS is a GPS based system with sub meter accuracy, which is under development at the moment. Depending on the progress in the development and the requirements related to range and placement of the reference stations relative to the survey area, it is likely that this system will be a feasible positioning source.

The survey vessel should also be fitted with acoustic positioning systems, for tracking of mobile units (ROV, AUV etc) and as a positioning source for the vessel. At the present Kongsberg Simrad has a low frequency (LF) Super Short Base Line (SSBL) system capable of operating at the depths in the survey area. The accuracy of the SSBL system is 1% of slant range (ca. 50m at depths of 5,000m).



SSBL - Super Short Base Line
Here the calculation of positioning is based on range, and on vertical and horizontal angle measurements, from a single multi element transducer. The system provides 3-dimensional transponder positions relative to the vessel.

Figure 7.11. Super (Ultra) Short Baseline Method (SSBL)

The acoustic positioning system should also be able to operate in Long Base Line (LBL) mode. Deployment and calibration of LBL arrays is a task the survey vessel should have the capability to do, at least when the large-scale survey is finished and the survey becomes a “high resolution” survey of smaller selected areas. In this stage a LBL array can be used for positioning the vessel. Kongsberg Simrad’s LBL multi-user system operates in a way that optimises the update rate, and should be suitable for operations in these depths. Kongsberg Simrad has transponders that can be deployed at the depths in the survey area.

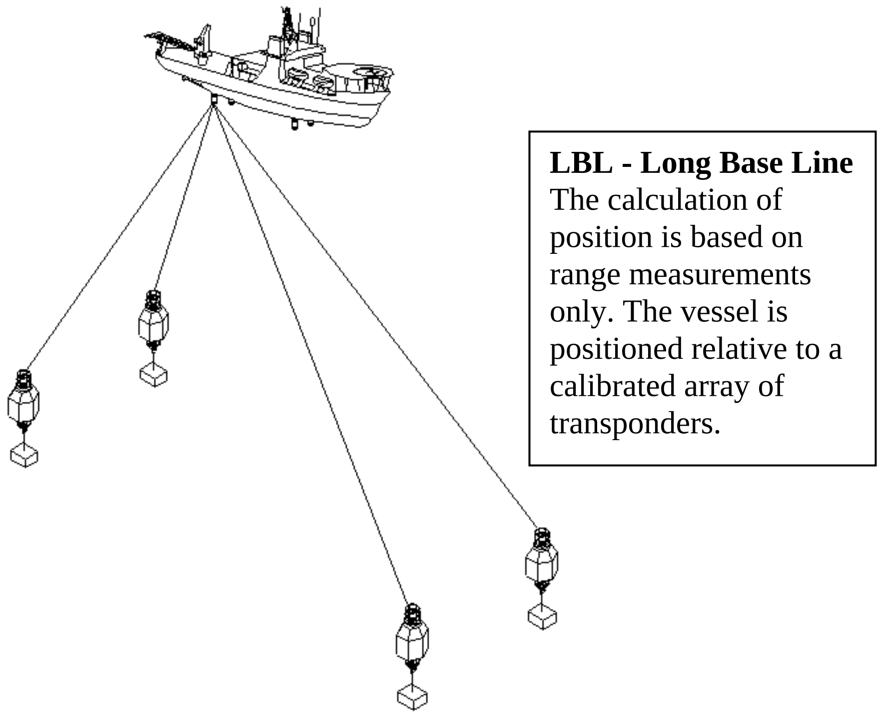


Figure 7.12. Long Baseline Method (LBL)

All of the above systems can also be utilised by the DP system that probably will be needed on a later stage in the project, both during test sampling and production.

7.5.2 Towed equipment

Towed equipment should be positioned with USBL systems. Kongsberg Simrad's LF USBL system has an accuracy of 1% of slant range and is capable of operating down to the depths in the survey area. Kongsberg Simrad also has the HiPAP system with better accuracy; this system is at the present not capable of the depths in the survey area.

Dependent on the range from the survey vessel to the towed equipment, a dedicated vessel for tracking of the towed equipment can be necessary.

7.5.3 Wireline equipment and remotely operated systems

Wireline equipment and remotely operated systems should be positioned with acoustic positioning systems. Dependent on the size of the area they are going to work in, USBL or LBL should be chosen. For areas smaller than approximately 25km^2 LBL can be used. A LBL array deployed can also be utilised for vessel and AUV positioning. LBL will typically give an accuracy of better than 0.5m relative position.

All remotely operated equipment should be designed with the possibility to let the acoustic positioning system transfer data through the umbilical and get power from the controlling unit. This is an area where development is needed to ensure utilisation of this option.

For positioning during test sampling and production, noise levels of the individual units can be a challenge. As far as possible, noise reduction of the units should be taken seriously during design of the units. Research and development on noise covering materials/baffles and special transducers for minimising the effect of the noise can be necessary.

During test sampling and production it is likely that the harvester will experience poor visibility. To improve operation conditions for the remotely operated systems and to minimise the dependency of cameras, 3D-visualisation software can be used. The Starfix Navigation Suite has a module, Starfix Hydrovista, which is a real-time 3D-visualisation software. The system can use digital terrain models (DTM) with data from the survey. Vessels, remotely operated systems and other objects can be created by means of standard CAD software. By connecting navigation sensor to the objects a virtual environment can be created.

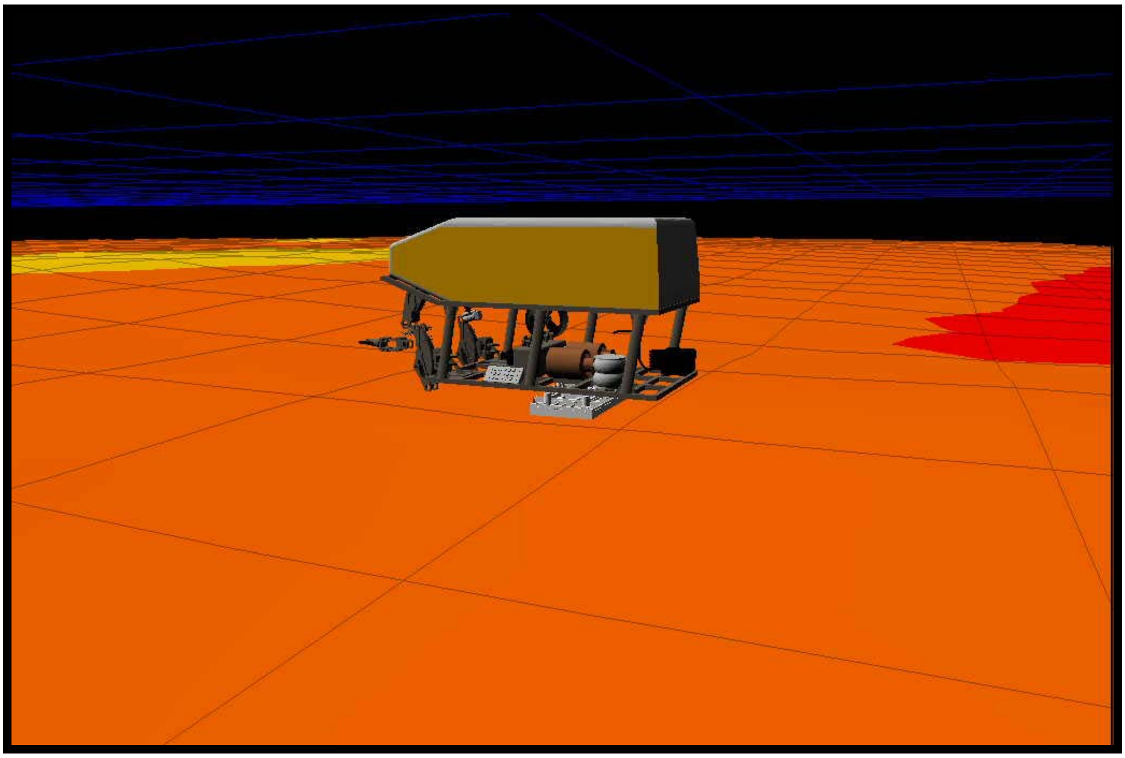


Figure 7.13. Starfix.Hydrovista 3D visualisation software

7.5.4 Free floating systems

AUVs should be positioned in the same way as the remotely operated systems. AUVs today are not capable of utilising a LBL array. The technology is known but has to be implemented into the AUV. Visualisation software like the Starfix.Hydrovista could be utilised with AUVs in the same way as for remotely operated systems.

For free floating equipment like oceanographic buoys, GPS or DGPS systems will be suitable. Depending on the requirement for sending real-time positioning data to the shore or survey vessel, positioning data has to be sent by a satellite or radio system, logging of position data should also be implemented.

7.5.5 Maintenance of underwater network during the mining phase

To maintain a LBL array during the mining period, a vessel with ROV capacity will be needed, both for replacing transponders that are defect or has spent their battery capacity, and for moving the array to cover the mining progress.

The LBL transponders should preferably be deployed to preinstalled stands. This will ease the replacement operations and ensure stable positions of the transponders.

7.6 Data base management, presentation and publication

A necessary prerequisite for any undersea resource exploration is a systematic approach to pre-survey planning, data base management, co-ordination with other available sources of data and a well founded policy for presentation and publication of results. The history of mineral mapping shows that many findings have been accidental discoveries, and not a result of systematic exploration.

7.6.1 Data reduction, storage and retrieval

The flow of collected input data of various types and origins for analysis and interpretation will be enormous during the entire project. There will be navigation and positioning data, various geophysical data, geotechnical and geological data, oceanographic and biological data, underwater video documentation and still photos. A management system for data reduction, storage and retrieval will be necessary to handle all these inputs. Furthermore a high degree of data format standardisation will be required.

The data flow does not relate to the exploration phase only, it continues during the mining phase.

7.6.2 Data processing, interpretation and reporting

The type of processing that is required will be different for the two phases of the surveying.

7.6.2.1 The overview survey processing

During the initial overview survey phase, MBE and SSS data will be the main data types to be processed. SBP data should also be used for the interpretation, but no processing will be needed. A first stage processing should take place onboard. Here, only predicted tide should be used to correct the depths. The rest of the MBE processing should be standard sound velocity profile (SVP) processing, spike filtering, some manual editing, digital terrain modelling (DTM), and contouring. The SSS data processing should include quality controls, and generation of coverage plots to check that the areas have been properly covered. In all of these processing tasks, positioning is vital, and position processing has to be included.

When the survey is finished, final processing should take place. Tide corrections based on measured values should be used for the MBE processing if necessary. The rest of the processing should be similar to the offshore processing. All data should be reprocessed to make the final maps. On the SSS side, mosaic work should be done to make SSS area maps.

The following will be the end products from a survey:

1. Vessel track plots
2. Towed equipment track plots
3. Contour maps
4. Shaded relief maps
5. Sonar mosaic maps
6. Seabed interpretation maps with seabed sample positions included

The geological interpretation is an important part of the final processing. Here all survey data should be included as well as external data from other sources. The maps will also be valuable for the Cook Islands authorities as a background for future exploration of the area. A relational data base system (RDBS) with a Geographic Information System (GIS) as the front end should be created as a part of the project, and in co-operation with the Cook Islands authorities. The results from the survey and processing should be loaded into this database, and the design and structure of the database should be agreed upon.

Based on the processed data and the interpretation, a report should then be made to summarise and conclude on the issue of selecting the pilot area for the Deep Sea Mining project. This will be the area where detailed surveying has to start. The report must be comprehensive and include all results from the survey. This will include oceanographic data and any operational experience as well.

7.6.2.2 The detailed survey processing

When the pilot area has been selected based on the overview survey report, requirements for the detailed survey must be decided upon. Requirements from the operational side of the nodule collector system must be evaluated, and proper survey methods and instruments to fulfil these requirements should be established. This may lead to a more or less comprehensive geotechnical program within the detailed survey part of the mapping project.

The detailed surveying processing will include all types of collected data to try to answer the uncertainties in connection with operation of the collector system. All AUV data will be processed as well as all the geotechnical data. Oceanographic data (with focus on current throughout the water column) will also be included. The processing can be done with today's methods. The ROV data should also be included in the study - both video and sample data.

MBE reflectivity data should also be collected by the AUV. MBE reflectivity maps should then be generated and used for interpretation and comparison with the SSS data. The reflectivity data from the MBE can also be used for seabed classification. This is an attempt to describe the material of the seafloor based on the reflectivity strength and variation in the MBE backscatter data. Kongsberg Simrad has a software application (Triton) which can do this today. The technique is immature, but will rapidly improve. There are also other systems on the market, but they are only single beam based, and will not give the necessary area coverage, which is important for classifying nodules on the seafloor. Classification maps should be generated and used together with the other data during the interpretation and reporting phase. If successful, the MBE reflectivity processing can be a vital part in the detection of the nodules, and in post-surveys to map the remaining nodules after harvesting. This phase of the survey and processing should open up for some R&D to exploit the classification option, since the later surveying and processing will benefit much from a reliable system based on classification.

A report of the survey must be generated to summarise the experience and the results. This report must include operational issues as well as the geological interpretation and maps.

The GIS must be updated with the new information, and more detailed maps must be generated. The type of presentations should at this stage be extended to 3D presentations and 3D flythrough videos. Video from the ROV and other image data should be part of the GIS and should be part of the digital version of the report. This digital version should consist of CD-ROMs and/or DVD laser disks.

7.6.3 Presentation and publication

Systematic user-friendly presentation of the collected data is important. The preparation and presentation of reports and maps shall not be aimed for the project participants only; the presentation must also be aimed towards the scientific community. In addition to papers and articles published by the project, the project must allow the international oceanographic and geological research society access to certain data, to promote publication of scientific papers. It will be important to create goodwill for the project and to have international approval of project results.

7.7 Identification of development challenges

Again the two different surveying phases have different challenges.

7.7.1 The overview survey

No major development challenges are identified for this phase. The main challenge is related to the operation of the vessels (bunkering distance, harbours etc). However, some oceanographic instrumentation may need some development dependent on the depths they are going to be used in.

7.7.2 The detailed survey phase

Here several challenges have been identified. These are mainly connected to the depth that the instruments are going to be operated in, but also to the processing of some of the data. The following main challenges have been identified:

7.7.2.1 Depth rating

For the AUV itself and most of the instruments onboard (not the SSS) the depths will become a problem. However, AUVs today operate to 3,000 meters depths (HUGIN from Kongsberg Simrad) and programs are in place to develop them for even deeper waters. The challenge for the AUV is not only the depth rating itself, but also indirect problems such as battery endurance, acoustic communication and navigation/positioning.

The SBP needs a lot of electrical power and the operation of this tool at these depths will influence the time the AUV can be submerged.

The GAMBAS refraction seismic tool must also be developed for deeper waters to be part of the proposed project. The importance of this instrument is depending on the requirements from the collector and production units that will have to operate on the seafloor. This is an evaluation for the next phase of the project.

For the other instruments the pressure at these depths is the main challenge.

7.7.2.2 Positioning

The needed precision for the detailed survey implies use of Long Baseline Systems (LBS). Pre-studies should be carried out to configure the optimal network of transponders on the seafloor to give the needed accuracy and range. The AUV will be able to operate by itself using an Inertial Navigation System (INS), but needs to update and correct its position after some time. A system or method development is needed, but is likely to be solved within reasonable time. The pressure should not be a problem for the transponders. Positioning the LBS network on the seafloor in absolute co-ordinates is not too important since it is the relative accuracy at the seafloor that matters the most. Positioning of surface vessels represents no major problems.

7.7.2.3 Seabed classification

This is an important development task to make the mining production efficient. The software today is immature and needs testing and verification. There is a MBE based system today that can be developed further. The challenges in this area is connected to the methods itself, the reliability of the results and the calibration of the system. The project should include some testing of this software to see if it is able to classify nodule resources. These tests could take place during the overview survey phase or earlier.

7.7.2.4 GIS development

There exists no dedicated system to take care of the data that will be produced in this project, and a design and implementation of a proper GIS system with potential for the future must be developed. The system should be developed in co-operation with the Cook Islands authorities to ensure good integration towards the national systems.

7.7.3 Technology gaps

Based on the list of development challenges above the following technology gaps have been identified:

1. AUV and payload depth rating
2. Seabed classification of nodules

The other issues are more related to normal development where the path forward is known, but a development job has to be done.

7.7.4 Performance limitations

All of the performance limitations on the surveying side are related to the detailed surveying phase and vessel operations in general. There is uncertainty related to the AUV performance in the depth range 3,000 to 6,000 meters. This must be accounted for in the preparations and test phase of the project.

If the seabed classification systems do not give the needed reliability and resolution the need for more ROV and geotechnical work can arise. This will increase the cost of the survey considerably. It might also be necessary to start R&D projects to find alternative solutions if the seabed classification option does not succeed.

The required navigation accuracy might necessitate a more dense and high frequency network, which may even need to be moved from one place to another. This will affect the overall survey cost, and slow down the operations.

7.7.5 Research and development

Based on the above, the following research projects have been identified:

7.7.5.1 AUV and payload depth rating

This is mainly a manufacturer's problem, but the project should be involved in the development to make sure that the mining project's requirements are included. It will probably be necessary to provide financial contributions to such projects.

7.7.5.2 Seabed classification

This is a project where the group needs to be in a steering position. It is vital for the cost and efficiency that this option of combined instrumentation, calibration, processing method, software development and map production can be developed to a reliable state. Active testing on actual nodules must be carried out.

7.7.6 Local infrastructure development

During the initial stages of the exploration and during the mining operation, all vessel operations must be self-supplied with all services. However, certain support functions and services must gradually be established in the Cook Islands. Local infrastructure must be developed due to safety reasons and due to cost reductions by simplifying the marine operations. By transferring certain tasks from the vessels to an onshore operations centre, the vessels can be more cost effective. Infrastructure development will be beneficial for the Cook Islands. The development must be kept under strict control and supervision, and the establishment of service functions must be co-ordinated with the islands' authorities in order to avoid a domestic boom of expectations.

7.7.7 Training of personnel and technology transfer

If and when the project will materialise, the project must accommodate training of personnel from the Cook Islands and allow certain technology transfer. The training sequence must be aimed for inclusion at all stages of the project and in accordance with a plan agreed to with the authorities. The training will include scientists, technical personnel and skilled labour.

7.7.8 Competitors and counterparts

The entire exploration part of the project is huge and comprises a multitude of marine operational tasks. Today we can not identify competitors or counterparts that have all necessary in-house facilities or capabilities for total project implementation. Today we can only solve the tasks through international subcontracting and co-operation.

7.8 Mapping and surveying analysis including cost estimate

The estimates are based on an overview survey area of 200,000 km^2 (somewhat less than 1/3 of the assumed actual area in the Cook Islands) and a detailed survey of 2,500 km^2 at mean depths of 5,000 m. Estimated costs for the different tasks of the survey project are presented in the following sections.

7.8.1 The overview survey

Survey vessel assumptions:

1. Survey area:	200,000 km^2
2. Mean depth:	5,000 m
3. Mean production pr day:	3,500 km^2
4. Estimated production days:	60 days
5. Estimated weather and crew change	15 days
6. Oceanographic measurements	25 days

Budget cost of around NOK 20-25 million.

7.8.2 The detailed survey

The survey vessel and AUV assumptions:

1. Survey area:	2,500 km^2
2. Mean swath:	200 m
3. Mean production pr. day:	25 km^2
4. Estimated production days:	100 days
5. Estimated weather and crew change:	30 days
6. Oceanographic measurements	10 days

Budget cost of around NOK 40-45 million.

In addition must ROV and CPT work with an estimate of NOK 15 million be included in a typical investigation. Such surveys require special survey vessels and equipment, and a program of 30 days is suggested.

7.8.3 Economic consequences

The economic part is split into a survey cost part and a development part:

7.8.3.1 Survey cost

The costs are based on an overview survey of 200,000 km^2 and a detailed survey of 2,500 km^2 as explained above. To be able to perform deep-sea mining, the operators have to know the topography in detail. As in the oil and gas business, no exploration can take place before all geophysical investigations have been done. Operations of expensive equipment in an unknown terrain will be hazardous, and cannot be excepted.

In addition to the pre-survey cost, post-survey activities to monitor the resource utilisation and the environment should also be included. The total survey cost based on the proposed survey activity will be as follows:

Overview survey (200,000 km^2)	NOK	25 million
Detailed survey (2,500 km^2)	NOK	45 million
Geotechnical survey (ROV + CPT)	NOK	15 million
Post-survey (detailed)	NOK	15 million
Total survey cost	NOK	100 million

The survey can either be completed prior to the mining or alternatively split over several years. The post-survey activity must be incorporated later if so required. Below are two alternative models for the cost over the 5 first years:

ALTERNATIVE A:

This alternative is based on a full survey of 200.000km^2 the year before start of production. With the assumption that a detailed survey of 2.500 km^2 will be enough to secure production for 5 years the cost will be related to the first year (the year before start of production), and no cost for the following 4 years:

SURVEY TYPE	COST
Overview survey (200.000 km^2)	NOK 25.000.000
Detailed survey (2.500 km^2)	NOK 45.000.000
Geotechnical survey	NOK 15.000.000
Total	**NOK 85.000.000**

For the first 5 years (year 0 being the first year of production) the project will have the following surveying cost (in NOK):

Year –1	Year 0	Year +1	Year +2	Year +3	SUM
85.000.000	*0*	*0*	*0*	*0*	*85.000.000*

ALTERNATIVE B:

This alternative is also based on a full survey of 200.000km^2 the year before start of production, but with the assumption of an annual detailed survey of 500 km^2. The assumption is that detailed surveys of 500km^2 will be enough to secure production each year. The following cost is expected over the 5-year period:

SURVEY TYPE (Year –1)	COST
Overview survey (200.000 km^2)	NOK 25.000.000
Detailed survey (2.500 km^2)	NOK 12.000.000
Geotechnical survey	NOK 6.000.000
Total	**NOK 43.000.000**

SURVEY TYPE (Year 0 to +3)	COST
Detailed survey (2.500 km^2)	NOK 11.000.000
Geotechnical survey	NOK 5.000.000
Total	**NOK 16.000.000**

For the first 5 years (year 0 being the first year of production) the project will have the following surveying cost (in NOK):

Year –1	Year 0	Year +1	Year +2	Year +3	SUM
43.000.000	*16.000.000*	*16.000.000*	*16.000.000*	*16.000.000*	*107.000.000*

The main reason for the total cost being higher is the mobilisation/demobilisation cost for bringing in two expensive survey vessels to a remote location like Cook Islands. Instead of having all mobilisation/demobilisation costs related to the first year, this will now apply for all 5 years.

The recommendation is to go for alternative B to save cost at start-up and to get experience about the need for further surveying. The production speed and available harvesting areas within the surveyed region will indicate when new surveys in addition to alternative B will be needed.

7.8.3.2 Development cost

The main development tasks and their associated costs are given in the table below. To what extent all the development will be needed is dependent on the project requirements. The expected development costs are listed below:

DEVELOPMENT	COST
AUV depth rating	NOK 5.000.000
Seabed classification software + testing	NOK 5.000.000

7.8.4 Proposed survey and mapping plan

As of today the project aims for detailed mapping in the Aitutaki Passage and the South Penrhyn Basin. Available information in the public domain reveals that a great abundance of nodules can be expected. So far exploratory expeditions have concluded that in certain places there is a 90% nodule coverage of the seafloor and that it contains up to 50 kg/m^2. In this respect it must be stressed that the presented figures are based on regional, random spot sampling, not on continuous surveying. There is no scientific indication that the figures are average values, they can only be highlight presentations of the nodule distribution. The various expeditions had many limitations on fieldwork parameters, and these facts will be studied in connection with the preplanning of the mapping work.

7.8.5 Proposed survey equipment

MBE, SSS and SBP should be part of all surveys. In addition geotechnical equipment such as CPT and detailed survey inspection using ROV should be included. Environmental surveying equipment to get information about currents, waves and other oceanographic parameters must also be included.

7.8.6 Proposed processing, interpretation and reporting

The processing, interpretation and reporting shall compile and generate the information and understanding of the conditions. This is partly traditional mapping and new seabed classification and AUV data type processing. The reporting must be done in close co-operation with the experts of the riser and collector systems to make sure that all of the questions that are relevant for these systems are answered.

7.8.7 Proposed post-survey control

When the mining operation proceeds and nodules are harvested, post mining survey control must be performed. It is of vital importance to monitor the harvester's coverage of the seafloor, primarily for verification of the mining plan, but also to have necessary feedback information for required operational adjustments of the harvester itself.

As it is unlikely we will achieve 100% coverage, the mining plan aims for 50% coverage, allowing repopulating of biological species from the adjacent untouched areas. Pre-mining fauna activity must be recorded and the post mining fauna activity must be observed on a long-term basis. The nodules rest on red clay, and fine seafloor particles lifted together with the nodules or disturbed by the harvester may take a long time to settle. Bottom currents will also transport the particles and keep them in motion. This can make it difficult to use video monitoring by ROV in the immediate period after mining, but geophysical monitoring can probably give adequate results. When transferring the nodules to the surface vessel, the concentration of mining effluents in the surface waters is believed to be rather low.

7.8.8 Proposed mining vessel support

Detailed mapping as well as mapping of new areas will continue with one or two vessels when the mining operation starts. One of the vessels will carry complete mapping instrumentation while the other vessel will be a combined vessel for bottom sampling, geotechnical investigations, oceanographic work and ROV support. To which extent the second vessel also can be used for ROV support to the mining operation will greatly depend on the project development. This survey vessel could also be diverted to carry out post mining survey control tasks if required and if vessel capacity is available.

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8 MINING TECHNOLOGY AND COST ESTIMATES

8.1 Existing proposals; "state of the art"

8.1.1 Trawl harvesting

The disadvantage of the proposed nodule mining systems of the 1970-80s was the high capital and operating costs (see Chapter 4). During their study, Bechtel noticed that the relatively low production rate enabled other low cost systems to be used. A consultant proposed the use of trawlers and bottom trawls to harvest the nodules. Bechtel's initial study found it feasible, and Bechtel proceeded with the development of this harvesting method. In order to produce 2652 tons of cobalt as targeted in the study, 1,097,360 tons of wet nodules have to be harvested annually. Allowing for 330 harvesting days per year, this necessitates a daily harvesting rate of 3325 tons.

Four trawlers will be required to meet this harvesting quantity requirement. The four trawlers will be approximately 100 meters in length, with 20-meter beam and 3.5 meter draft. They will be equipped with differential GPS and dynamic positioning systems so as to accurately control movement and execute fully pre-programmed harvesting cycles. The harvest area of each trawler will be demarcated by a number of hydroacoustic transponders anchored to the seabed to form a long-baseline array of position locators. Each trawl will be equipped with a transponder which will show the position of the trawl relative to the transponder network. An altimeter will measure the distance between the trawl and the seabed.

The trawls will be of the beam trawl design with a rigid front frame, with a foot chain of heavy steel strung across to make the nodules bounce up in front of the trawl. The top and sides of the trawl frame will be fitted with hydrofoils to give proper orientation to the trawl (i.e. to keep it upright) during lowering and trawling. The bottom of the trawl net will be made of steel netting to ensure contact with the bottom, while the sides and the top will be made of SPECTRA filament to make it float. The bottom will be protected by wear liners to minimise the abrasion damage to the net.

Trawling will be at a speed of 1 m/s. At this speed the rope will extend down at an angle of approximately 60 degrees from the vertical and require a length of about 7900 meters from the trawler to the trawl. Lowering and raising will be at a speed of 2 m/s, resulting in a harvesting cycle of approximately 180 minutes. This allows eight trawls per day at 100 percent availability. Each trawl will be suspended on a SPECTRON 12 braided rope with an embedded armoured and sheathed electric cable. The weight of the rope, the trawl and the drag forces on the loaded trawl moving through water will add a load on the cable, however the design was based on a total payload capacity of 60 tons. Since the specific gravity of the nodules is 2, the payload weight in air is 120 tons, and the theoretical harvest rate for each trawler is then 960 tons. Net guard monitors will keep track of the stretch in the net in order to sense the process of filling up with nodules. The trawlers will be designed to take on a nodule load of 2500 tons, representing 2.6 days of continuous harvesting. At the end of that period the trawler will rendezvous with a transport ship and transfer its cargo to it by pumping a mixture of seawater and nodules.

The Bechtel study recommends custom building special purpose harvesting trawlers. The capital cost for the four trawlers and the trawling equipment was estimated at US$ 50 mill in 1996-dollar value, with an operating cost close to US$ 8 mill per year. The accuracy of this estimate is stated as ±25 percent.

It should be noted that there are several elements of uncertainty related to harvesting by trawls, the main one being that bottom trawling has never been done in waters deeper than 1200 meters, while the Cook nodules lie at approximately 5000 meters depth. However, PMB Engineering, Bechtel's marine and offshore entity evaluated the proposed trawling operation and a basic trawl design provided by a prominent supplier of trawls and fishing gear. It also used sophisticated computer simulation programs to examine the expected behaviour of the trawling system, including the trawl rope, during deployment, trawling and retrieval. The studies found the proposed method technically feasible with no fatal flaws; however they pointed to the need for a rigorous design, testing and evaluation program in the course of the implementation of the project. This must especially verify that the proposed 330 day 80% utilisation of the four trawlers is realistic.

8.1.2 The Norwegian system

During this study the Norwegian Deep Seabed Mining Group has developed an alternative solution. This system consists of:

- A subsea harvesting system (Section 8.2)
- A riser / lifting system system (Section 8.3)
- A surface vessel (Section 8.4)
- A control system / power supply system (Section 8.5)

The following three main versions of the riser/lifting system configuration have been studied:

- Slurry transportation in riser from a nodule grinding and fluid mixing unit
- Fluid transportation with full size nodules in riser
- Mechanical cargo transportation of full size nodules

8.2 Subsea Harvesting System

8.2.1 Introduction

The Subsea Harvesting System has architecture similar to a standard work ROV/trencher spread including;

- Control System
- Launch and Recovery System
- Subsea Harvesting Vehicle

The control container includes control panels for operation and monitoring of all Subsea Harvester Functions.

The Launch and Recovery System includes an A-frame with umbilical winch and a Tether Management System (TMS).

The Subsea Harvester Vehicle (SHV) is adapted from existing ROV/Trencher systems. Functions for harvesting of the nodules, pre-processing them, and conveying them to the subsea base structure is based upon known, proven agricultural machinery for rock removal.

8.2.2 Control System

The typical topside control system consists of a 20-ft container including control panels and the control system hardware/software. The control system is pc/plc based, sending control signals to the system and receiving signals from system indicators. This is common technology used on underwater robotics and ROVs. For all video and data transmissions fiber optic cables are used.

The control system may typically consist of:

- Launch & Recovery System control/monitoring
- Vehicle control/monitoring
- Visual control
- Position control/navigation

Launch & Recovery System control/monitoring; control of launch and recovery operations is performed via joystick and pc-based on screen controls. Separate cameras are mounted on the A-frame base structure and TMS for monitoring, all sensor feedback is displayed on the Launch and Recovery System control screen.

Vehicle control/monitoring; vehicle propulsion and manipulator controls are joystick controlled from a control panel. All vehicle processing controls is controlled from pointing devices on the control PC-screens, which is also displaying all alarms and status indicators in real time.

Visual control; is provided using a video multiplexer system with 8 uncompressed video channels at all times (which may be displayed) on one single-mode optical fiber. Normally 4 displays give sufficient information for safe operation of the proposed system. Switching between channels and positioning of cameras may be performed both from the control screen and control panel using joysticks and push buttons.

Position Control/Navigation; all navigation data from ship, subsea processing unit and vehicle are displayed on a separate navigation console. All navigational inputs and controls for the Subsea Harvesting Vehicle are via the same console. Typical navigation aids for the vehicle are gyro/fluxgate compass, pitch/roll sensor, auto functions (heading/depth/altitude). A scanning sonar on the vehicle will enhance the functionality.

8.2.3 Launch and Recovery System

The Launch and Recovery System (LRS) consists of an A- frame, motion compensated umbilical winch and a Tether Management System (TMS).

The Tether Management System (TMS) is a sub-sea spooling winch assembly used to store and deploy a neutrally buoyant tether cable linking the Subsea Harvesting Vehicle to its host surface vessel via a main lift umbilical. The TMS eliminates the effect of umbilical drag on the ROV, thus maximizing vehicle performance, and extending its operational ”footprint”.

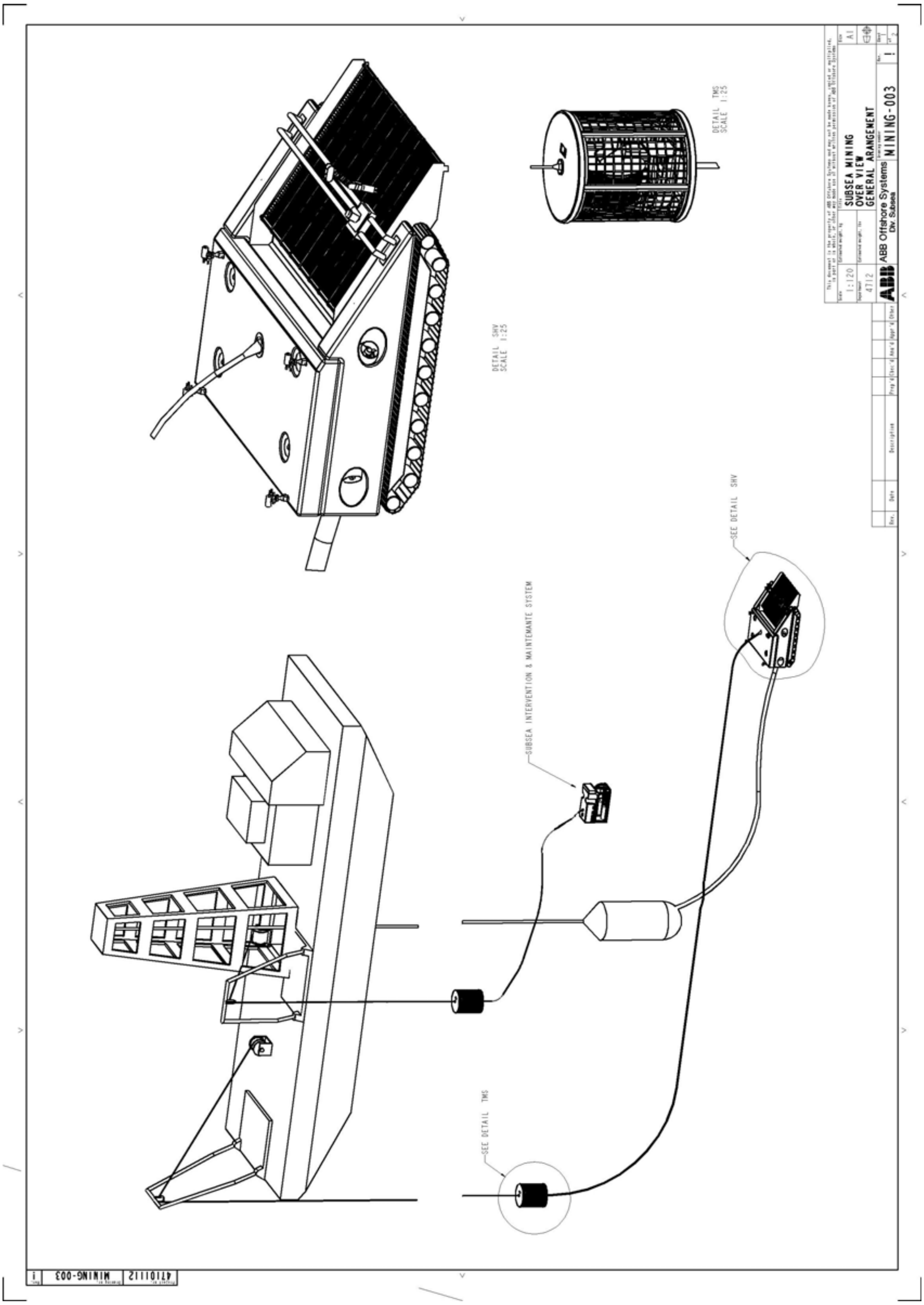


Figure 8.1. Subsea mining – general arrangement

8.2.4 Subsea Harvesting Vehicle

General:

The Subsea Harvesting Vehicle basic design is based on known ROV technology. The SHV has the dimensions 6.5m x 5.5m x 2.4m (L,W,H), weight approximately 10 tons in air. In the water the vehicle is neutral. The harvesting speed is max 3 km/hour, which will harvest 160 tons/hour. This is based upon an average nodule ratio of 20 kg/m^2.

Propulsion:

The SHV is equipped with four variable displacement hydraulic thrusters mounted in the vectored configuration. Vertical lift is provided by two centrally mounted thrusters. Two rear-mounted thrusters provide pitch control. Seabed propulsion is provided by two individually controlled/driven caterpillar belts enhancing steering capabilities. A dedicated 2 x 125-hp hydraulic power unit powers the typical SHV propulsion system. The propulsion system is designed to minimize the disturbance of the local environment.

Harvester:

The SHV harvesting system design is aimed at harvesting manganese nodules with minimal seabed penetration. The SHV harvesting system collection unit is similar to the rock pickers used for agricultural purposes. The modules and soil will be gently transferred to a conveyer belt via a sieve (where the soil is shaken off), the remaining soil will be washed off by the integrated flushing system.

The cleaning process enables effective handling of nodules and reduces the environmental impact. The nodules are then transported to a Nodule Processing unit, by a suction pump (located on the Nodule Processing Unit on the Base structure) via a 30m flexible buoyant pipe (300mm). A 125-hp hydraulic power unit power the harvesting system and additional vehicle internal functions.

To aid the harvesting process the SHV is equipped with a manipulator arm, located above the screen. The manipulator will be used for removal of elements stuck into the screen.

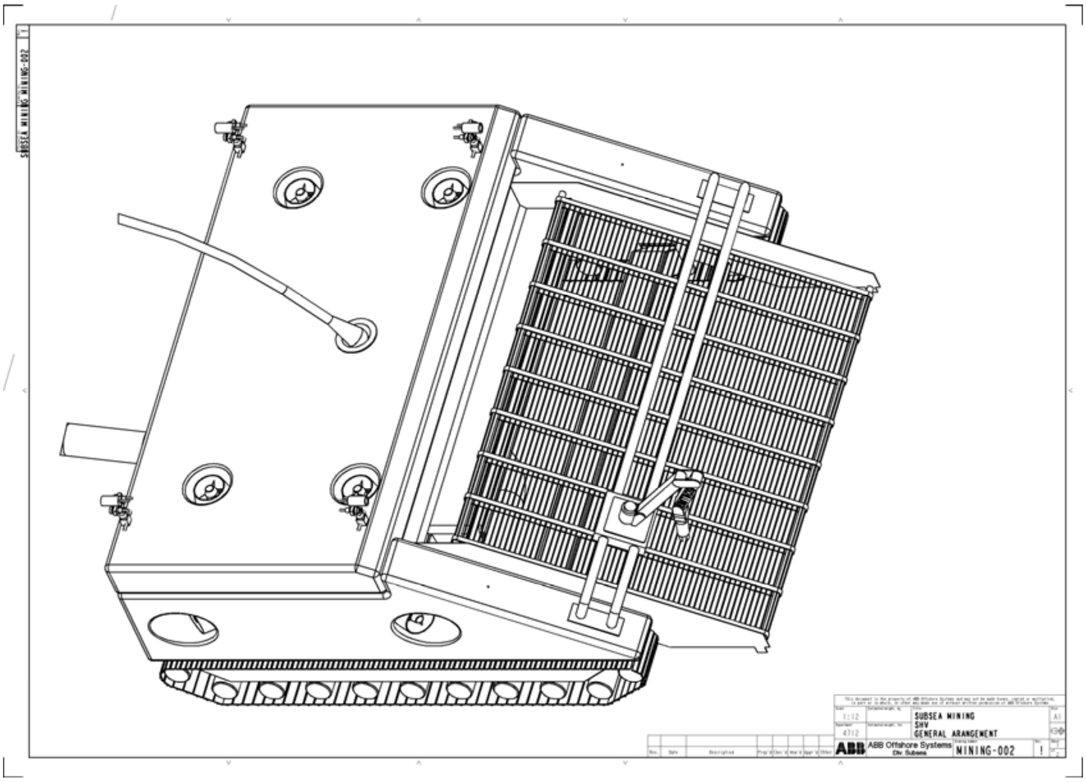


Figure 8.2. The subsea harvesting vehicle (SHV)

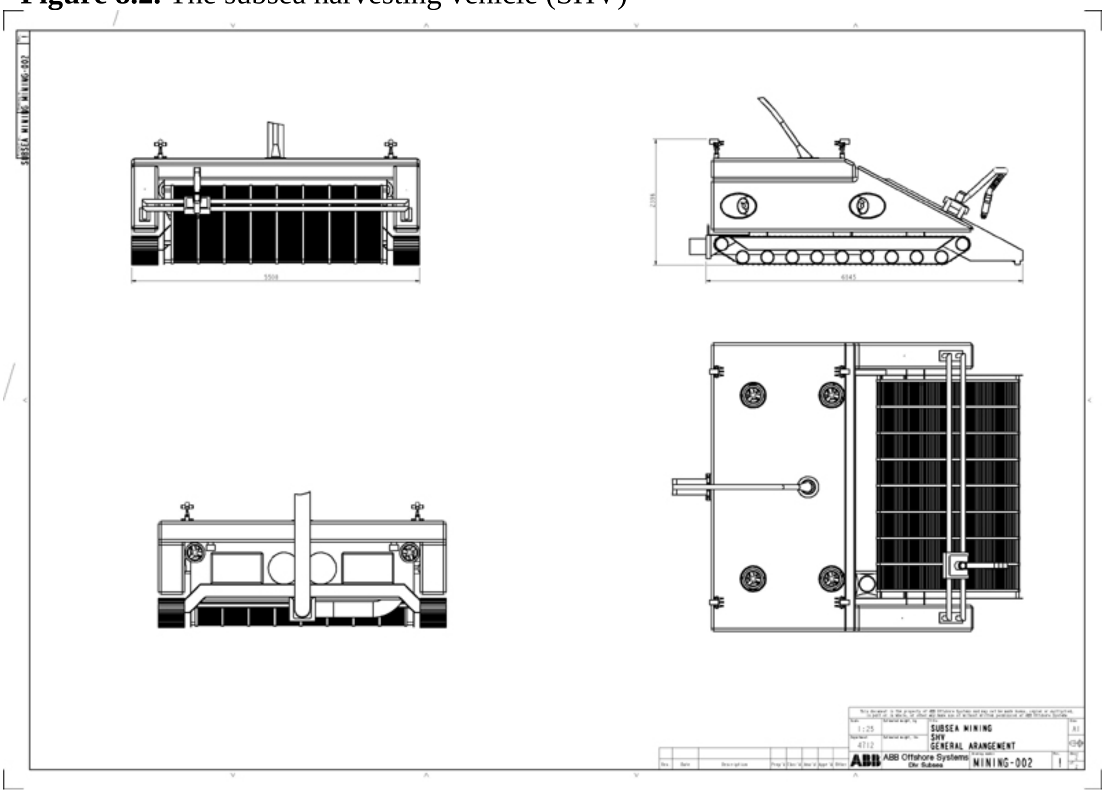


Figure 8.3. SHV details

Instrumentation:

The harvesting process is carefully monitored. The system allows for 8 camera systems (camera, pan & tilt, lights) to record real time. All motions are monitored using state of the art position indicators, pressure and torque transmitters.

Telemetry:

Transmission via 2 single mode optical fibers, 8 real time video channels, and 15 data channels (5 RS232, 5 RS 422/RS 485, 5 TTL).

Navigation:

The system is equipped with the following navigation aids: gyro/flux compass, pitch roll sensor, depth gauge and sonar.

Interfaces:

The SHV is in general self-sufficient. The only interfaces to other parts of the mining system is:

The flexible suction pipe, which is installed by a support ROV on the rear of the SHT.

Position data is also continuously exchanged by the SHV, SBS and support ROVs and process ship.

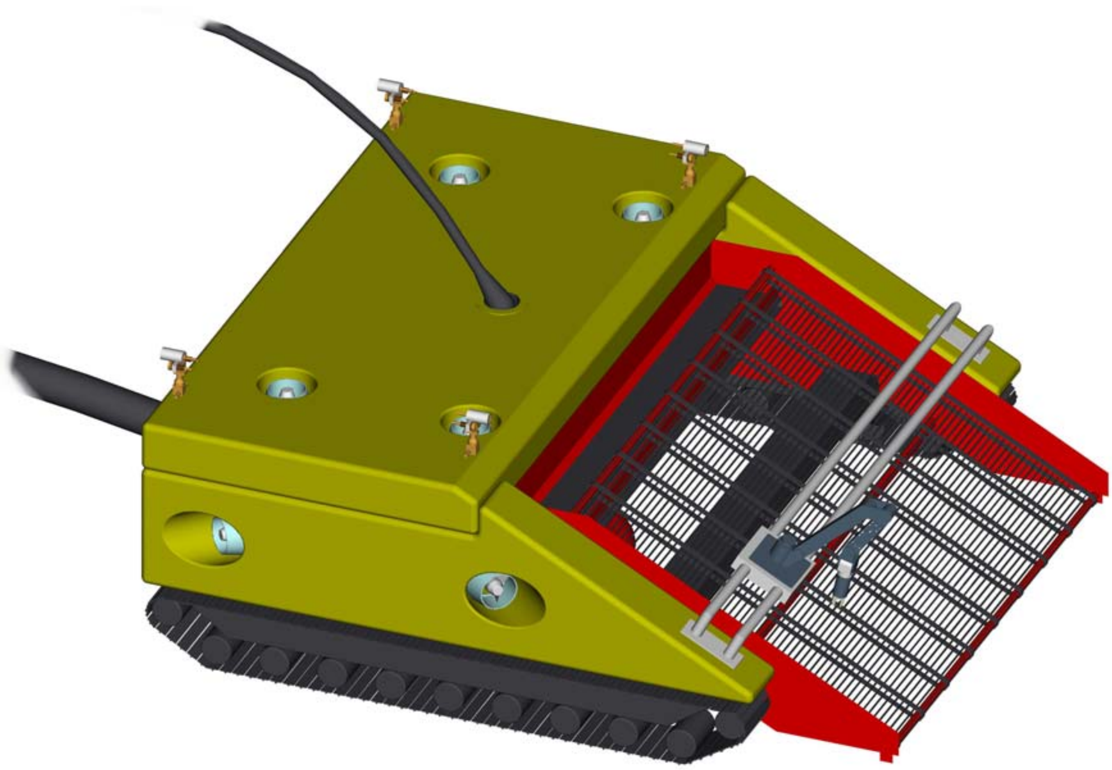


Figure 8.4. Subsea Harvesting Vehicle

8.2.5 Subsea Intervention and Maintenance System – ROV system

All subsea intervention, inspection and maintenance tasks are carried out by a standard Work ROV spread. Such tasks will typically include: routine inspections of subsea base and pumping system, operation of system overrides in emergency situations, and intervention tasks such as anode replacement, dredging and connection/disconnection of SHV suction and pipe/hose.

The typical Work ROV system will consist of:

- Control cabin /w control console
- Handling system (A- frame/umbilical winch)
- Tether Management System
- ROV
- Work Skids
- Tool Kits

8.2.6 CAPEX estimate subsea harvesting system

The Subsea Harvester will have the same configuration in all of the 3 studied riser/lifting scenarios.

Type of equipment	No off	Cost kNOK per unit	Total cost kNOK
A –Frame	1	2000	2000
Umbilical Winch	1	5000	5000
Umbilical	2	3250	6500
Tether Management System (TMS)	1	4000	4000
Subsea Harvesting Vehicle	2	25000	50000
20 ft Control Container	1	6000	6000
20 ft Work shop Container	1	500	500
10 ft. spares container	1	200	200
Testing and certification	1	7000	7000
Operational spares (one season)	1	4000	4000
TOTAL			**85200**

Table 8.1. Subsea harvesting system CAPEX; Riser/lifting scenario 1,2,3

8.2.7 CAPEX estimate work ROV system

Type of equipment	No off	Cost kNOK per unit	Total cost kNOK
A –Frame	1	1000	1000
Umbilical Winch	1	4000	4000
Umbilical	2	3250	6500
Tether Management System (TMS)	1	2000	2000
Work Class ROV	1	11000	11000
20 ft Control Container	1	4000	4000
20 ft Work shop & Spares Container	1	500	500
TOTAL			**29000**

Table 8.2. Work ROV system CAPEX; Riser/lifting scenario 1,2,3

8.2.8 CAPEX subsea base structure

The SBS structure will have a slightly different configuration for the 3 different riser-lifting scenarios, thus 3 different CAPEX tables are given below.

Type of equipment	No off	Cost kNOK per unit	Total cost kNOK
Electro hydraulic control system for nodule measuring, pump speed control, chute level monitoring etc.	1	3000	3000
Chute Level Meter	2	2000	3000
Riser Density Meter	2	1000	2000
Position measuring equipment for SBS structure	2	500	1000
TOTAL			**9000**

Table 8.3. CAPEX SBS, scenario: nodules pumped whole to the surface

Type of equipment	No off	Cost kNOK per unit	Total cost kNOK
Electro hydraulic control system for nodule measuring, pump speed control, chute level monitoring, crusher control and monitoring etc.	1	3500	3500
Chute Level Meter	2	2000	3000
Riser Density Meter	2	1000	2000
Position measuring equipment for SBS structure	2	500	1000
Monitoring and control for crushers	3	500	1500
TOTAL			**11000**

Table 8.4 CAPEX SBS, scenario: nodules pumped as slurry

Type of equipment	No off	Cost kNOK per unit	Total cost kNOK
Electro hydraulic control system for nodule measuring, chute level monitoring, elevator control and monitoring etc.	1	3500	3500
Chute Level Meter	2	2000	3000
Elevator nodule level meter	2	1000	2000
Position measuring equipment for SBS structure	2	500	1000
Monitoring instrumentation for elevators	2	500	1000
TOTAL			**10500**

Table 8.5. CAPEX SBS, scenario: mechanical lifting

8.2.9 OPEX estimate for the subsea harvesting system

The OPEX cost is approximately equal for the various riser/lifting scenarios, thus only one estimate is given here.

Type of cost	Cost per year kNOK
Electrical Power, 2 kW @ 0.25 NOK/h	4
Hydraulic fluid (assumed to be replaced yearly), 5 m3 @ 10 kNOK/m3	50
Replacement of parts of control system, estimated to 5% / year of original CAPEX, appr. 150 kNOK/year	150
Spare parts for harvester and ROV	8500
TOTAL	8704

Table 8.6. OPEX estimate, subsea harvesting system

All operation and maintenance manning costs for the subsea systems are included in the OPEX for the mining ship.

8.3 Riser system / lifting system

The riser system may have several functions:

- Transportation system for the fluid mix of nodules and seawater
- Transportation of hydraulic fluids to provide power to subsea units
- Hang-off system for the subsea pumps, nodule grinding, ROV, TMS systems, etc.
- Guide for running of tools, ROVs, mechanical nodule transportation units, etc.

The riser configurations will vary with the following main scenarios:

- Slurry transportation from a nodule grinding and fluid mixing unit
- Fluid transportation, which may involve full size nodules
- Mechanical cargo transportation of full size nodules
- Combinations of the above

8.3.1 Risers for pumping of nodules

Nodules can be pumped to the surface via a riser system. The main principles considered are:

- Transportation of nodules in the form of slurry
- Transportation of whole nodules

Transportation of whole nodules to the volume in question is considered highly impractical. In order to pump the nodules uncrushed the Disc Flow pump technology has been identified as the best alternative. However, the pump requires a mixing of nodules and water in the ratio 1 : 50 to obtain acceptable flow characteristics for the 5.5 km lift. This would involve several grand size risers wasting the economy of the project and therefore this alternative has been abandoned.

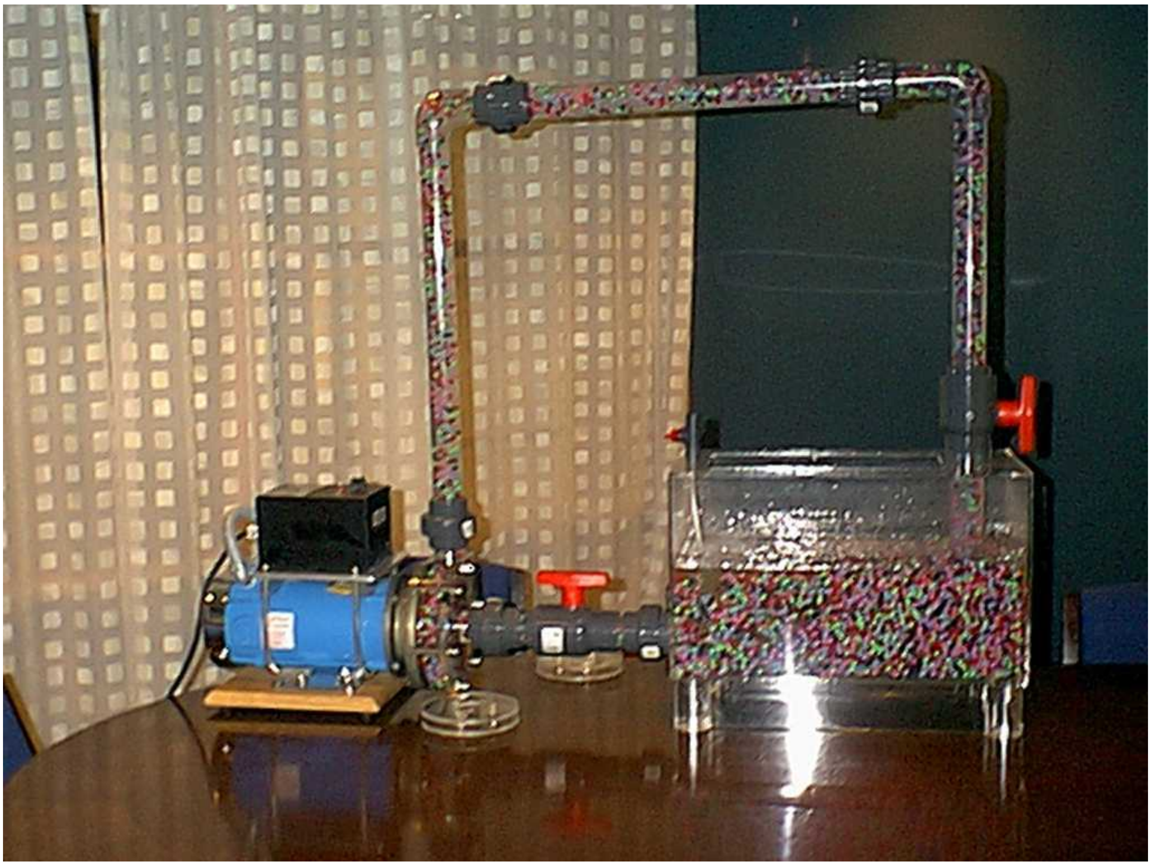


Figure 8.5. Disk Flow Pump simulating nodule transportation

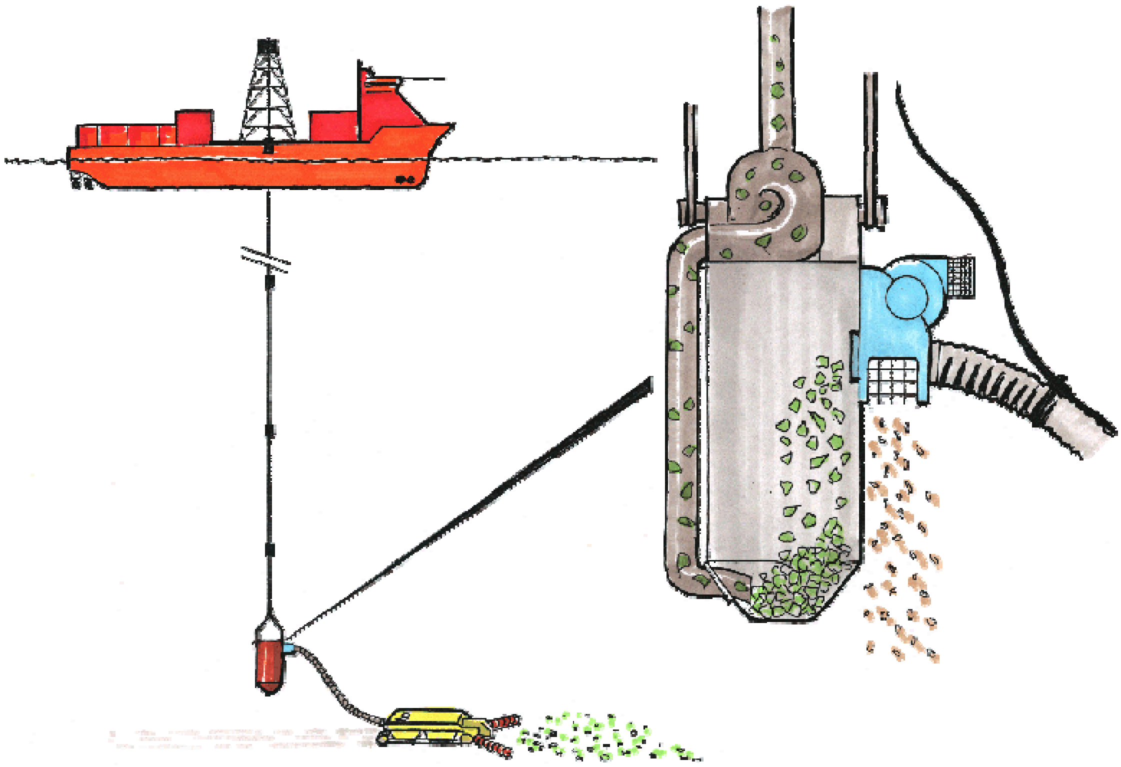


Figure 8.6. Nodules pumped whole to the surface

8.3.2 Slurry transportation

The nodules will have to be crushed upon entry into the subsea temporary storage unit and mixed with water to a ratio of 1:3. The resulting slurry can be pumped to the surface via a rotary pump type (single screw pump) through a 7“ riser. See figure below.

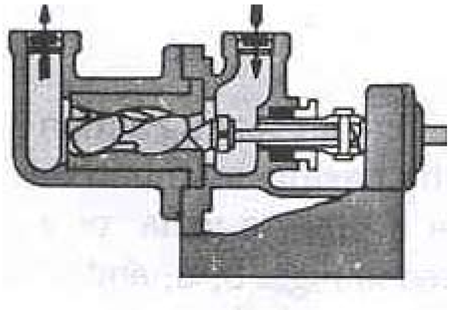


Figure 8.7. Slurry pump

The pump system shown will require power in the order of 2MW to lift the volume involved. Configuration and pump details represent a technology gap which must be studied further. Moreover, slurry transportation is not considered feasible at present due to the low regularity expected for the nodule grinding machinery. This alternative was therefore abandoned.

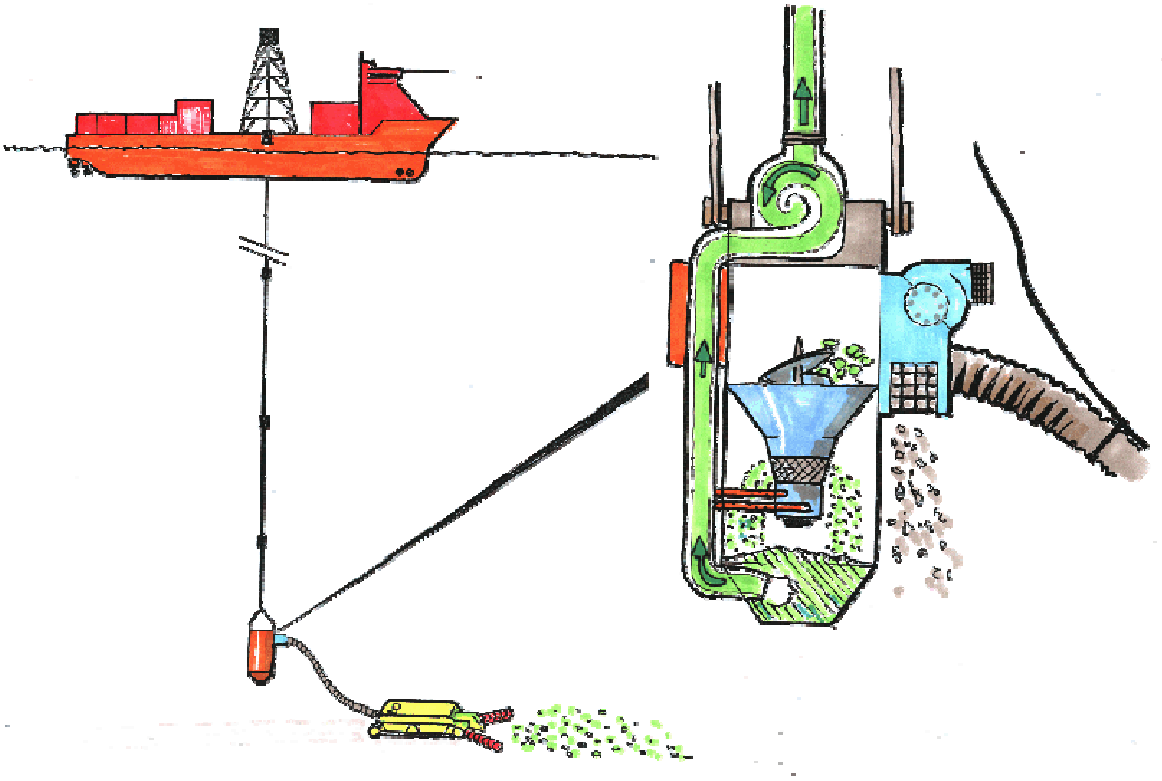


Figure 8.8. Nodules crushed, slurry pumped to the surface

8.3.3 Mechanical lifting system

The lift system shall include:

- Riser
- Hoist cable and winch for the nodule transportation buckets
- Nodule transportation buckets

The capacity of the lift system shall be:

- Nodule carts: 125 tonnes equivalent to one hour production
- Nodule storage: 375 tonnes, equivalent to 3 hours production
- Cart transportation speed: 2.5 – 3.0 m/s, leaving about 20-30 minutes for loading/emptying buckets.

Winches and lift cable

High Density Poly Propylene (HDPP) rope will be used for hoisting the buckets. Two rope winches will be acting together on hoisting and launching the cart system. One or two storage winches will be necessary at both ends in addition to the lift winches, totalling the number of winches to 6.

Table 8.7 shows that steel wires cannot be used as most of the load carrying capacity is utilised to carry the wire itself.

The lifting system will also be used to:

- transport tools and machinery between the seabed and the surface facilities
- transport hydraulic fluid for the subsea power generator

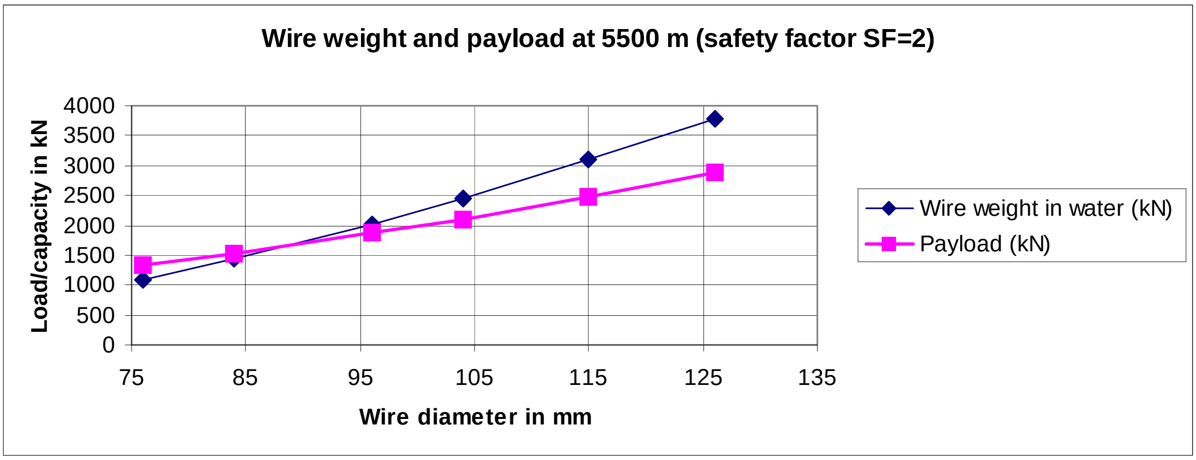


Table 8.7

8.3.3.1 The riser

A 9” riser has been chosen based on the requirements for torsional stability of the riser system. The wall thickness of the riser is controlled by the hang-off loads and not the internal pressure. The riser shall serve as hang-off for the subsea base (temporary nodule storage), and the SHV etc. Thus with a varying wall thickness the resulting hang-off load will be approximately 1500 tonnes (see Table 8.8).

The connectors shall be of the bolted type of clamped connectors in order to integrate the riser and power cable needed for the subsea tools. The connector type shall also accommodate the requirements for riser joint line-up, dictated by the guiding and lift system (see next section).

In the case where the subsea base is being hoisted to the surface it is assumed that the whole riser system is retrieved.

Hangoff loads with varying requirements to weight at bottom of 9" riser:

Depth/ section	WT, inch	Section weights w/ 200 T	Depth/section	WT, inch	Section weights w/500T
4500-5500m	0,5	62,0	4500-5500m	0,9	111,6
2000 - 4500 m	0,9	279,0	2500-4500 m	1,5	371,9
0-2000m	1,5	371,9	0-2500 m	2,5	774,9
Surplus weight		300	Surplus weight		500
Hang-off load:		**1012,9**	**Hang-off load:**		**1758,4**

Table 8.8. shows that an optimisation may result in 1500 tonnes hang-off at riser top

8.3.3.2 Guide system

The guide system shall be complimentary to the hoisting system and provide a steady and controlled transport of the items going back and forth between the sea bottom and the surface. See details in Figures 8.9-8.11.

A guidewireless system is provided by this proposal.

The guide system (tubular) shall be dimensioned to take the weights of the:

- Temporary storage container
- Transportation buckets in the string
- TMS systems (2 off)
- Pumps, structural works, etc.

With a mechanical bucket transportation system the temporary storage must be able to carry 3 hour production, i.e. 375 tonnes derived from a peak production at 125 t/hr.

Figure 8.9 Riser and lifting cart system

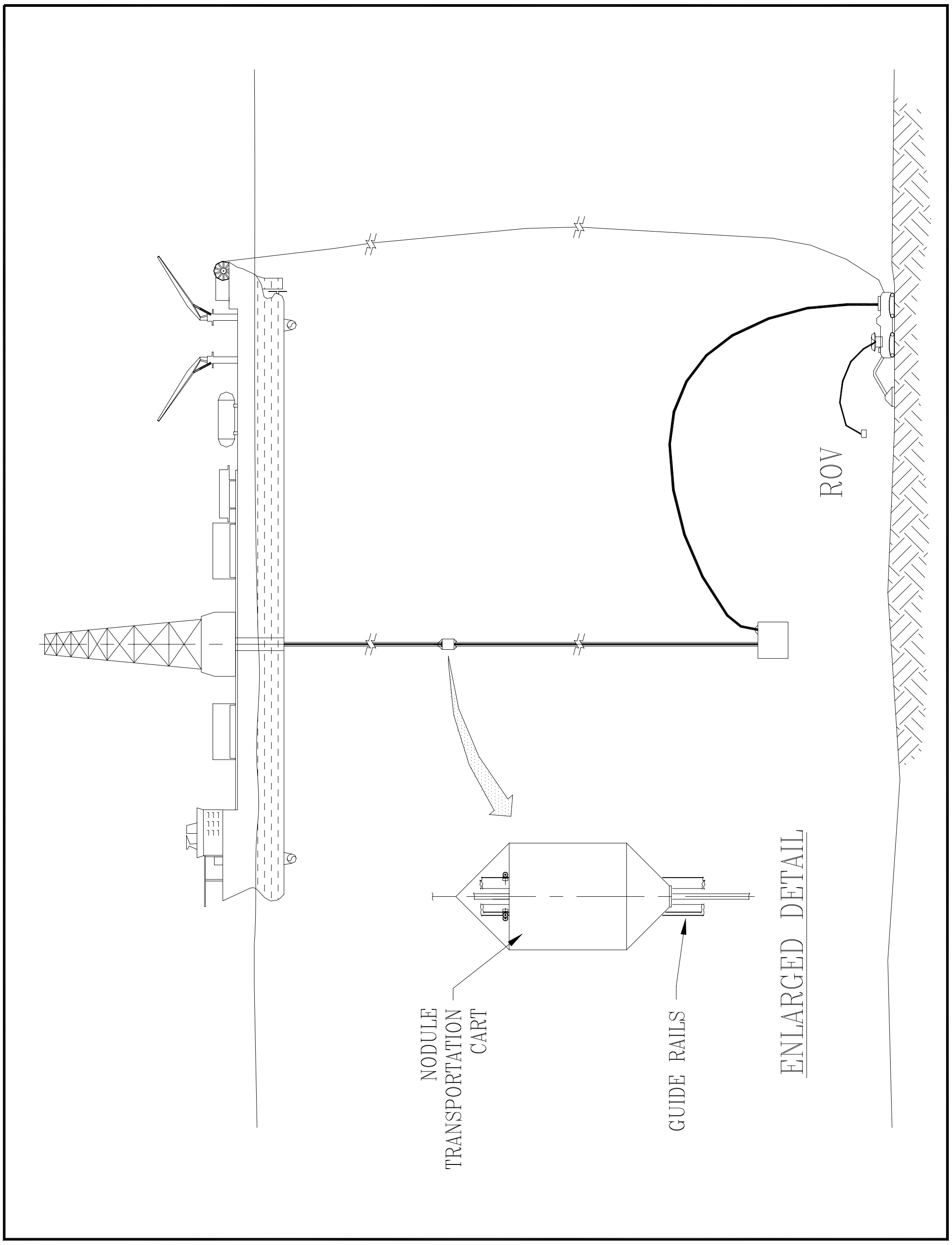


Figure 8.10 Nodule cart details

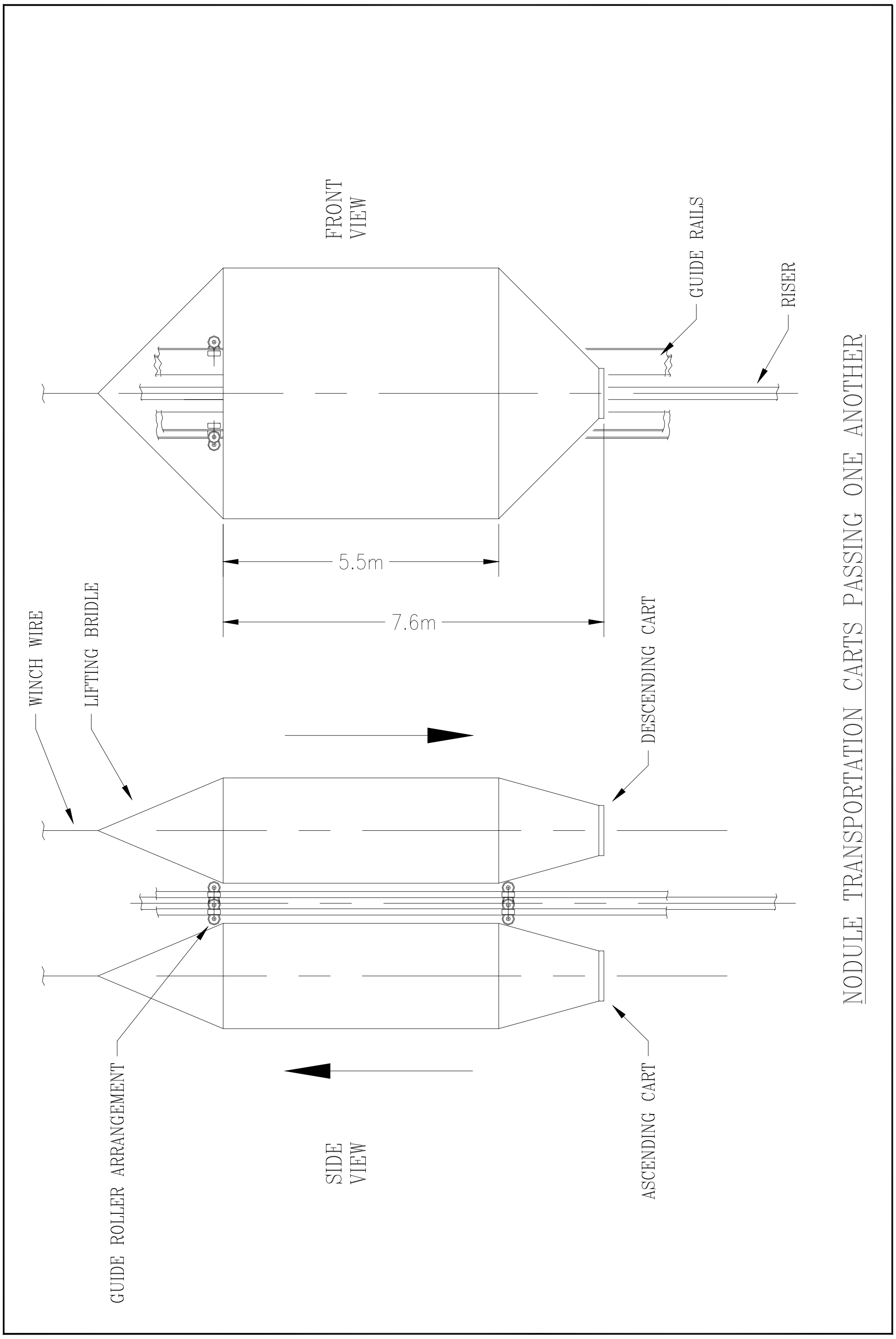
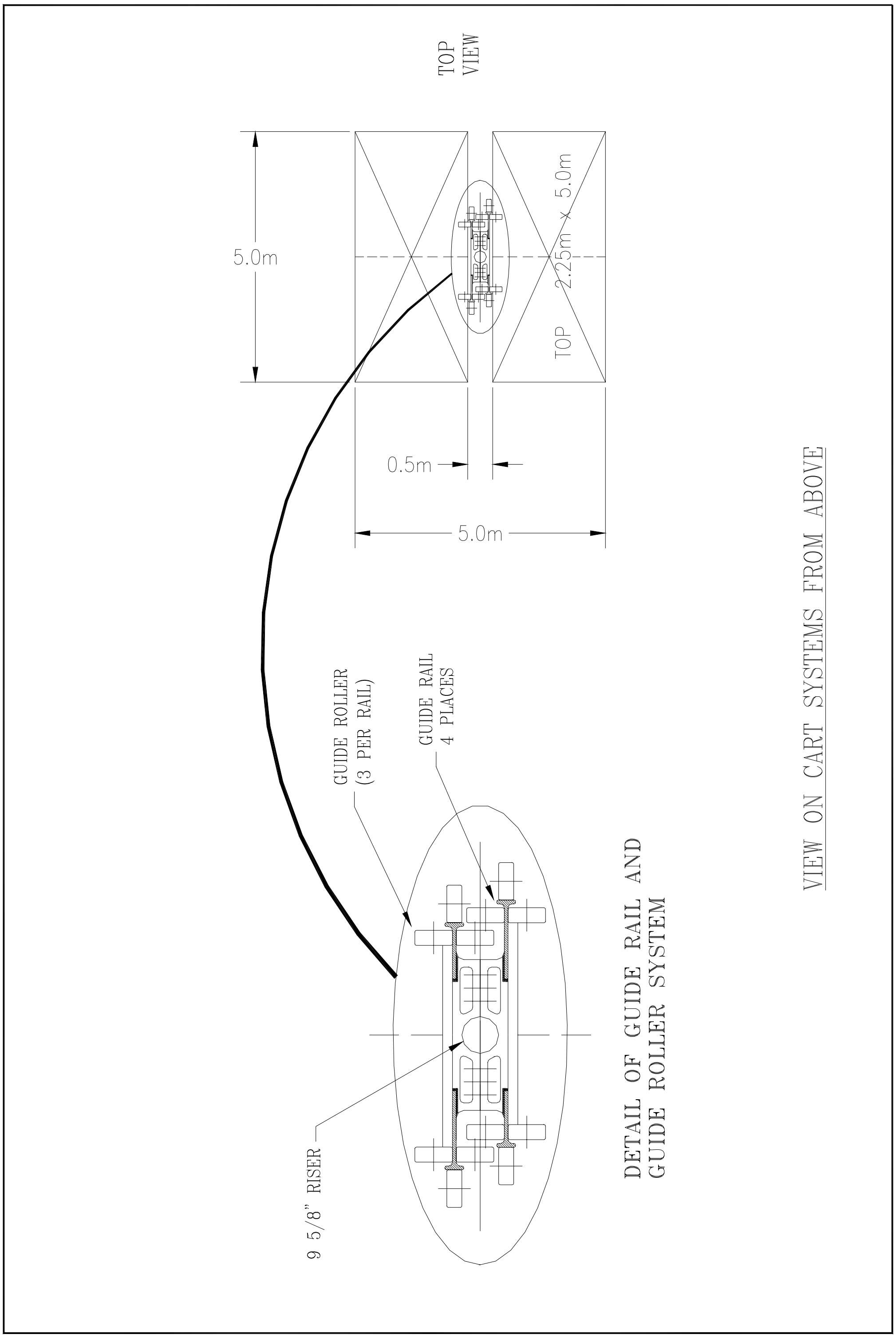


Figure 8.11 Nodule cart guide system details



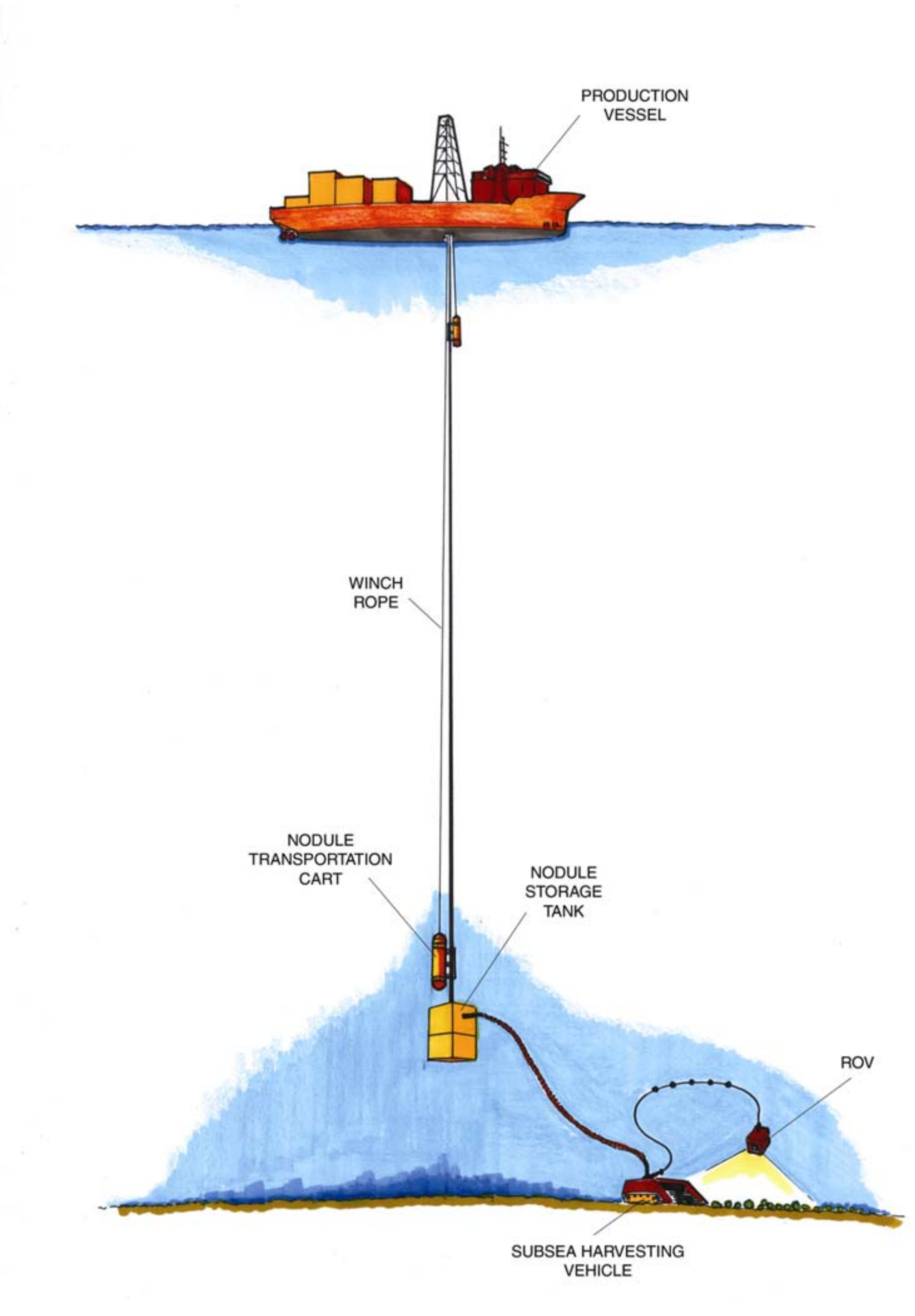


Figure 8.12. Nodules transported whole via a chute elevator

8.3.4 Riser Management System

The Kongsberg Simrad Riser Management System (RMS) is an advisory and monitoring system for optimum handling of a riser, and can be interfaced directly with the vessel's DP or positioning system. The RMS will give efficient assistance in all phases of the mining operation from planning of riser make-up through deep-sea mining in varying environmental conditions. The system may keep track of where and when the different riser components are used as required for maintenance planning. A powerful and easy-to-use riser simulator may be included in the system ensuring a well-planned riser deployment. For the mining crew, the RMS provides a number of monitoring functions including riser strain, top tension and tension distribution along the riser, as well as connector loads.

Through integration with the Kongsberg Simrad Dynamic Positioning (DP) system, the RMS provides the DP operator with an optimum position advice for the vessel, limiting the stress and loads within pre-set limits. This ensures less wear of the riser. The vessel position advice relative to the buffer storage is shown to the DP operator in the DP position display view.

By using information from the DP system about the consequence of a worst-case single failure (re IMO DP Class 2 and Class 3 Operation), the RMS can provide information on the "time to go" margin before an emergency sequence has to be initiated (if relevant).

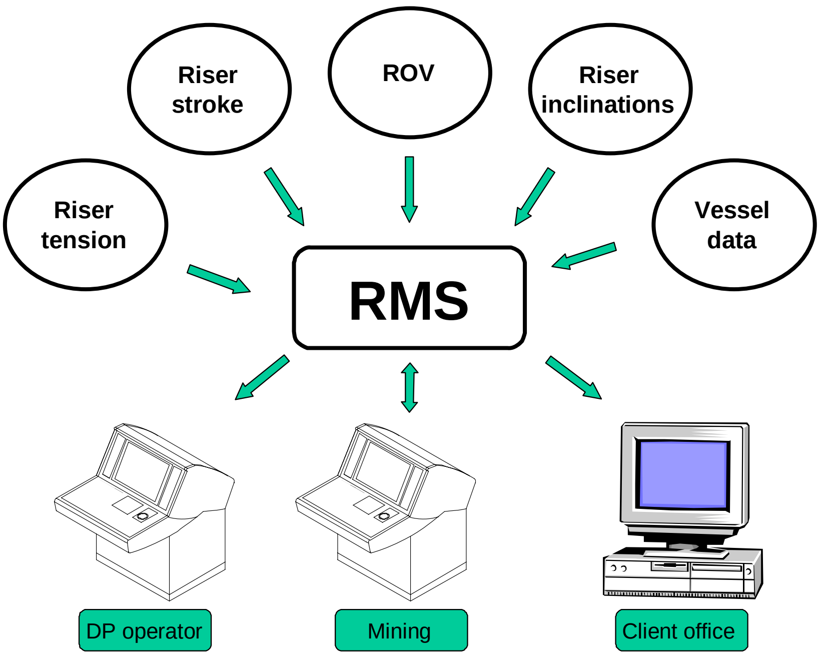


Figure 8.13. Riser management system

Riser Management System

The capital cost for the RMS system is 4 - 5 mill NOK. This includes:

- Operator station
- Software
- Interface to DP system
- Strain sensor
- Interface to riser tensioning system
- Software for dynamic analysis of the riser
- Engineering
- Commissioning

The operational cost of the RMS system over 20 years is 3 - 4 mill NOK. This includes:

- Midlife upgrade
- Periodical sensor calibration
- Service and maintenance
- Spare parts

8.3.5 Technology Gaps

The recommended Riser and Lift system do not possess significant technology gaps, however, system demonstrations should be set up to validate design proposals before constructing the final system.

The technology gaps identified for the alternative systems are:

- Subsea nodule grinding system: Due to the poor operational availability expected at 5500m water depth a system involving a nodule grinding system was abandoned.
- Subsea pumps for slurry transportation systems:
- Slurry pumps: The capacity required for this application can be achieved by further studies, but the improvements of the accompanying grinding system will have to be solved first.
- Disk Flow pumps: Transporting the nodules unprocessed via the Disk Flow pump is by far the most rational method of transporting the nodules for lower volumes and at lower lifting heights. Disk Flow pumping techniques should be studied with a view to improving this technology to meet the project requirements.

8.3.6 Studies for the next Phase

Prior to progressing with the proposed Riser & Lift concept the following should be studied.

- Details of the lift cable and carts
- Details of the railing (guide) system functionality
- Torsional stiffness of the riser with respect to twisting of the riser.

The cost of these studies are included in various/development costs, see Chapter 11.

8.3.7 Cost of riser and lift system

Systems		No. off		Weight in tonnes	Unit price	Total cost Slurry system	Total Cost Mech lifting
	Main Items	In water	Spare		1000xNOK	1000xNOK	1000xNOK
Riser system	Riser	458	100	800	75	90000	60000
	Connectors	460	20	80	150	9600	12000
	Pumps	3	1	20	300	6000	0
Mechanical lifting system	Buckets	2	2	10	40	0	400
	Lift cables, HDPP	2	1000m	12	2600	0	31200
	Lift umbilicals	0		300	60	0	0
Guiding system	Rails on riser	450	30	200	50	0	10000
	Guidewires	0	0	200	15	0	0
	Polyethylene guides	0	0	1	0,4	0	20
	Power cable guides	0		0	10	0	0
	Top lift						200
Winches	Guidewires	0	0			0	0
	Lift for buckets	2	1			0	25000
	Power cable	0	0			0	0
Grinding system	Detailed else where	1	1	400	N/A	Note 1	N/A
CAPEX					**MNOK**	**106**	**139**
OPEX/yr.					**MNOK**	Note 1	**10,2**
Note # 1:	Not estimated						

Table 8.9. Cost of riser and lift system

The riser management system adds MNOK 4.5 to give a total CAPEX equal to MNOK 143.5.

8.4 Surface vessel

8.4.1 Design basis

General
The vessel shall operate in the offshore environment off the Cook Islands and shall be capable of supporting the necessary deep sea mining facilities, and receiving, storing and exporting the produced nodules. The nodules are brought to the vessel by the riser/lift system in natural condition. At the vessel the nodules are stored in the vessel storage tanks before being offloaded to shuttle tankers for export to New Zealand for further processing.

Design Data:

Environmental
- Water depth 5500m
- 100 year storm condition
  Waves H1/3 5m
  Period Tp 10 sec
  Wind speed 20 m/sec
  Surface current 1 m/sec

Nodules
- Wet spv. 2
- Dry spv 5,2
- Bulk storage natural spv 1,3

Production Capacities
- Wet nodules 140 tonnes/hour
- Production efficiency 0,9

Nodule storage
- Storage Capacity 10,5 days of production

Export System
- One way distance to shore 4000 km to New Zealand
- No of shuttle tankers 3
- Shuttle tanker capacity 30000 tonnes
- Shuttle tanker efficiency88%

8.4.2 Surface Vessel General

The surface vessel is similar to a drilling vessel in shape, but unlike a drilling vessel it is equipped with storage tanks for nodule storage and offloading. The vessel is a Dynamically Positioned (DP) vessel. This is necessary due to the extreme water depth. The vessel is assumed to be a new build, but a conversion is also a viable alternative.

The vessel is arranged with a mid ship moon pool for subsea access and with a riser handling derrick on top. In order to have free access to the moon pool the derrick is arranged on a substructure elevated above the moon pool. The riser is suspended below the substructure and through the moon pool. The deep sea mining support equipment is mainly arranged on main deck around the moon pool.

At the bow a living quarter with helideck is arranged. Between the living quarter and moon pool is a deckhouse for mining support equipment, utilities and a workshop. Aft of the moon pool is a similar deckhouse for power generation and distribution arranged. Riser joint storage is arranged on top of this deckhouse. Power generation is diesel electric. Two deck cranes are arranged one on each side.

Most equipment is arranged topside. The hull is consequently simple and contains some utility equipment forward, the eight storage tanks, four forward and four aft of the moon pool, the moon pool and a slop tank and pump room aft. Further two compass thrusters are arranged forward and three aft with corresponding access shafts. The hull is also equipped with ballast tanks and necessary other liquid storage tanks.

Offloading to the shuttle tankers is assumed by pumping through two loading arms arranged on each side of the vessel, conveyor belts or grabs. Side by side mooring of the shuttle tankers is proposed due to the rather soft weather conditions. Soft rubber fenders are installed on each side for ship separation.

Main particulars of the vessel are as follows:

Length between perpendiculars Lpp	195 m
Breadth B	37 m
Draft loaded d	10,9 m
Draft ballast d	6 m
Depth moulded D	18 m
Free board f	7,1 m
Block Coeff, CB	0,85
Displacement gross	66847 tonnes

Other particulars:

Manning	70
Living quarter capacity	80
Installed power	17500 kW

No of storage tanks	8
Storage tank size (100%)	5620 m3
Storage tank volume (100%)	44962 m3
Required DP capacity (single vessel)	10200 kW
Required DP capacity (with shuttle tanker)	13800 kW

8.4.3 Riser and Deep Sea Mining equipment handling facilities

This is the equipment necessary for handling the riser and Deep Sea Mining equipment on the vessel deck and through the moon pool.

The riser pipe consists of 15 m joints to be stored in two riser rack sections on top of the aft deck house. Each rack section is serviced by an overhead crane. A shuttle system transports each joint from the rack to the riser handling derrick where the riser is connected up. The derrick contains a riser lifting winch, riser make up table and tools for riser make up and handling. As the riser is made up it is lowered through the support table and into the moon pool.

Before the riser is lowered through the moon pool it is connected to the temporary storage unit. This operation is done at main deck level. In addition the guide rails and power cable are run with the riser.

When the riser has reached the designated depth it is hung off in the riser suspension system located underneath the derrick substructure.

Once the riser is installed the Subsea Harvesting Vehicle (SHV) is run and landed on the sea bottom. The SHV is run on the riser pipe and suspended by its umbilical. The work ROV is run in a similar way.

The basket operation is by two single baskets running on guides attached to the riser (and possibly guidelines). The baskets are operated in sequence and by one winch each. At the sea bottom the baskets are being filled up from the temporary storage tank and lifted to the vessel by the winches. At the vessel the baskets are discharged into a temporary storage tank on deck before being transferred to the selected storage tank.

A guiding system is arranged in the moon pool for safe deployment of equipment into the sea. The equipment for subsea equipment handling is located on or underneath the derrick substructure or on main deck at the moon pool.

8.4.4 Deep Sea Mining Support Facilities

The deep sea mining support facilities are the systems installed on the vessel to power, monitor and control the deep sea mining facilities.

Estimated power requirement for support of the deep sea mining facilities is 3000 kW. This is distributed from the switchboard room in the aft deckhouse. Power to the

SHV/ROV is integrated in the umbilicals and the other equipment is powered by a separate cable.

Status monitoring and control of the deep sea mining facilities are carried out from the Central Control Room (CCR) located in the Living Quarter forward. The vessel will have an overall Safety and Control System, and control of the deep sea mining facilities will be integrated in this system

The SHV/ROVs will have one operator each located in the CCR. Control is through the control umbilicals attached to the riser. The SHV will be operated according to a beacon system on the sea bottom and will be monitored by a CCTV system. Operation of the SHV is linked to the vessel Automatic Positioning Monitoring system (APM) such that speed and heading of the ROV and SHV is coherent

SHV/ROV support is carried out from the ROV shop in the forward deckhouse where the spare SHV is located. Umbilicals, one for each SHV/ROV and one spare are stored on powered umbilical reels located underneath the derrick substructure. The umbilicals will be attached to the riser guidelines by clips. Lifting of the ROVs to be attached to the riser is carried out by lifting equipment arranged on deck at the moonpool.

The basket system will have its own control system and requires one operator. Operation may be semi-automatic and active operation of the system may be required.

Integration of the deep sea mining control system into the overall safety and control system will action interfacing systems and prohibit damage in case of equipment break-down.

8.4.5 Storage and Export facilities

Storage of the nodules on the vessel is in tanks. Eight storage tanks are arranged in the hull, four aft and four forward of the moon pool. Nodule transport is by pumping, conveyor belts or grabs (see Section 8.7).

8.4.6 Power generation and distribution facilities

Main power generation amounts to about 17500 kW and is assumed to consist of 4 x 4500 kW diesel powered generators arranged in the aft deck house. Depending on the selected DP class one or two engine rooms may be selected. This deck house will also contain an engine control room, switchboard room and auxiliary engine rooms.

8.4.7 Utilities

Utilities will consist of cooling and heating systems, hydraulics and pneumatics, fuel and lubrication, HVAC and sanitary equipment. This equipment will be partly arranged in the forward hull, and in the forward and aft deckhouse as appropriate.

8.4.8 Hull

The hull is designed with double hull in the tank area and with a centre longitudinal BHD. Double hull in the tank area is selected due to required clean ballast capacity and to have storage tanks without internal stiffening.

The hull consists of the moon pool area with four storage tanks arranged forward and four aft of the moon pool. A rectangular type moonpool is selected to gain better moon pool space for running the SHV and carts on the riser. The forward hull part contains utilities and tanks for fresh water etc. and access shafts for the forward thrusters. The aft part contains a slop tank, fuel tanks, pump room, and access shafts for the aft thrusters.

8.4.9 Marine Systems

The marine systems consist of the station keeping system, the ballast and bilge systems, tank sounding and vent and anchoring system.

Five thrusters are installed, three forward and three aft. The ballast pumps are installed in a pump room aft.

8.4.10 Living Quarter

The living quarter is arranged forward and contain messing and sleeping facilities for about 80 persons including ten visitors. A two 35-man shift per day is supposed. In addition the living quarter also contains the central control room. A helicopter deck is arranged on top of the living quarter. Two lifeboats are installed, one on each side of the living quarter.

8.4.11 Dynamic Positioning System

The Kongsberg Simrad Dynamic Positioning (DP) system is a computerized system enabling automatic position and heading control of a vessel. Set-points for heading and position are specified by the operator and are then processed by the DP system to provide control signals to the vessel's thruster and main propeller systems. The DP system always allocates optimum thrust to whichever propeller units are in use.

To control the vessel's heading, the DP system uses data from a gyrocompass. A position-reference system enables the DP system to position the vessel. Deviations from the desired heading or position are automatically detected and appropriate adjustments are made by the system. A production vessel is subjected to forces from wind, waves and currents as well as from forces generated by the propulsion system and from the riser. The vessel's response to these forces, i.e. its changes in position, heading and speed, is measured by the position-reference system and the gyrocompass. The system calculates the deviation between the actual position of the vessel and the required position, and then calculates the forces that the thrusters must produce in order to make the deviation as small as possible. The system controls the vessel's motion in three horizontal degrees of freedom - surge, sway and yaw.

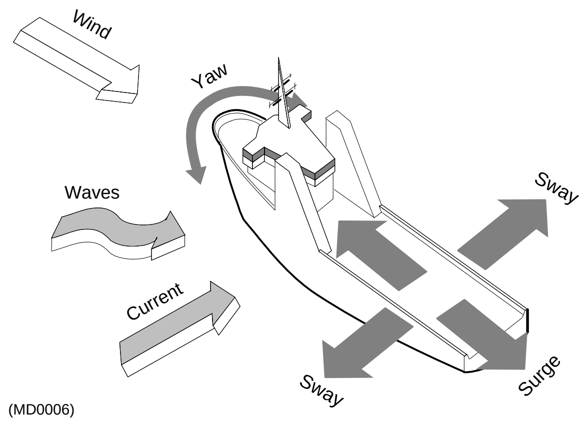


Figure 8.14. Forces acting on the vessel

The DP system is designed to keep the vessel within specified position and heading limits. The block diagram of the DP control system is shown in Fig. 8.15. The different parts are treated in more details in the following.

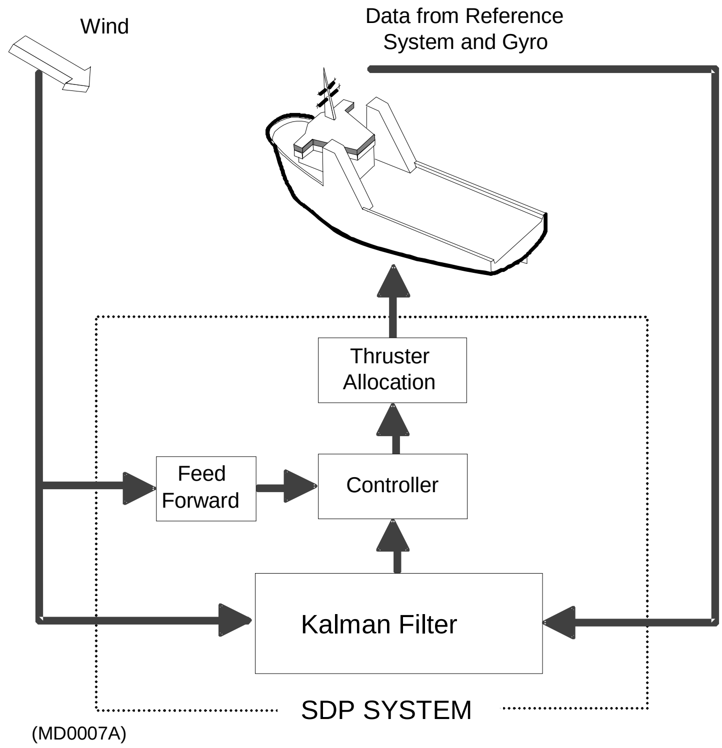


Figure 8.15. DP block diagram

The Kalman filter estimates the vessel's heading, position and velocity in each of the three degrees of freedom - surge, sway and yaw. It also incorporates algorithms for the estimation of the effect of sea current and waves.

The Kalman filter utilizes a mathematical model of the vessel. The mathematical model itself is never a 100% accurate representation of the real vessel. However, by using the Kalman filtering technique, the model can be continuously corrected. The vessel's heading and position are measured using a gyrocompass and a position-reference system, and are used as the input data to the DP system. These measurements are compared with the predicted or estimated data produced by the mathematical model, and the differences are then used to update the mathematical model to the actual situation.

The Kalman filter provide the following advantages:

- Noise filtering of heading and position measurements
- In the absence of position measurements, the model provides a "dead-reckoning" mode. This means that the system is able to perform positioning for some period of time without updates from a position-reference system.

The Controller is calculating the resulting force to be exerted by the thrusters/propellers in order to keep the vessel on position and heading (surge, sway and yaw). The Controller consists of the following parts:

- Excursion feedback
- Wind feedforward
- Current feedback

Excursion feedback
The differences between operator specified position/heading setpoints and the actual position/heading data, and similar differences with respect to the vessel's velocity and heading rate, drives the excursion feedbacks. The differences are multiplied by gain factors giving a force demand required to bring the vessel back to its setpoint values while also slowing down its movements.

Wind feedforward
In order to counteract the wind forces as quickly as possible, the feed-forward concept is used. This means that the DP system will not allow the vessel to drift away from the required position, but counteracts the wind-induced forces as soon as they are detected.

Current Feedback
The excursion feedback and wind feed-forward are not sufficient to bring the vessel back to the desired setpoints due to unmeasured external forces (waves and current). The system evaluates these forces over time, and calculates the force demand required to counteract them.

The force demand in the surge and sway directions and turning moment calculated by the controller is distributed to the various thrusters and propellers by the Thruster Allocation Module.

Measurements of vessel's position and heading at any point in time are essential for dynamic positioning.

Up to three position reference systems may be interfaced to the DP system, but only one used at a time.

Before the input from the selected reference system is used, it is checked for variations outside normal limits. Readings exceeding these limits will be ignored.

Similar applies also to heading measurements.

The vessel can be controlled in several different modes. The main difference between these modes is how the position and speed set-points are generated.

- The *Joystick* mode allows the operator to control the vessel manually using a joystick for position control and a rotate controller for heading control.
- The *Auto Position* and *Auto Heading* modes automatically maintain the required position and heading.
- The *Autopilot* mode enables the vessel to steer automatically on a predefined course.

- The *Track Pilot* mode enables the vessel to automatically follow a predefined sailing route.
- The *Seismic Track* mode enables the vessel to automatically and accurately follow straight lines between predefined waypoints

The DP systems are designed to meet the IMO MSC/Circ.645 *Guidelines for Vessels with Dynamic Positioning Systems* and corresponding classification notations.

8.4.11.1 The proposed DP configuration

The proposed DP system for deep sea mining production is a SDP 21 system. The principles of a SDP 21 system is shown in Figure 8.16. The SDP 21 system is designed to meet the IMO Class 2 operation requirements. It is however assumed that the IMO class 2 requirements do not strictly apply for the deep sea mining operation.

For class 2 operation, IMO requires 3 independent reference systems (e.g. 1 GPS, 1 taut wire and one HPR would meet the requirements). For the type of operation here, the only possible reference systems are GPS, GLONASS and HPR.

GPS has currently 4 options: Standard GPS, dual frequency GPS, differential GPS (DGPS) and DGPS in combination with GLONASS.

Standard GPS would give an accuracy of 15 - 25 meters. Dual frequency GPS has an accuracy of 5 meters. DGPS has an accuracy of 1 - 5 meters depending on the quality of the receiver. DGPS used in combination with GLONASS does not give better accuracy than standalone DGPS, but the combined system has more satellites available and is thus less sensitive if one or more satellites should fall out. Due to the distances to the nearest known good ground reference stations for DGPS, it can not be used with a good result in the Cook Islands area. Therefore, as an alternative, it should be considered to establish a new reference station.

As a conclusion the preferred reference system is dual frequency GPS. This gives an accuracy of 5 meters (95% of all positions are within 5 meters) which is good enough for the type of operation.

Within 2 - 3 years a wide area DGPS will be introduced. This has an accuracy of 3 meters. It is therefore recommended to use this type of GPS when it becomes available.

GLONASS as a separate system does currently not have enough satellites to be a 24 hour reliable system and it is also questionable whether the number of satellites is increasing or decreasing. Currently it is best used together with DGPS.

HPR systems are now rated for depths down to 6,000 meters. Since the production vessel is moving, it is however questionable if HPR is a suitable reference system for the DP. It would require at least 4 transponders on the seabed, and with a recommended maximum distance between them of 3 km, the maximum production area would be 9 square kilometres. Assuming an annual production of 665,000 tons, an average harvest rate of 10 kg nodules per square meter and continuous production 7 days a week, the transponders would need to be moved at least every 7 weeks. By using 6 transponders instead of 4, the area can be doubled (6 km x 3 km = 18 square km) and the transponders need to be moved every 14 weeks.

The proposed system therefore has three dual frequency GPS systems and no HPR systems. Triple redundancy is also used for the wind sensors, gyrocompasses, MRU's (Motion Reference Units used as vertical position reference) and UPS (Uninterruptable Power Supply).

SDP 21

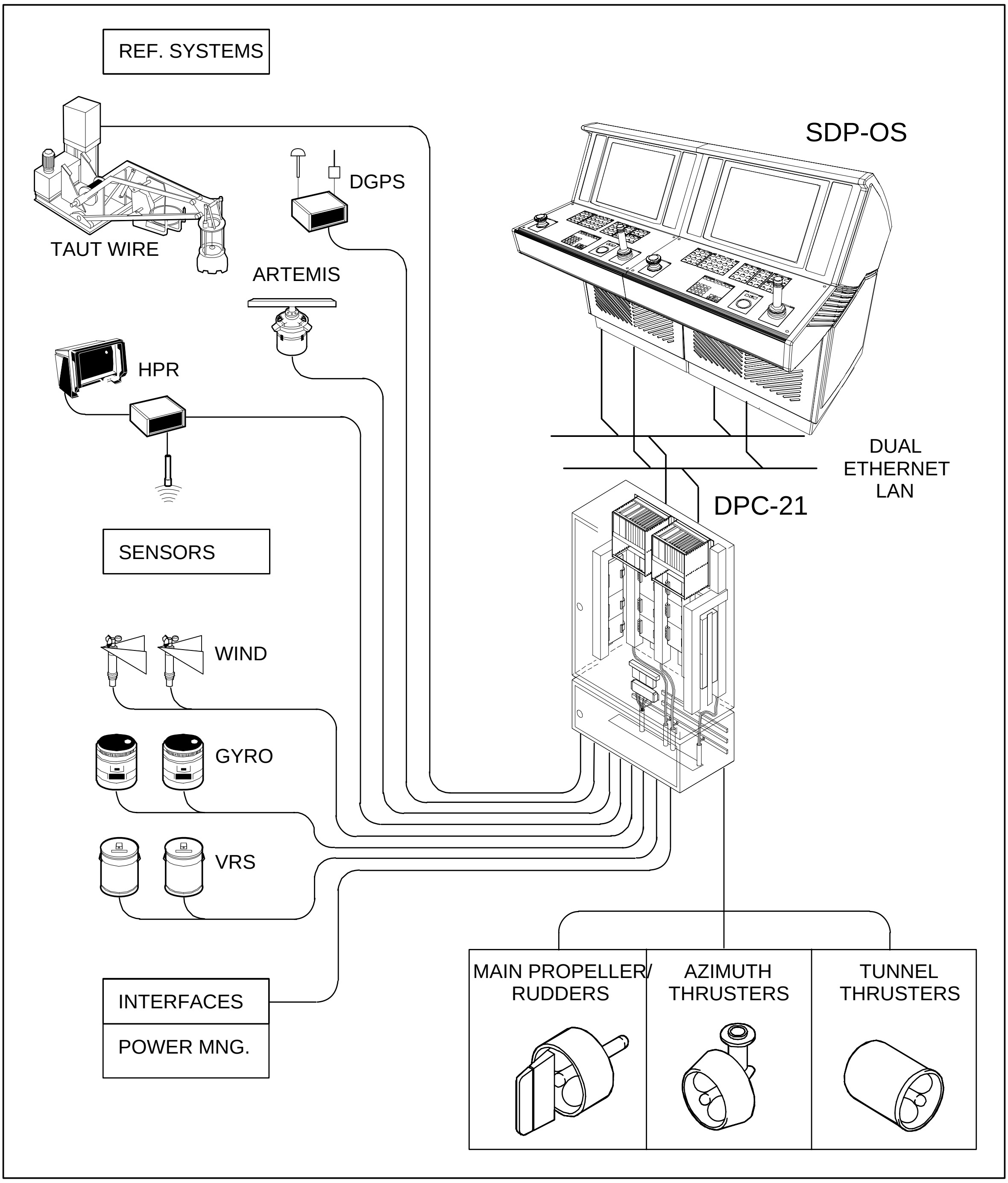


Figure 8.16. The proposed DP configuration

8.4.11.2 Hydroacoustic Position Reference system

The new generation Low Frequency (LF) Kongsberg Simrad SPT and MPT transponders are the subsea and seabed elements of the Kongsberg Simrad underwater positioning and navigation systems rated for depths down to 6,000 meters.

The transponder models have 30 channels for use with a HPR 400 LF system. Common for all the models are that they, on interrogation, will reply with a single- or multipulse response. This contains different information for the HPR 400 LF system depending on the application.

Applications:

- Dynamic position reference for the surface vessel
- Navigation of the underwater vehicle (ROV) and Subsea Harvester (SHV)
- Riser angle monitoring

The transponders can be positioned up to 3 km from each other. This makes it possible to cover an area of up to 9 square kilometres without moving the transponders.

8.4.11.3 Technology gaps – Dynamic positioning System

Position reference system
Ideally three different reference systems should have been used instead of three equal reference systems as proposed for the state of the art DP system.

It is a question whether three equal GPS systems gives good enough redundancy. If, for some reason, like disturbances due to sun spot activity, the GPS system falls out, then all three GPS systems fall out and the DP has no reference system in this time period. Such incidents are however rare and it is very unlikely that the DP system ever must run in dead reckoning mode for more than 15 minutes.

As described above, a wide area DGPS will become available within 2 - 3 years and should then be employed rather than the dual frequency GPS. Possible new suitable position reference systems should be employed as and when available to increase the safety of the operation.

Track and follow ROV functionality
The type of DP operation for deep sea mining will most likely require an update on the current "Follow Target" and "Follow Track" functionality available. This can however not be regarded as a technology gap, but would be an adjustment to the current functionality using state of the art technology.

8.4.11.4 Competitors – Dynamic positioning system

The following companies are competing in the DP market (in the order of market share):

- Kongsberg Simrad AS (65%)
- Nautronix (23%)
- Alston (formerly Cegelec) (10%)
- ABB (2%)

8.4.12 DP – Fuel consumption

Based on a simulation using estimated parameters, Kongsberg Simrad AS is able to present the average fuel consumption for the deep sea mining operation.

The simulation is based on the following assumption:

- 66,000 tons production vessel (typical FPSO):
  Length: 195 m
  Breadth: 37 m
  Draught: 10.7 m
  Depth moulded: 18 m
  Block coeff: 0.85
  Superstructure in the front, then deck house, rig (drilling like) and another deck house in the aft,
- Supply vessel (fastened side by side with the production vessel):
  Length: 175 m
  Breadth: 25 m
  Draught: 10 m
  Block coeff: 0.85
- Weather conditions (slightly harsher than West Africa):
  Wind: 20 m/s
  Current: 1 m/s
  Wave H_s: 5 m
  Period: 10 s

Table 8.10. Environmental data Cook Islands (Based on West Africa scatter diagram, scaled according to given 100-year condition.)

	H_s [m]	T_z [s]	Wind 10m, 1hour [m/s]	Current [m/s]	Probability of occurrence [-]	Cumulative probability [-]
Fine	1.2	6.3	5	0.07	0.11	0.11000
Smooth	1.8	7.2	10	0.17	0.45	0.56000
Medium	2.4	7.8	15	0.24	0.30	0.86000
Rough 1	3.0	8.3	15.5	0.24	0.06	0.92000
Rough 2	3.5	8.7	15.75	0.62	0.077	0.99700
1 year	4.0	9.1	16	1.00	0.0027	0.99970
10 year	4.5	9.4	18	1.00	0.00027	0.99997
100 year	5.0	9.7	20	1.00	0.000027	1.00000

Wind spectrum is Harris, Wave spectrum is Pierson-Moskowitz.
Wind, current and waves are assumed co-incident.

Table 8.11. Operational vessel set-up: Thrusters

Number	Position	Type	Thrust [tf]	Power [kW]
1	Bow	Tunnel	+22 / -22	1600 / 1600
2	Bow	Tunnel	+10 / -9	640 / 806
3	Bow	Azimuth	+30 / -12	1400 / 1400
4	Stern	Azimuth	+45 / -20	2600 / 2400
5	Stern	Azimuth	+45 / -20	2600 / 2400

All thrusters are rpm-controlled.

Vessel Set-up: Position Reference Systems

Two DGPS’s are used. Both have a measurement noise typical for North Sea Conditions

Table 8.12. Heading relative to prevailing weather

	Probability of occurrence		
	Head weather	Quartering weather	Beam weather
Fine	0.33	0.33	0.33
Smooth	0.33	0.33	0.33
Medium	0.33	0.33	0.33
Rough 1	0.50	0.33	0.17
Rough 2	0.50	0.50	0.00
1 year	1.00	0.00	0.00
10 year	1.00	0.00	0.00
100 year	1.00	0.00	0.00

Table 8.13. Supply vessel moored alongside

	Fraction of time alongside
Fine	0.33
Smooth	0.33
Medium	0.33
Rough 1	0.05
Rough 2	0.00
1 year	0.00
10 year	0.00
100 year	0.00

Table 8.14. Power consumption

	Hours per year [hrs] * Average power usage [kW]						Energy per year [MWh]
	Nodule-vessel with supply vessel alongside			Nodule-vessel alone			
	Head weather	Quartering weather	Beam weather	Head weather	Quartering weather	Beam weather	
Fine	107 * 599	107 * 678	107 * 625	214 * 281	214 * 425	214 * 503	462
Smooth	438 * 873	438 * 1213	438 * 1528	876 * 372	876 * 951	876 * 1499	4056
Medium	292 * 1647	292 * 2850	292 * 3506	584 * 781	584 * 2206	584 * 3250	5979
Rough 1	13 * 1880	8.8 * 3422	4.4 * 3939	250 * 852	166 * 2670	83 * 3943	1055
Rough 2	0 * 2949	0 * 5537	0	337 * 1417	337 * 4698	0	2061
1 year	0 * 5232	0	0	24 * 2379	0	0	57
10 year	0 * 5782	0	0	2.4 * 2587	0	0	6
100 year	0 * 6326 [1]	0	0	0.24 * 3177	0	0	1
						Totals	10667

The power consumption figures are based on simulations over half an hour, and the statistical confidence is therefore rather low.

The supply vessel is taken into the calculations when stated, but the methods for doing so and the effects of it are somewhat uncertain.

The main contributor to the (relatively) high power consumption in mild sea-states is the position measurements sinusoidal noise. This effect is (seems to be) due to quite ‘sharp’ tuning of the system, caused by high position accuracy requirements and (close to) resonance. It is expected that proper tuning of the system could reduce this resonance.

Fuel consumption

Based on the power consumption of 10667 MWH per year, and an assumed fuel consumption for the diesel engines equal to 200 g/kWh, the estimated fuel consumption is 2135 tons/year.

The confidence in this estimate is low. (An example of that: If the supply vessel is moored alongside at all times, the fuel consumption would be 3306 tones/year.) The confidence is however high that the fuel consumption will not exceed the double of the estimated 2135 tons per annum, i.e. 4270 tons per annum (12 tons per day) is a fairly safe estimate to be used in the economical study. Based on more accurate vessel parameters and vessel description, a more accurate simulation can be carried out.

[1] The vessel drifts off position, but is able to maintain heading.

8.4.13 Costs – surface vessel

8.4.13.1 Capex – Hull

Table 8.15. Capex, hull

MONOHULL PROJECT:			MONOPRODCOST ESTIMATING PROGRAM DEEP SEA MINING SHIP COST ESTIMATE											COST LEVEL: 2000 DATE:13.12.00	
ENGINEERING, MANAGEMENT, FABRICATION, ONSHORE AND OFFSHORE HOOK UP AND COMM. OF HULL															8,7
DESCRIPTION	NO OF	MT EACH	QUANTITY	UNIT	Mat Cost fact	MATERIALS NOK/UNIT	MATERIALS 1000 NOK	DIR & INDIR LABOUR FACTOR	HRS/UNIT	HOURS	FACTOR	NOK/HR	1000 NO	TOTAL 1000 NOK	TOTAL 1000 USD
PROJECT ENGINEERING AND MANAGEMENT:															
Project management			14 373	Tonnes				1,0	1,5	21 560	0,7	378	8 149	8 149	937
Detailed design primary steel			13 173	Tonnes				1,0	1,5	19 760	0,8	336	6 639	6 639	763
Detailed design equipment and bulk			1 200	Tonnes				1,0	30	36 000	0,8	336	12 096	12 096	1 390
Procurement			14 373	Tonnes				1,0	1,0	14 373	0,8	336	4 829	4 829	555
Project facilities			14 373	Tonnes									5000	5 000	575
Total Engineering and Management			14 373	Tonnes					6	91 692				36 714	4 220
EQUIPMENT:															
Equipment static	1	0	75	Tonnes	1,0	150 000	11 250	1,0	35	2 625	1,0	210	551	11 801	1 356
Equipment semi static	1		105	Tonnes	1,0	200 000	21 000	1,0	45	4 725	1,0	210	992	21 992	2 528
Equipment rotating	1		258	Tonnes	1,0	250 000	64 500	1,0	55	14 190	1,0	210	2 980	67 480	7 756
Equipment total			438	Tonnes			96 750		49	21 540			4 523	101 273	11 641
BULKS:											1,0	150			
Primary steel	1	0	13 173	Tonnes	0,7	5 000	65 865	1,0	45	592 785	0,9	189	112 036	177 901	20 448
Outfitting steel	1	0	291	Tonnes	0,7	6 000	1 746	1,0	120	34 920	0,9	189	6 600	8 346	959
Piping carbon steel	1	0	198	Tonnes	0,7	42 000	8 316	1,0	200	39 600	0,9	189	7 484	15 800	1 816
Piping stainless steel	1	0	34	Tonnes	0,7	63 000	2 142	1,0	450	15 300	0,9	189	2 892	5 034	579
Piping GRP	1	0	28	Tonnes	1,0	136 400	3 819	1,0	500	14 000	0,9	189	2 646	6 465	743
Eletrical	1	0	31	Tonnes	1,0	100 000	3 100	1,0	750	23 250	1,0	210	4 883	7 983	918
Fire and safety	1	0	5	Tonnes	0,7	77 000	385	1,0	400	2 000	0,9	189	378	763	88
HVAC	1		5	Tonnes	0,6	45 000	225	1,0	655	3 275	0,8	168	550	775	89
Instrumentation and Communication	1	0	13	Tonnes	0,7	140 000	1 820	1,0	550	7 150	1,0	210	1 502	3 322	382
Architectual	1	0	27	Tonnes	0,7	57 330	1 548	1,0	390	10 530	0,9	189	1 990	3 538	407
Cathodic protection	1	0	68	Tonnes	0,7	22 050	1 499	1,0	65	4 420	0,9	189	835	2 335	268
Corrosion protection paint	1	0	62	Tonnes	0,7	94 500	5 859	1,0	800	49 600	0,8	168	8 333	14 192	1 631
Total bulk			13 935	Tonnes			96 325			796 830			150 129	246 453	28 328
ONSHORE TESTING AND PRECOMM.	1	0	1 200	Tonnes		0	0	1,0	10	12 000	1,2	312	3 744	3 744	430
OFFSHORE HOOK-UP AND COMM.	0		0	Tonnes		1	0	1,0	2	0	1,5	390	0	0	0
YARD PRELIMINARIES															
Contractor profit											0,050		154 652	7 733	889
Contractor fixed overhead											0,055		154 652	8 506	978
Contractor facilities											0,060		154 652	9 279	1 067
Yard management	1		14 373	Tonnes				1,0	3,5	50 306	1,000	285	14 337	14 337	1 648
Yard engineering	0		0	Tonnes				1,0	5,0	0	1,000	225	0	0	0
Yard Other											0,020		154 652	3 093	356
Total Yard preliminaries										50 306			632 946	42 948	4 937
Total			14 373	Tonnes			193 075			972 368			791 343	431 133	49 555

8.4.13.2 Capex – Topside

Table 8.16. Capex, topside

MONOHULL PROJECT: — MONOPRODCOST ESTIMATING PROGRAM, DEEP SEA MINING SHIP COST ESTIMATE — COST LEVEL: 2000, DATE:13.12.00

ENGINEERING, MANAGEMENT, FABRICATION, ONSHORE AND OFFSHORE HOOK UP AND COMM. OF TOPSIDE

DESCRIPTION	NO OF	MT EACH	QUANTITY	UNIT	Mat Cost fact	MATERIALS NOK/UNIT	MATERIALS 1000 NOK	LABOUR Factor	LABOUR HRS/UNIT	LABOUR HOURS	LABOUR Factor	LABOUR NOK/HR	LABOUR 1000 NO	TOTAL 1000 NOK	TOTAL 1000 USD
ENGINEERING AND MANAGEMENT:															
Project management			3 173	Tonnes		0	0		2,0	6 346	0,8	432	2 741	2 741	315
Detailed design structural			1 729	Tonnes		0	0		2,0	3 458	0,8	336	1 162	1 162	134
Detailed design equipment and bulk			1 444	Tonnes		0	0		40	57 760	0,8	336	19 407	19 407	2 231
Procurement			3 173	Tonnes					4,0	12 692	0,8	336	4 265	4 265	490
Project facilities			3 173	Tonnes									5000	5 000	575
Total Engineering and Management			3 173	Tonnes					25	80 256				32 575	3 744
EQUIPMENT:															
Equipment static	1	0	165	Tonnes	1,0	150 000	24 750	1,0	35	5 775	0,8	96	554	25 304	2 909
Equipment semi static			560	Tonnes	1,0	200 000	112 000	1,0	45	25 200	0,8	96	2 419	114 419	13 152
Equipment rotating			417	Tonnes	1,0	250 000	104 250	1,0	55	22 935	0,8	96	2 202	106 452	12 236
Equipment total			1 142	Tonnes			241 000		47	53 910			5 175	246 175	28 296
BULKS:												150			
Primary steel	1,1	0	1 020	Tonnes	0,7	5 000	5 100	1,1	50	50 490	0,9	189	9 543	14 643	1 683
Outfitting steel	1,1	0	709	Tonnes	0,7	6 000	4 254	1,1	132	93 588	0,9	189	17 688	21 942	2 522
Piping carbon steel	1,1	0	59	Tonnes	0,7	42 000	2 478	1,1	220	12 980	0,9	189	2 453	4 931	567
Piping stainless steel	1,1	0	13	Tonnes	0,7	63 000	819	1,1	495	6 435	0,9	189	1 216	2 035	234
Piping GRP	1,1	0	0	Tonnes	0,7	95 480	0	1,1	500	0	0,9	189	0	0	0
Eletrical	1,1	0	71	Tonnes	1,2	120 000	8 520	1,1	825	58 575	1,0	210	12 301	20 821	2 393
Fire and safety	1,1	0	8	Tonnes	0,7	77 000	616	1,1	440	3 520	0,9	189	665	1 281	147
HVAC	1,1	0	26	Tonnes	0,6	45 000	1 170	1,1	721	18 733	0,8	168	3 147	4 317	496
Instrumentation and Communication	1,1	0	19	Tonnes	0,7	140 000	2 660	1,1	605	11 495	1,0	210	2 414	5 074	583
Architectual	1,1	0	94	Tonnes	0,7	57 330	5 389	1,1	429	40 326	0,9	189	7 622	13 011	1 495
Cathodic protection	1,1	0	0	Tonnes	0,7	22 050	0	1,1	72	0	0,9	189	0	0	0
Corrosion protection paint	1,1	0	12	Tonnes	0,7	94 500	1 134	1,1	880	10 560	0,8	168	1 774	2 908	334
Total bulk			2 031	Tonnes			32 140			306 702			58 823	90 963	10 456
ONSHORE TEST & PRECOMM.	1	0	1 444	Tonnes		0	0		12	17 328	1,2	234	4 055	4 055	466
INSHORE HOOK UP & PRECOMM	1	0	1 444	Tonnes		0	0		10	14 440	1,2	234	4 224	4 224	485
OFFSHORE HOOK-UP AND COMM.	1		0	Tonnes		0	0		3	0	1,5	293	0	0	0
LOAD OUT & SEAFASTENING	1	0	0	Tonnes		0	0		1	0		0	0	0	0
YARD PRELIMINARIES															
Contractor profit											0,050		13 766	688	79
Contractor fixed overhead											0,055		13 766	757	87
Contractor facilities											0,060		13 766	826	95
Yard management	1		3 173	Tonnes				1,0	3,5	11 106	1,000	359	3 988	3 988	458
Yard engineering	0		0	Tonnes				1,0	5,0	0	1,000	284	0	0	0
Yard Other											0,020		13 766	275	32
Total Yard preliminaries										11 106			59 053	6 535	751
Total			3 173	Tonnes			273 140			483 742			131 330	384 527	44 198

8.4.13.3 Capex - Dynamic positioning system

The capital cost for a dynamic positioning system for a production vessel operating according to IMO DP Class 2 is in the range 12 - 15 mill NOK. This system includes the following:

- Dual-redundant DP system
- One backup system (located separately)
- Three Gyrocompasses (triple redundancy)
- Three wind sensors (triple redundancy)
- Three MRU's (Motion Reference Unit - used as vertical reference system) (triple redundancy)
- Three UPS (triple redundancy)
- Three GPS (dual frequency Global Positioning Systems).
- Functionality for following ROV
- Functionality for following a track
- Commissioning

8.4.13.4 OPEX – Mining ship

Table 8.17. Opex mining ship

DEEP SEA MINING PROJECT

YEARLY OPEX CALCULATIONS mill NOKs

	No	Unit cost	Cost est	Cost	Tot cost
OFFSHORE COST					98
Spares				9	
Consumeables				1	
Fuel	10000	2000	20000000	20	
Manning	70	200000	28000000	28	
Catering	70	100	2555000	5	
Services				10	
Maintenance ship				10	
Maintenance subsea				15	
LOGISTICS COST					14
Transport				10	
Base				4	
LAND SUPP COST					15
Adm				5	
Technical				10	
INSURANCE					20
TAX					10
FEES					5
OTHER					5
OPEX TOTAL					167
Fuel cost NOK/kg	25	1,886792			
DP fuel t/year		3306			

8.4.13.5 OPEX – DP system

The operational cost over 20 years is 12 - 14 mill NOK, including the following:

- One midlife upgrade
- Two annual support visits
- Training of three operators per annum (operator turnover)
- Service and maintenance
- Spare parts

8.5 Control system / power supply system

8.5.1 Introduction

In this section we discuss the control and instrumentation issues related to the proposed deep sea mining project in Cook Islands. We also discuss the power supply system. As the concepts are fairly loosely sketched, no detailed analysis is possible at this stage. However, we discuss different components that are likely to be incorporated into the final system.

8.5.2 System Overview

The system has been described in detail in the previous sections. Basically, the system consists of a Subsea Harvester Vehicle, connected to a base (nodule storage) close to the seafloor. The base is connected to the surface vessel via a riser structure. The nodules will be transported to the surface using one of the following three methods:

- Whole nodule pumping (whole nodules are pumped up through the riser)
- Nodule Slurry Pumping (nodules are crushed subsea, and a nodule slurry is pumped up through the riser)
- Elevator (whole nodules lifted to the surface in a mechanical elevator)

Each part of the system has various instrumentation and control functions as described in the next sections.

8.5.3 Subsea base functions

The subsea base structure (SBS) has several functions as listed below.

Hydraulic Power Distribution. It may be feasible to supply all hydraulic power from topside via the main umbilical, this will depend on the final design of the harvesters. If frequent hydraulic manoeuvring is necessary, a subsea hydraulic power unit becomes necessary. This may then be located on the SBS, and supplied with top-up hydraulic fluid from topside to compensate for hydraulic fluid losses only. Alternatively, a HPU may be located on the harvester, supplied with top-up fluid from the SBS.

The SBS is intended to move at a certain height over the seabed. A system for measuring the height over the seabed is therefore necessary (e.g. based on ultrasonics). Such systems are routinely used on ROVs, and this is thus not considered a technology gap.

Nodule processing on the SBS. The nodule handling on the SBS will be different for the three cases, and is roughly outlined below.

8.5.4 Nodule processing on SBS - whole nodule pumping

Nodules are transported from the harvester to the SBS via the umbilical. In the SBS the nodules are washed and collected in an intermediate storage bin. The amount of nodules in this storage bin is monitored via a level meter. The whole nodules are then fed via e.g. a feed screw mechanism to the pump inlet, where they are mixed with seawater and pumped whole to the surface. The ratio of nodules to water is monitored via a densitometer at the riser. The density at the water pump outlet can be monitored by densitometers, which directly measure the density of the water/nodule slurry. Densitometers are routinely used topside, and have been used subsea for e.g. level meters. Some marinisation work will be necessary in order to qualify such a meter for the necessary depth.

The speed of the water pump can be adjusted. The speed of the feed screw mechanism can likewise be adjusted. If the storage bin overflows, the surplus nodules will fall to the seabed.

In order to keep the rising density to its nominal value, the SBS control system automatically adjusts the speed of the seawater pump and the feed screw mechanism. The speed of the seawater pump can e.g. be controlled in response to the level, and the speed of the feed screw can be controlled in response to the density (as the density varies greatly as whole nodules pass through the density meter, it is the average density over e.g. 10 seconds which is the actual control parameter).

If the harvester suddenly reaches an area rich in nodules, then the water pump speed will increase and the feed screw speed will decrease.

If the harvester finds more nodules than the lifting system is capable of pumping to the surface, then the storage chute before the feed screw mechanism will simply overflow, and the surplus nodules will drop to the bottom.

If the harvester reaches an empty area, then the density at the pump outlet will drop to the density of seawater. In response, the speed of the feed screw will increase and the speed of the water pump will decrease to idling values.

The water pump speed control is actually more convoluted than described, as one needs to take into account the rising pillar of nodules. If the water flow ever goes below a certain value, the nodules will stop travelling upwards in the riser, and will instead return downwards.

It will take some time to accelerate the 5 km water/nodule slurry column, since the water pump speed can only be accelerated and decelerated slowly. On the other hand, the feed screw speed can be adjusted much faster. We can in principle control rapid variations with the feed-screw, and slower variations with the seawater pump speed. One possible way to do this would be to let the feed screw be controlled by the density in the riser, and let the water pump speed be controlled by the nodule level in the chute. A sketch of this control scheme is found below. This figure shows the nodules entering the chute. The level of nodules is monitored by a level meter, e.g. of a capacitive type. In the bottom of the chute, a feed screw is feeding the nodules to the suction side of the pump. A large amount of seawater is added separately, so that the resulting density is within design parameters. By varying the speed of the feedscrew and the speed of the water pump, a wide range of nodule feeds can be handled.

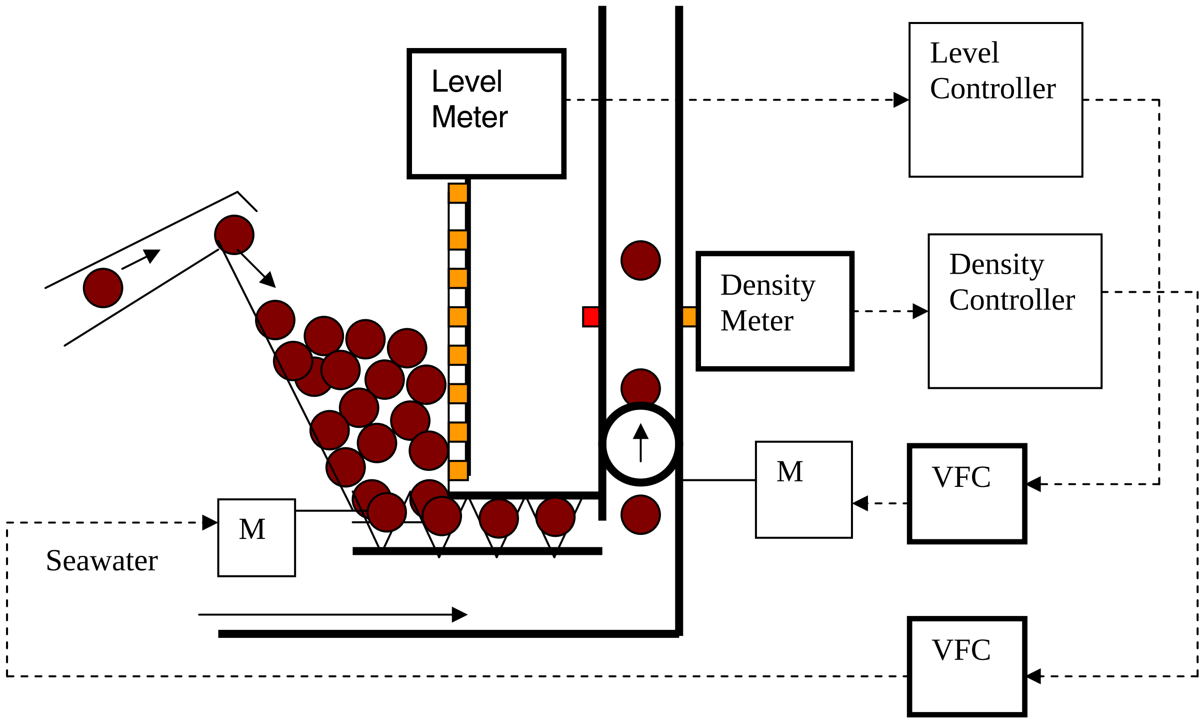


Figure 8.17 SBS control system sketch: Whole nodule pumping

8.5.5 Nodule processing on SBS: nodule slurry pumping

The difference between this case and the previous case is that the nodules will be crushed before pumping.

In this case it is thus assumed, that the harvested nodules will be washed, crushed and pumped to the surface. The ratio of nodule mass to water must be controlled such that the total density is less than e.g. 1.05 kg/m^3. We assume that a ore crusher with a feed screw mechanism with variable speed will be used for grinding and feeding nodules into the water pump inlet. Such crushers are routinely used topside, but some work will be necessary to give them a sufficient lifetime for the intended use. Several crushers may be mounted in parallel for redundancy and increased availability.

The density at the water pump outlet can be monitored by densitometers as in the previous case.

A simplified sketch of this system is found below.

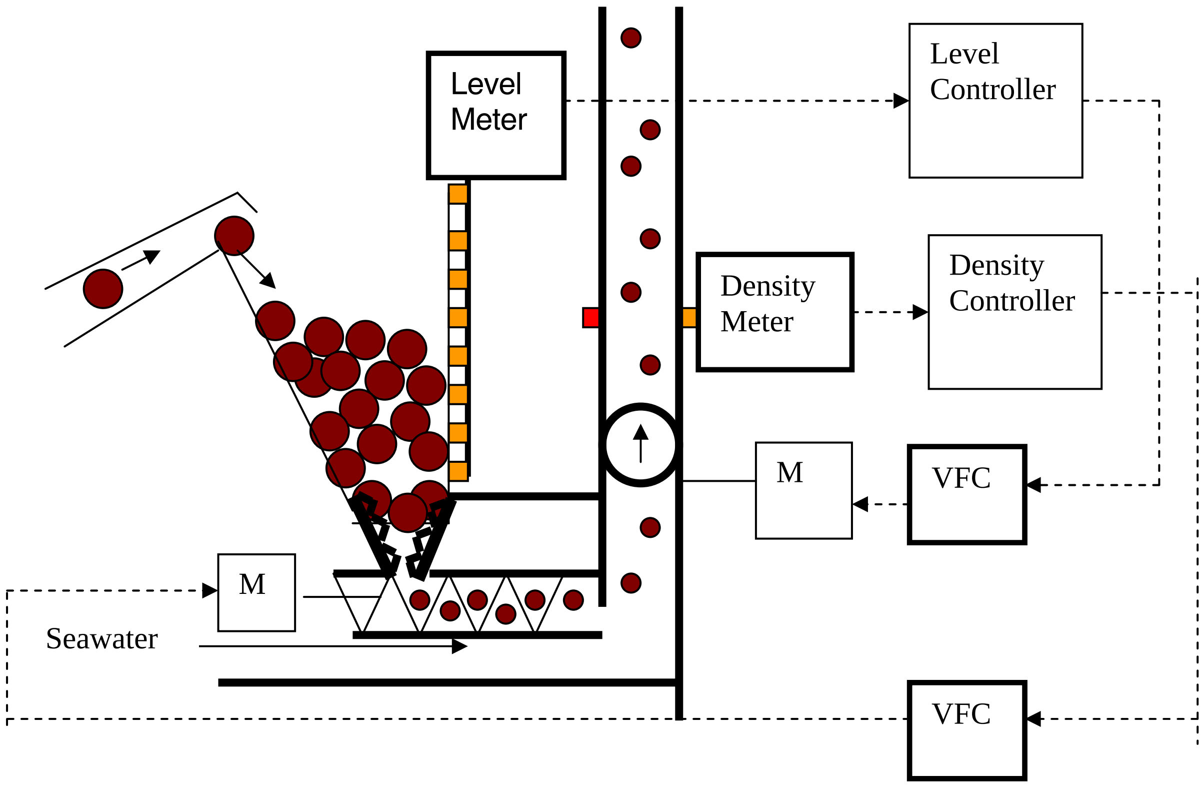


Figure 8.18 SBS control system sketch: Nodule slurry pumping

8.5.6 Nodule processing on SBS: nodule elevator

In this case it is assumed, that the harvested nodules are washed subsea, and then stored in an intermediate storage bin. At intervals, an elevator mechanism fetches a batch of nodules for transport to the surface.

Two elevators are used, and can be operated independently of each other.

Each elevator can be raised and lowered with a speed of up to 2.5 m/s. For a 6000 m riser, this gives a round-trip time of 1.3 hours. Assuming that the elevator can be emptied topside in 10 minutes and filled subsea in 0.5 hours, each elevator cycle will then take 2 hours as follows:

- 30 minutes for subsea filling
- 40 minutes for ascent
- 10 minutes for emptying topside
- 40 minutes for descent

Assuming the subsea intermediate storage has capacity for approximately 1 hours production (120 tons of nodules), there will then be some spare capacity. If we e.g. have a simple scheme of parallel operation (one elevator starts ascending at the same time as the other starts its descent) the intermediate storage will be 2/3 full when the descending elevator reaches the subsea base station. If the descent is delayed 20 minutes, the subsea storage will become full. As it is difficult to slow down the ship’s movement, the harvesters will then raise the collection unit (effectively driving straight over the nodules) until the level in the intermediate storage is reduced.

The SBS control system then monitors the amount of nodules in the storage bin, and supervises the elevator loading. When the elevator is fully loaded, a signal is sent topside and the elevator is lifted to the surface.

The level meter for the elevator can e.g. be based on a nucleonic density meter. When the nodule level in the elevator interferes with the beam from the nucleonic source to the detector, the elevator is regarded as fully loaded. Such level meters are routinely used topside.

A simplified sketch of this system is shown below.

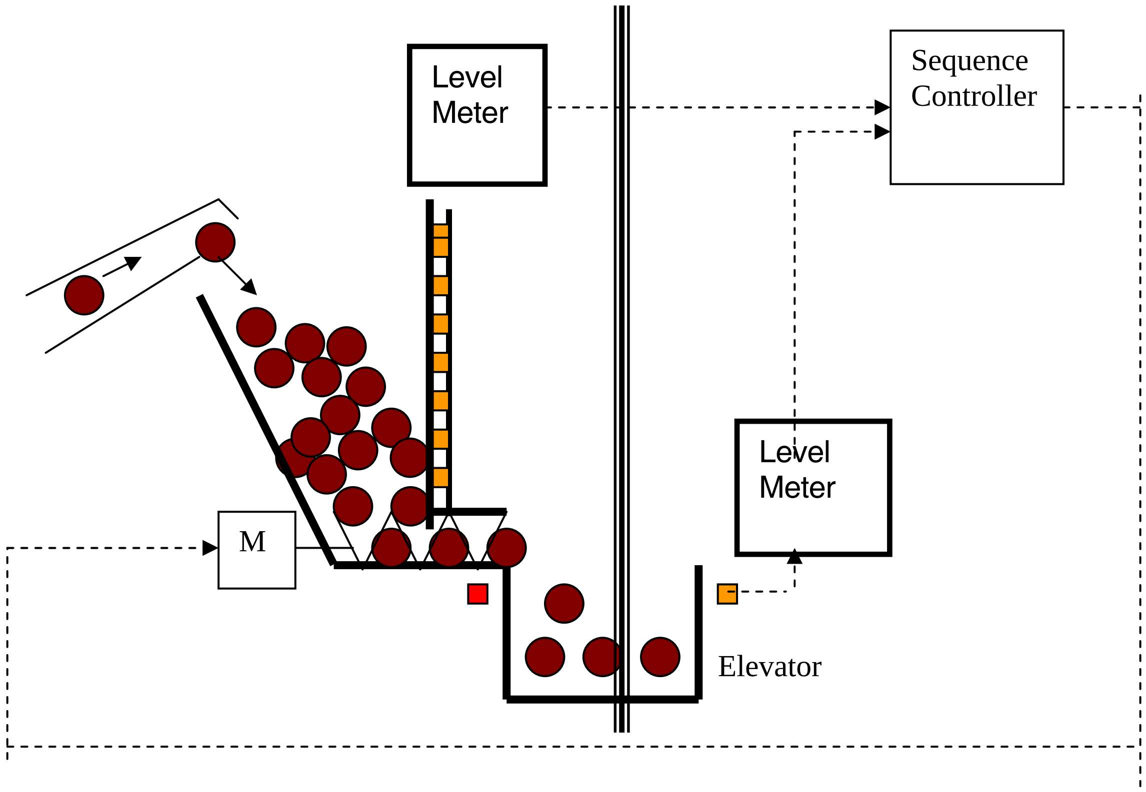


Figure 8.19. SBS control system sketch, chute elevator

The actual system is of course slightly more complex, as we have two elevators. We currently assume that there will be one harvester operating, two storage units and two elevators. The current design of the intermediate storage module is shown in the sketches below.

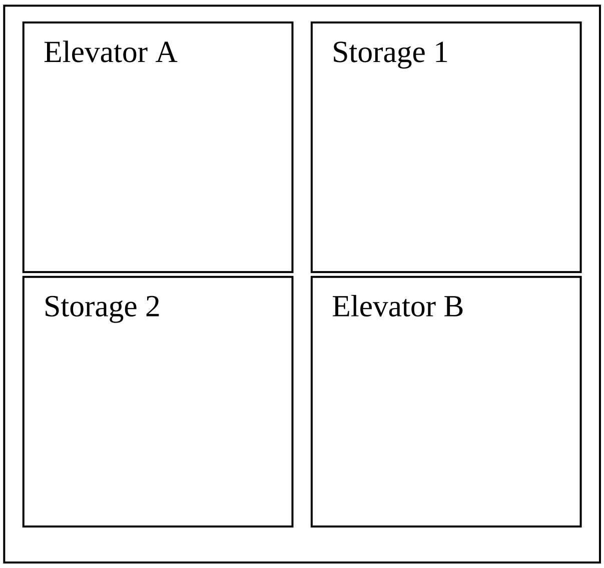


Figure 8.20. Intermediate storage: top view

Harvester#1 feeds into Storage#1 and into Storage#2. Each storage tank can feed nodules into each elevator via a feed screw system. A diverter sends the output from the feed-screw mechanism to either elevator A or elevator B.

Each storage tank has capacity for 1 hour production, i.e. 60 tons of nodules or 30 m^3. Assuming a 4 x 4 m overall size for the SBS, each storage tank will then have the size 2 x 2 x 8 m, and each elevator 2 x 2 x 16 m.

If we assume that the elevators dock below the storage tanks, the whole SBS structure will have the size 4 x 4 x 24 m.

Below is a sketch showing this arrangement in a side view.

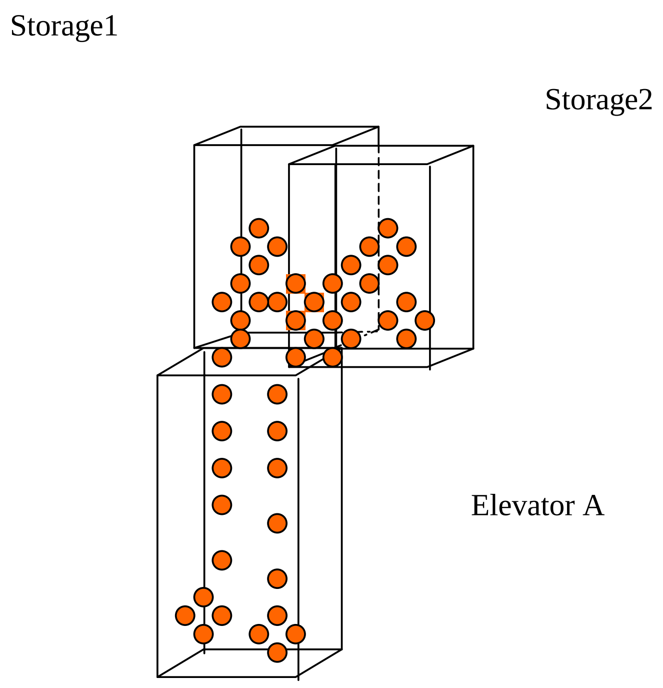


Figure 8.21. Simplified sketch of SBS with elevator A being loaded

The elevator will be cigar-shaped with rounded ends to give reduced friction when being hoisted up through the water.

For loading and unloading, there can e.g. be two sliding sleeves, one in the upper end (for loading) and one in the lower end (for unloading).

This arrangement is sketched below, with the sleeves shown in various positions (travelling, loading and unloading).

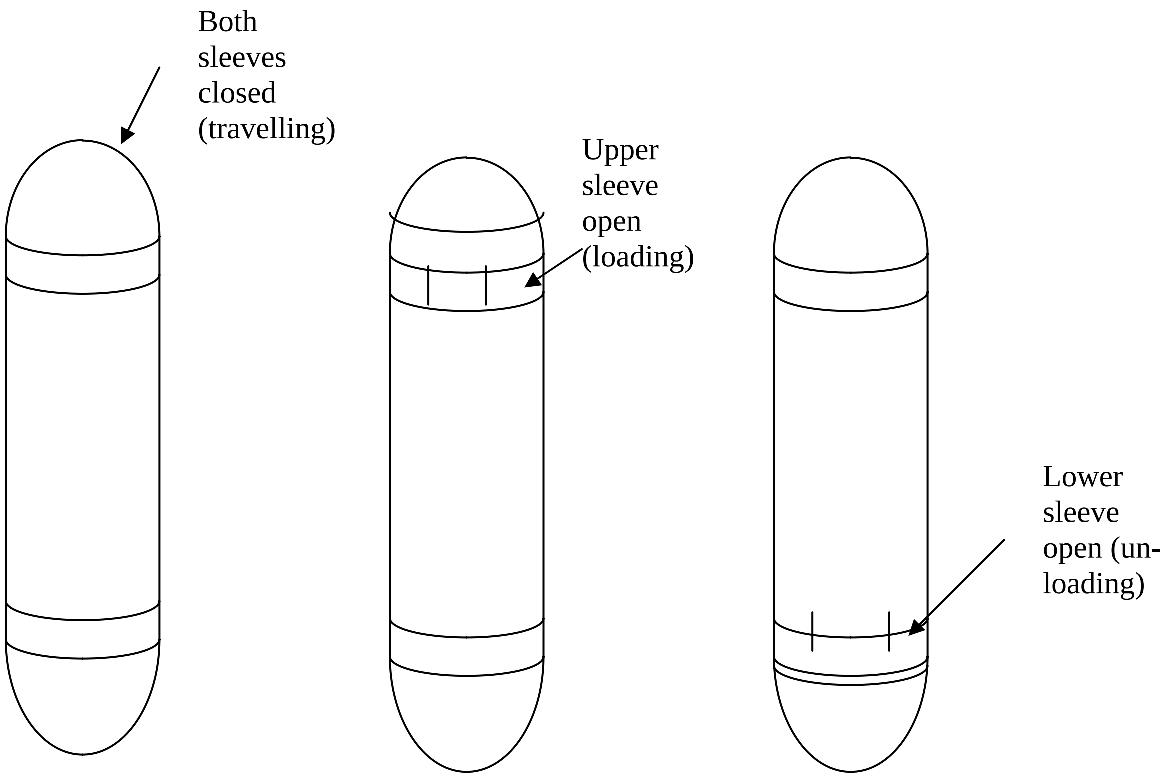


Figure 8.22. Elevator sketch (travelling, loading and unloading)

Topside, when the lower sleeve is moved, the nodules inside will fall out driven by their own weight (and a sloping floor in the elevator). As the weight of the nodules is pressing against the lower sleeve from the inside of the elevator, a certain amount of power will be necessary to move the sleeve. This is assumed to be done hydraulically.

Subsea, the upper sleeve needs to be opened as the elevator docks. As the elevator is empty, not much power is required to do this.

The amount of equipment needed in the SBS can thus be summarised for this case:

- Two level meters for intermediate storage (one for each storage vessel)
- Two level meters for elevators (one for each elevator)
- 2 screw feeders (one per storage vessel), hydraulically driven
- 2 diverters (such that each screw feeder can be diverted to each elevator), hydraulically driven

8.5.7 Topside system functions

The topside system has the following functional requirements:

- Position monitoring for the subsea base structure
- Navigation of ship to enable the subsea base structure to follow desired paths
- Operation of flushing, crushing and pumping equipment on subsea base structure
- Operation and monitoring of topside slurry receiving equipment
- Monitoring, prediction and avoidance of abnormal situations

The topside control system interfaces to the subsea system via the following interfaces:

Fiber optic modems (for data communication and video signal transmission).

Low voltage (e.g. 220 VAC) is supplied from the surface vessel topside to power the various control modules.

High voltage (e.g. 10 kVAC) is supplied from topside in order to power water pumps, feed screws and crushers (pumping). High voltage is not necessary for case 3 (elevator).

Hydraulic fluid (top-up) is supplied via umbilical to the subsea hydraulic HPUs for top-up purposes. It may possibly be feasible to have the HPUs topside and supply hydraulic power via the umbilical, but for the purpose of this study we assume that the HPUs reside subsea.

For navigation, the system can via DP control move the subsea base structure along the seabed at a certain height in a certain direction. Due to the long riser structure, the SBS can only be controlled fairly slowly.

The harvester (which needs to be capable of moving quicker than the SBS) will then move ahead of the SBS, much as dogs straining at a leash. Basically, the harvester will attempt to keep a certain distance ahead of the SBS.

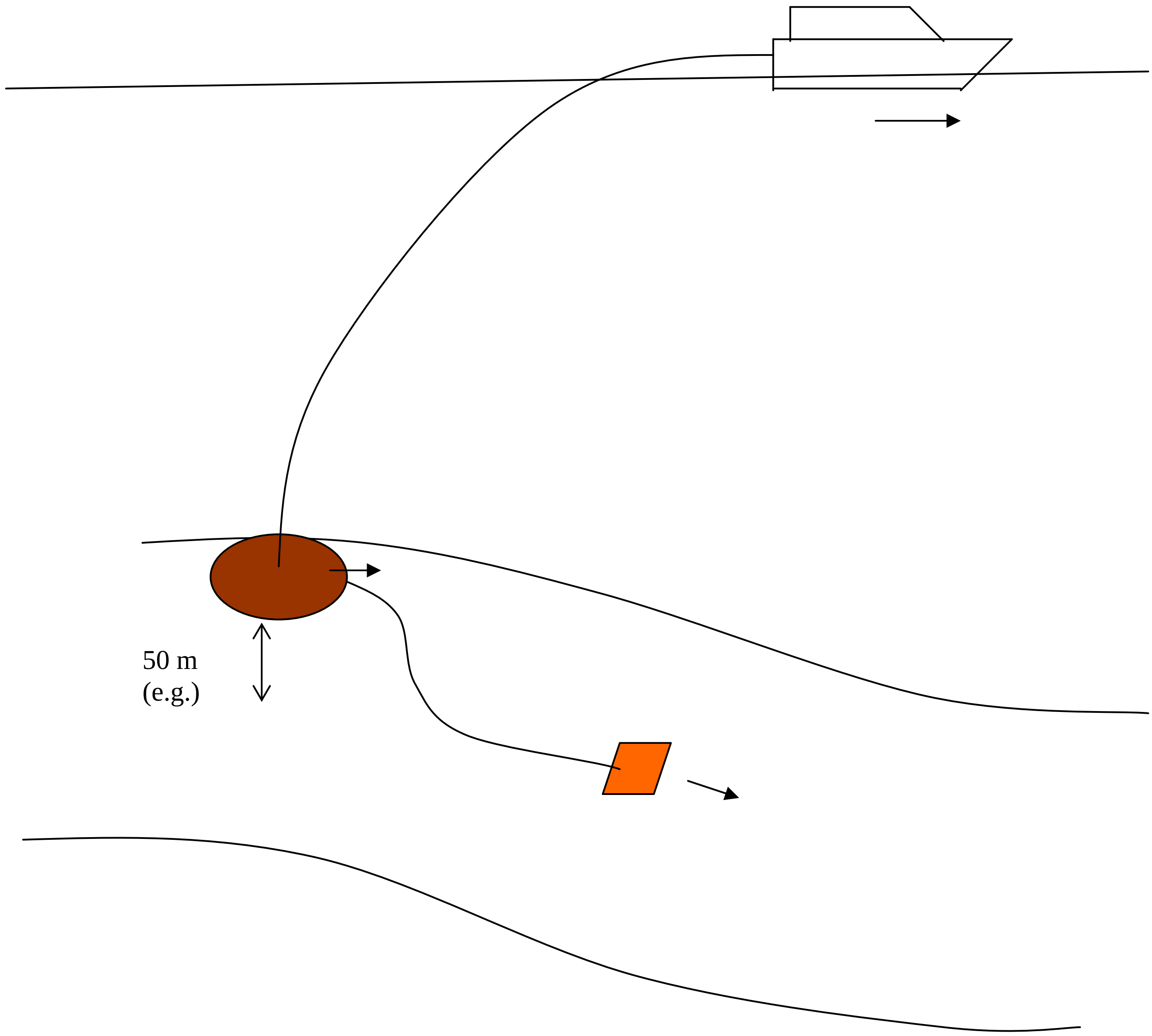


Figure 8.23. Harvester leading the SBS structure (perspective)

8.5.8 State of the art of technology

Standard ROV systems are currently available for depths down to 3000 m (see e.g. http://www.canyonrov.com/rovequipment/index.html). Many ROVs are however, stated by vendors, optionally available for 6000 m depth. Navigation and propulsion systems for the ROVs (including video systems and lighting systems) are considered to be available with no or little technology gap.

General subsea hydraulic control systems are only qualified down to approximately 2000 meters depth. This therefore represents a technology gap. We can either use an existing ROV type electro-hydraulic system and extend it to fit our needs, or use a standard subsea control system and modify it for 5000 m depth.

Subsea connection systems are available for the required depth (dry and wet mateable connectors, penetrators etc.), see e.g. http://www.seaconbrantner.com/products.html.

Sensors for pressure and temperature are routinely available down to 3000 m depth:
http://www.offshore-technology.com/contractors/instrumentation/
http://www.schaevitz.com/products/pressure/pdf/172-174.pdf

Specialised sensors for e.g. bathymetric use are available for the required depth (see e.g. http://www.hydrovis.demon.co.uk/uk94spe.htm).

On/off valves have been installed on subsea well trees down to 2000 m depth, if such valves are required for the deep sea mining project this will constitute a technology gap.

Hydraulic valve actuators have also been installed down to 2000 m depth, if required for larger water depths, this will also constitute a technology gap.

Modulating control valves with actuators have not been installed subsea yet, and constitutes a technology gap if needed.

Level sensors for sensing the nodule levels in chutes and/or elevators may be necessary (depending on the design). These represent a technology gap. A capacitive principle can possibly be used, as the permittivity of the nodules are different than the permittivity of sea water. Alternatively, a density meter with several detectors can be used (as the density of the nodules is different than the density of the seawater).

To monitor the ratio of nodules to seawater, a density meter can be used, which monitors the average density in the riser. If the density goes below its setpoint, it is possible to speed up the nodule feed screw and reduce the seawater pump speed. If the density goes above its setpoint, it is conversely possible to slow down the feed screw speed and accelerate the water pump speed.

8.5.9 Technology gaps - control system

The following technology gaps for instrumentation and control (and estimates of the time and cost needed to close them) have been identified. Note that not all of these components will be needed for each scenario.

Table 8.18. Estimate, technology gaps - control system

Component	Necessary work in order to close gap	Time estimate (months)	Used in cases	Cost estimate (kNOK)
Electro hydraulic control system	Extend ROV type electro-hydraulic control system, or modify standard subsea electro hydraulic control system	12	All	2000
Nodule level meter in chute	Verify feasibility of capacitive or nucleonic level metering principle. Qualify level meter for 5000 m depth.	6	All	500
Slurry Density Meter	Adapt to required water depth, and qualify	6	1,2	500
Nodule Crusher	Adapt to subsea use, and qualify.	12	2	3000

8.5.10 Measurement and control system

The following engineering activities will be necessary prior to construction of the proposed control system. An estimate of the necessary time involved is also included. The costs related to engineering and closing technology gaps have been included in the development costs in Chapter 11.

Table 8.19. Estimated engineering activities, control system

Activity	Manhours needed
Specify detailed functional requirements of subsea control system	200
Specify detailed functional requirements of subsea sensors and actuators	120
Specify detailed interface to topside control system	120
Prepare qualification plan for necessary equipment	160
Total	600

8.6 Necessary investments / operating costs

The following summarizes the cost estimates developed in this chapter:

CAPEX subsea:		
Subsea harvesting system	85.2 mill NOK - equals	USD 10.0 mill
ROV system	29.0 mill NOK - equals	USD 3.4 mill
Base structure / elevator	10.5 mill NOK - equals	USD 1.2 mill
Total CAPEX, subsea:		USD 14.6 mill
OPEX, subsea:		USD 1.0 mill
CAPEX, riser / lifting system:	143.5 mill NOK - equals	USD 16.9 mill
OPEX riser /lifting system:	10.2 mill NOK - equals	USD 1.2 mill
CAPEX, surface vessel		
Hull		USD 49.5 mill
Topside		USD 44.2 mill
DP	13.5 mill NOK - equals	USD 1.6 mill
Total CAPEX, surface vessel		USD 95.3 mill
OPEX, Surface vessel		USD 19.6 mill

TOTAL CAPEX PRODUCTION SYTEM: USD 126.8 mill

TOTAL OPEX PRODUCTION SYTEM: USD 21.8 mill

8.7 Transportation & Logistics

The nodules must be transported from the mine site in the Cook Islands to a processing plant. Based on the Bechtel study, which includes a detailed analysis of the transportation and logistics, the processing plant could tentatively be located near

Whangerei on the North Island of New Zealand. The distance between the harvesting site and this processing plant is approximately 4000 km. Assuming 12 kn sailing speed, 16 days are needed for the round-trip voyage between the harvesting site and the plant.

The 1,097,360 wet tons necessitates a transportation of 707,859 tons per year. Bechtel plans to use carrier vessels with 30,000 tons capacity and approximately 175m length, 25m beam and 10m draft to transport the nodules from the harvest site to the process plant. One ship can accommodate 10.4 days of harvesting by four trawlers. Unloading is estimated to take 1.1 days, for a net total cycle time of 27.5 days for receiving the harvested nodules, making the roundtrip and unloading at the processing plant. 3 vessels can accommodate the harvest of 31.2 days, resulting in a ship utilisation of 88 percent, which allows for miscellaneous activities and occurrences such as preparation for unloading, ship re-supply, minor repairs and delays in transit.

The three carrier vessels have an estimated capital cost of approximately USD 75 mill and an estimated operating cost of approximately USD 10 mill per year.

Alternative analysis

The nodules will during transport still contain water in the pores, but all the water is completely drained from the nodules. This means we can use a “dry cargo vessel” for the operation. The vessel must however be able to pump out a limited quantity of water that might come off the cargo during the cargo operation, or during the voyage from Cook Islands to Whangerei.

Because the cargo is in “solid form” when stored in the surface vessel, it is not practical to utilise a slurry transfer operation to the transport vessel. A slurry operation would also mean that the surface vessel would have to be more of a “tanker” and it would also mean a bigger ship, more steel and a higher price. The cargo-transfer operation must, however be studied in more detail and in relation to how the mechanical devises will react in relation to the cargo and also the weather and wave situation.

On the basis of the information we have received, we believe the best alternatives are either:

1. a simple grab-operation
2. a scraper-system

In case of **1**), it is probably best to have the cranes placed on the mining vessel. Depending on the size of cranes and grabs and subject to weather and waves, it should be possible to transfer 10,000 tons pr day (24 hour operation).

2) A scraper system is not too complicated but the investment is higher than for a grab operation. Briefly it is a conveyor belt at the tank-top, and the belt is fed by a “scraper”. The conveyor is feeding an elevator that takes the cargo to deck-level and transfers it to a conveyor. The conveyor is then used for loading the Ocean Going Vessel (OGV). The loading will be very quick and probably faster than a grab operation.

The number and size of vessels will depend on:

1) Storage at the surface vessel
2) How quick the load operation will be and consequently the round trip

Theoretically it should not be any reason why it should take more than 5 days to load a 45.000 dwt vessel and theoretically it can take only 1-2 days. Discharge should also be very quick. As mentioned, Bechtel have used 10 days for loading and (for some reason) 1,1 days for discharge. We believe it is unrealistic to calculate with only 1,1 day for discharge, while 10 days for loading seems to be "over the top".

The distance from the Aitukai passage to Whangerei is 1564 nautical miles or about 5 days with 13,5 knots one way. Allowing one extra day for weather plus 3 extra days for picking up crew for the surface vessel, we calculate with total 14 days for steaming.

The OPEX cost for a normal handy-max vessel is about USD 5000/day depending on flag, crew etc. We assume we can use a foreign flag vessel. The capital cost for a handymax of USD 27 mill will amount to about USD 9000/day. Please note that we have not built in anything extra for additional accommodation for the surface vessel transfer of crew operation.

Whether we use 10 +1 day or 5 + 5 days, the round-trip will be about the same i.e. about 25 days. A round-trip of 25 days means that the vessel will be able to do 14,6 round voyages per year - say 14. Dividing 707,850 tons on 14 trips actually means that one vessel can do the whole operation based on about 50,000 tons on each voyage; alternatively two vessels with cargo capacity of about 25,000 tons. Decision of one/two vessel will depend on how sophisticated the OGV must be or if one can fix a vessel from “the market” in case the dedicated vessel should face an accident.

Alternative I: One 50,000 dwt vessel

Charter rate: USD 16000/day x 365 days		
Capital cost: USD 9000/day		
Operating costs: USD 7000/day	USD	2,600,000
Bunkers & various	USD	1,000,000
Portcost incl. tugs	USD	900,000
Misc.	USD	100,000
TOTAL OPERATING COSTS	USD	4,600,000

This equals about USD 11-12/ton.

Alternative II: Two 30,000 dwt vessels:

Charter rate: USD 13000 x 365 days x 2		
Capital cost: USD 8000/day		
Operating cost: USD 500/day x 365 x 2	USD	3,700,000
Bunkers & various	USD	1,600,000
Portcost incl. tugs	USD	1,500,000
Misc.	USD	200,000
TOTAL OPERATING COSTS	USD	7,000,000

This equals about USD 18-19/ton

Conclusion

Based on this we have used the following estimates:

2 vessels with a cargo capacity of 25,000 tons

CAPITAL COSTS: USD 27 mill per ship, a total of USD 54 mill.

OPERATING COSTS: USD 7 mill.

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9 PROCESSING

9.1 Introduction

The harvested nodules must be processed in order to extract the interesting metals, Mn, Co, Ni and Cu. The Bechtel Corporation considered several different processing alternatives in their pre-feasibility study. The results of their analysis are presented in the report Deep Sea Nodule Prefeasibility Study (Job No. 23134-000), which is an extensive and relatively up-to-date study of nodule processing. This chapter includes a short summary and analysis of the processing solutions suggested by Bechtel, followed by a short introduction to processing alternatives for sulphides, and an assessment of whether or not these alternatives can also be used for nodule processing.

9.2 Summary of the Bechtel processing solution

The harvested nodules will be delivered by transport ships to a processing plant at the annual rate of 1,097,360 wet tons (equals 665,000 dry tons). The processing plant must be located adjacent to the shore to allow for unloading of the transport ships next to the plant. Bechtel considered several sites in Australia and New Zealand for locating the plant, but Marsden Point near the town of Whangerei in New Zealand was finally selected as the most promising plant site. The nodules will be unloaded at the plant using a Marconaflo hydraulic pumping system and stored in circular storage basins with a capacity of 130,000 tons. This will provide the process plant with a feedstock for 50 days.

The extraction of the metals will be a two-stage process. First pyrometallurgy is used to make a granulated sulphide matte/concentrate. At the planned production rate, approximately 8200 tons of matte/concentrate will be made annually. This product will then be treated further in a hydrometallurgical plant in order to make pure cathode cobalt, nickel and copper in quantities of approximately 2652, 1718 and 955 tons per year respectively.

Two pyrometallurgical (smelting) processes were considered for the first step of the metal extraction. A conventional electric furnace smelting process was eventually selected. Wet nodules are fed to a rotary dryer that is fired at the feed end with pulverised coal. The dried nodules are then transferred to a rotary reduction kiln which is fired with pulverised coal to a temperature of 850-950°C, resulting in a partial reduction of the metal oxides contained in the nodules. Final melting of the nodules takes place in the electric furnace where manganese and most of the iron, in the form of oxides, report to the slag, which is tapped and granulated for stockpiling. The molten alloy of cobalt, nickel, copper, and some iron is then transferred into a Peirce-Smith converter. Flux is added in the converter and the bath is blown to oxidize the iron, which can be collected as slag. The blown bath is then sulphurized to convert the alloy into sulphide matte. Finally the matte is granulated.

Hydrometallurgy including chlorine leach, solvent extraction and electrowinning processes are used to accomplish the extraction of metals from the matte. The leaching take place in a two step countercurrent leach circuit in which the first step is the cementation leaching and the second step is completion leaching. The ground matte is split with 75 percent flowing to cementation leaching and 25 percent going to completion leaching. In the cementation tanks the ground matte containing some metallic nickel will be contacted with solution from the completion leaching step. Soluble copper ions will cement out on the metallic nickel present in the matte, forming metallic copper, while a corresponding amount of nickel metal will be dissolved. Slurry from the cementation tanks will be separated into solid and liquid fractions by filtration. Solids will be returned to completion leaching. The cementation leach solution which contains a variety of metal ions will then be oxidized by adding chlorine gas and by blowing air through the solution, before it is sent to solvent extraction.

Completion leaching is the chlorination leaching of the combined 25 percent of the ground matte slurry, and the solids filtered out at the end of the cementation process. Chlorine gas serves as a powerful oxidizing agent that reoxidizes the copper and introduces it back into the solution. The slurry from the completion leaching is then filtered to yield a solid and a liquid fraction. The liquid fraction, containing essentially all of the metal values, is recycled to cementation leaching as described above. This is continued to put all of the metals into solution.

Solvent extraction (SX) is used to separate the metal substances from the mixture by treating the aqueous solution of the mixture with a solvent that extracts the required substances and leaves the other undesirable materials behind. In this case iron, considered a contaminant, is extracted first followed by cobalt and nickel. The solution containing the cobalt and nickel is then treated in an electrowinning process (EW). Electrowinning is an electrochemical process in which a metal dissolved within an electrolyte is plated onto an electrode resulting in pure metal. The electrolyte is pumped through a series of electrolytic cells where a DC current is supplied to alternating cathodes (usually stainless steel) and anodes (lead, silver or tin alloy). The cobalt and nickel are plated onto the cathodes, which are routinely removed from the cells for harvesting of the metal. Finally the completion leach filtrate is also sent to a similar electrowinning process where the product of the process is copper powder, which is suitable for further refining. The anode gases (chlorine) released during these processes are reused in the completion leaching process.

The total capital cost for this refining system is estimated to USD 271,100,000, (first quarter 1996) in addition to owner’s and development costs of USD 39,000,000. The cost breakdown is made up of:

USD 10,914,000 for nodule storage and reclaim
USD 221,342,000 for the pyrometallurgy plant
USD 38,844,000 for the hydrometallurgy plant

The operating cost of USD 22,921,9100 is related to:

USD 18,566,500 related to pyrometallurgy
USD 4,355,410 related to hydrometallurgy

9.3 Some comments regarding the Bechtel processing solution

Professor Gunnar Thorsen from the Department of Chemical Engineering at the Norwegian University of Science and Technology recently evaluated the processing solution proposed by Bechtel. His analysis suggests that the proposed solution is well proven and effective, but not the most cost-effective. As will be described in the next sections alternative solutions are now emerging that have the potential for large cost reductions.

Director Weldon Thoburn of the Canadian minerals company Hatch has also evaluated the Bechtel solution. He points out that the annual quantity of nodules to be processed, and the concentration of nickel and cobalt appear to be far too low to support an economically viable greenfields operation that would produce cobalt, nickel and copper metals. According to his estimates, the capital and operating costs provided by Bechtel are reasonable on an order-of-magnitude basis. However, at realistic metal prices, operating revenue barely covers the direct operating costs.

Considering the lead time, the people resources and the money needed to establish a refining operation, particularly by a company new to the industry, Thoburn therefore points out that it would be better to let a joint venture partner do the processing or alternatively to supply the nodules or an intermediate product to an established producer. This intermediate product could be a matte, a metallic smelter product or a sulphide precipitated after pressure leaching (see below).

Bechtel also indicates, in their report, that an outside metal refiner with an existing processing plant might be found who could be interested in buying and processing the matte for a fee or percentage of the contained metal values. If this refiner could be found, the hydrometallurgy plant would not be built, and the sulphide matte could be shipped in standard sea containers for off-site processing.

Bechtel also points out that the pyrometallurgical process utilises a rotary kiln for partial reduction of the nodules. It is however possible that this is not necessary and that this may simplify the plant design and reduce both the capital and operating costs. This will however not represent a major cost cut.

It must also be noted that the smelter will produce approximately 1450 tons of residue (slag) per day, which contains about 330 tons of manganese. In order to stockpile the 25 years of residue from a production of 11.3 million dry tons, an 80 meter high stockpile must be built with sloping sides and a base of 540 m^2.

9.4 Processing of sulphides

Sulphide ores have traditionally been beneficiated by flotation and other techniques to form metal concentrates that are processed by smelting and refining (electro-refining) to produce refined metals. However, processing by leaching has become increasingly used to either leach sulphide concentrates directly (in the case of zinc) or to leach intermediate products (such as mattes in the case of nickel or nickel PGM concentrates). Moreover, direct leaching of certain copper ores (oxides and transitional sulphides) is practised widely to produce a solution that can be treated by solvent extraction (SX) and electrowinning (EW) techniques to produce high purity cathode metal.

In leaching, the soluble metals are extracted from an ore, concentrate or intermediate by contacting the host material with an acidic solution. For conventional concentrates, this is normally done in an enclosed tank at elevated temperatures and pressures; it has so far been commercially successful for zinc. Nickel intermediates are also treated in enclosed vessels (using either sulphuric or hydrochloric acid, or ammonia). Copper oxide and transitional sulphide ores are usually treated by passing the lixiviant (sulphuric acid) through above-ground heaps of fairly coarse ore. The ore is placed on an engineered, synthetically lined, impervious pad, the surface of the ore heap is wetted with an alkaline solution that usually contains low concentrations of cyanide. This solution percolates through the ore, producing a soluble, precious metal-cyanide complex, known as the “pregnant” solution. The pregnant solution drains through the heap to the pad liner, then flows within a pipe drainage system to the pregnant solution storage pond. The pregnant solution is then pumped from the pregnant pond to the processing facility, where the precious metals are extracted from the solution with SX-EW technology.

Except for copper oxide and transitional sulphide ores or concentrates, leaching rates are impractically slow at ambient temperatures. Therefore, as noted above, direct leaching of sulphide materials must generally be done at high temperatures (up to 250ºC). This approach is also being attempted for oxide nickel ores (laterites) in Australia, a development that is very relevant to oxide sea nodules. This is called pressure acid leaching (PAL).

Laterites are secondary deposits formed near a surface by chemical weathering and oxidation over considerable time. Nickel and cobalt rich laterites are localised over ultramafic rocks and are typically restricted to a maximum depth from surface of 50 meters. PAL processing use sulphuric acid to extract the nickel and cobalt into solution in an autoclave at elevated temperatures and pressure. SX technology is then used for purification and concentration of the nickel and cobalt, followed by subsequent refining by either electrowinning or reduction techniques.

Another processing method known as bioleaching, which is a combination of biotechnology and metallurgy is also developing fast. In an attempt to overcome the drawbacks of leaching at high temperatures, extensive development work has been done on using bacteria to catalyse ambient temperature reactions.

Bioleaching extracts metals from ore using only water, air and microorganisms. Compared to chemical reactions alone the catalytic action of bacteria, such as Thiobacillus ferroxidans and Thiobacillus thiooxidans, accelerate chemical oxidation reactions by as much as one million times. It is however still a relatively slow process. Bioleaching works at atmospheric pressure and slightly above ambient temperatures, but is not yet a proven industrial process. Research is needed to increase the knowledge about the organisms that are involved in bio-oxidation of metals, including the biochemistry, physiology and genetics of the microorganisms.

Nevertheless, some success has been achieved with commercial scale operation for pre-treatment of gold refractory sulphide ores. However, even in this application, pre-treatment by pressure acid leaching is still more widespread. The problem is that even though the bacteria accelerate leaching, the kinetics are still at least two orders of magnitude slower than PAL.

The capital and operating costs for current and proposed leach-SX-EW plants compare very favourably with smelting-refining. Compared to pyrometallurgy leaching is less capital and maintenance intensive, and has less environmental problems. Capital costs are significantly lower than for traditional smelting and refining processes. Operating costs are also lower, at least for small to medium scale operations. Generally speaking capital and operating costs will be at least 50% cheaper with PAL leaching. If heap- or bioleaching is possible, it will make the plant and operating costs at least 60% cheaper, although the recovery would be slightly less. Leaching has in addition the potential of being installed on ships. This makes it very interesting for marine mining operations.

The US based marine mining consortium Deep Sea Minerals and Phelps Dodge Exploration intend to use leaching technology to process the sulphides from their SMS deposits. Their approach is based on PAL technology, which is now in an advanced stage of development, with several pilot plants operating and at least one test plant in operation in Australia. In essence, crushed ore from the mill will be treated in an autoclave (at elevated pressure and temperature) where the sulphides are oxidized. The ore is then leached with weak sulphuric acid that puts the metals in solution, before conventional SX-EW technology is used to produce cathodes.

Precious metals report to the residues from the process and are treated by conventional cyanide leach and recovery.

Nautilus Minerals are also considering leach technology including bioleaching and salt water leaching. As both of these processes have the potential for drastically reducing the processing costs, Nautilus plans to build a local heap processing plant on a nearby island and use barges to transport the material from the production unit. Nautilus also considers the possibility of not building a hydrometallurgy plant (SX-EW) but rather sell concentrates for an estimated 50% of the contained metal value.

The salt water leaching method is developed by Intec Copper Pty Ltd in Australia and leaches metals with saline solutions at 85°C and then electrowins the metal onto specially designed cathodes. A recent study estimated a capital cost of around USD 1400 per ton per year, a third the cost of a smelter. Operating costs at the test site were US 9.2 c/lb, around half the normal smelting cost.

All of the leach processes involve chemical separation where metals and minerals are isolated from the ore by chemical processes. Alternatively, physical separation techniques can also be used to separate valued substances from the more undesired substances. The most common physical separation technology is flotation. Flotation is mineral separation in which a variety of reagents are added to an agitated and aerated mixture of liquids and solids. This causes certain finely crushed minerals to adhere to air bubbles and to rise to the surface where they enter a froth, leaving the remaining minerals behind. Both Deep Sea Minerals/Phelps Dodge Exploration and Nautilus Minerals are considering using flotation to produce concentrates from seafloor SMS deposits.

9.5 Processing alternatives for nodules

It would be extremely useful if the smelting could also be avoided when processing nodules. If leach processes could be utilised instead (with the concentrates further refined by SX-EW technology or alternatively sold for further refining somewhere else), this would clearly result in a more cost-effective process solution. Many of the technical aspects of sulphide leaching are applicable to the oxide nodules, but it is more difficult to leach ferromanganese oxides, due to inherent reaction conditions. Physical beneficiation (flotation) is not possible for oxide nodules.

The obvious starting point could be the recent progress in laterite processing. Cost-effective PAL processing of the nickel and cobalt rich laterites can, as discussed in Chapter 3 lead to a depression of cobalt prices. However, if PAL processing can also be used to process nodules, the processing cost of a possible nodule project could be drastically reduced. This will not be possible, however, without further development and adjustment of the PAL process.

Another alternative is the Drinkard process. According to Drinkard Metalox in Charlotte, North Carolina the Drinkard Process can also be used to oxide nickel-cobalt ores. The company indicates that they have quite a few years and a number of millions invested in testing nickel deposits with this process. According to the company the Drinkard Process works very well on the nickel oxide ores on which it has been tested, and it will typically equal and usually better what has been achieved with pressure autoclaves, without the need for autoclaves.

Both capital and operating costs will supposedly be lower with this process according to a study in which the Drinkard process was compared with sulphuric and pressure autoclaves. The company will, however, require some preliminary test work and plant cost estimation to be done before the suitability for nodules can be finally confirmed. Tests should include both heap leach and vat leach possibilities, plant and capital cost estimates etc and would probably be an approximately USD 20,000 exercise.

Bioleaching has also been considered for nodules. Professor Emeritus Henry L. Ehrlich from the Rensselaer Polytechnic Institute has studied the theoretical framework for bioleaching of manganese nodules[2]. One alternative is to use bacteria that are found among the members of the typical manganese nodule flora. However, to eliminate interference from seawater salts, it may be more advantageous to use terrestrial bacteria, which allow bioleaching in fresh water. Obviously this has only been examined in bench-scale experiments and tests must be carried out on a pilot and industrial scale before a final conclusion can be made of the validity of this approach. It is also likely that a nutrient, such as pyrite, must be added to provide the acid solution required for dissolution of the metals.

It is, however, clear that a more detailed study of alternative processing alternatives should be considered, as the possibility of using alternative leach methods compared to pyrometallurgy would drastically reduce both the capital and operating costs. According to Phelps Dodge and others a leach processing plant of this magnitude can probably be built for USD 30,000,000 and operated for USD 8,000,000 per year. Even if we include a USD 20,000,000 development cost, and use Bechtel's figures for the hydrometallurgy plant and nodule storage and reclaim, the total capital cost can be reduced from USD 270,100,000 to USD 100,000,000, in line with the general estimates presented above. The operating costs can also be reduced with at least USD 10,000,000 per year. This will clearly influence the viability of the project.

[2] H.L. Ehrlich, Ocean manganese nodules: Biogenesis and bioleaching possibilities, Minerals & Metallurgical Processing, May 2000, Vol. 17, No. 2, 121-128.

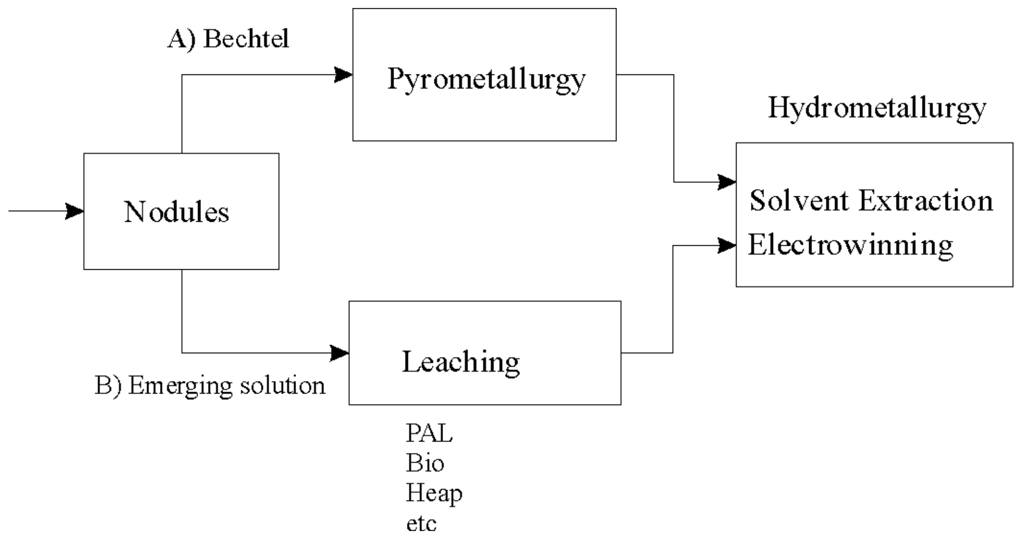

Figure 9.1. Processing alternatives for nodules

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10 ENVIRONMENTAL ISSUES

10.1 Environmental Consequences

Comprehensive work has been carried out during the past ten years to study the environmental consequences of marine mining. Environmental studies constitute a major area of research in deep seabed mining today. However, it should be emphasised that up to the present it has only been possible to study the effects of small-scale, short-term mining. There is broad agreement among scientists that only under long-term pilot mining operations will it be possible to study the environmental consequences satisfactorily.

There are three main environmental problem areas that can be expected from exploitation of the nodule deposits:

- The first relates to what happens on the seabed. As the collector unit collects nodules, it will damage the top few centimetres of the seabed as it proceeds forward. This may cause some disturbance and disruption to the flora and fauna in the mining tracks. In addition, the propulsion system of the collector unit may stir up some sediments. In the mining tracks, some scientists have estimated a mortality rate of 95-100 per cent. However, further analysis should be carried out for the proposed harvester before a conclusion can be made. It will also be attempted not to mine 100% of the seabed, to allow for re-population.

- The second relates to the discharge of wastewater from the mining ship. After the nodules have been collected by the collector unit, they will be washed clean by water jets and transported to the surface. Most systems envisage a slurry transportation of nodules with subsequent discharge of wastewater containing particulate matter and trace metals. This discharge may interfere with light penetration and reduce photosynthesis in the surface layers. Furthermore, the wastewater will be considerably colder that the surface water. However, our proposed system of a mechanical elevator will not involve discharge of any contaminated water.

- The third relates to onshore processing. This includes wastewater, tailings, and slag. This will be the same as in land-based mining operations.

It is important to distinguish between problems that are manageable and possible to live with, and significant adverse changes that can seriously harm the environment. A significant adverse environmental impact may be defined as: important harmful changes in ecosystem diversity, the productivity of the biological communities with the environment; or the threat to human health through direct exposure to pollutants, or through consumption of exposed aquatic organisms; or important loss of aesthetic, recreational, scientific, or economic values.

In our case, the most significant environmental impacts will be those caused by the collector unit on the seabead. Although more research is needed, it is likely that this will not constitute a significant adverse environmental impact.

The environmental consequences in connection with the mining phase is summarised in Table 10.1 (Markussen, 1994).

Table 10.1: Environmental consequences of deep-sea based mineral mining – mining phase

Impact	Impacted area	Duration	Near-field or far-field	Recovery	Significance
Physical impact to seabed material	Seabed	Long.term	Near-field	Slow	High
Mechanical damage at track edges	Seabed	Long-term	Near-field	Slow	Moderate
SPM from propulsion system	Water column	Short-term	Near-field	Slow	Moderate
SPM from mineral inlet	Water column	Short-term	Near-field	Slow	Moderate
Accumulated plume effect	Water column	Long-term	Near-field	Slow	High
Re-sedimentation	Seabed	Long-term	Near-and far-field	Slow	High
Nutrition hindrance	Seabed	Long-term	Near-field	Slow	Low
Pump motors	Water column	Short-term	Near-field	Rapid	Low
Thrusters	Water column	Short-term	Near-field	Rapid	Low
Expelling fish and marine mammals	Water column	Short-term	Near-field	Rapid	Low
Temperature decrease	Surface layer	Short-term	Near-field	Rapid	Low
Light reduction	Surface layer	Short-term	Near-field	Rapid	Low
Increase in particulate matter	Surface layer	Short-term	Near-field	Rapid	Moderate
Light intensity and quality reduction	Surface layer	Short-term	Near-field	Rapid	Low
Increase in trace-metal concentration	Surface layer	Short-term	Near-field	Rapid	Low
Exhaust	Surface layer, air	Short-term	Near-field	Rapid	Low
Noise	Air	Short-term	Near-field	Rapid	Low
Interference with commercial fishery	Water column	Short-term	Near-field	Rapid	Low
Collision	Surface	Short-term	Near-field	Rapid	Very low
Loss of mining ship	Seabed	Long-term	Near-field	Slow	Very low
Loss of subsea system	Seabed	Long-term	Near-field	Slow	Very low

Notes:

Duration: *Short-term:* disturbance on a short-time scale, in the order of weeks;
Long-term: disturbance over a longer period of time, in the order of years.

Recovery: *Rapid:* impacted environment will recover within months;
Slow environment will recover more slowly, with recovery to normal state taking years.

Significance: *Low*: not considered to cause any severe disturbance to the environment;
Moderate: considered to cause a noticeable effect on the environment, but no major problem to the community in the environment in question;
High: considered to cause severe harm to the environment; further studies needed prior to full-scale commercial mining.

10.2 Environmental regulations

There are no environmental regulations for the potential Cook Islands manganese nodule mining so far. A detailed set of rules to protect the environment should be formulated if mining should be initiated. There have been some attempts earlier to formulate environmental regulations for deep ocean mining in general.

In the United States regulations have been formulated - assuming that the companies will use a mining system consisting of a self-propelled collector unit, a flexible link to a buffer storage unit and a riser. It is a condition that an environmental impact study should be carried out prior to commercial production. The analysis is to be evaluated by an independent part appointed by US authorities before a possible permit for mining is given – cf. The US Deep Seabed Hard Minerals Act.

The United Nations is in the process of formulating similar regulations – and a draft version was ready last year. The Fridtjof Nansen Institute prepared the first environmental report for the United Nations in this field (Berge et.al, 1990).

The Underwater Mining institute has also recently proposed a regulation for environmental mining (Ellis, 2000). Marine mining companies that are signatories to this Code commit themselves to responsible environmental management in their current and potential operations throughout the world. The Code has been developed for industry signatories to show that they are proactive in setting voluntary and standardised environmental management for their operations.

Industrial signatories commit themselves:

1. to implement the Code
2. to report publicly on their implementation at their operating sites
3. to use external auditors for reviews of their implementation

Signatories to the Code will observe the policies and respect the aspirations of State, Territory and Sovereign governments, and of international authorities including such requirements as ISO 14,000, as relevant to mineral developments.

10.3 Some Comments on Crusts and Sulphides

It is important to distinguish between various types of deep seabed minerals, since these may represent quite different environmental problems. Future exploitation of polymetallic crusts and sulphide deposits will for instance concern relatively small areas, in which one will probably be mining larger quantities.

10.3.1 Environmental issues of SMS mining

The demand for metals and mineral products must be satisfied from either terrestrial or marine sources. Substituting a terrestrial source with a SMS source could offer a way to limit the net environmental impact of mining, since SMS mining can reasonably be expected to have several environmental advantages compared to both terrestrial mining and other marine mining ventures.

High grades and a lack of overburden mean a low proportion of waste will be produced by a SMS operation. The waste might even be returnable to the environment where it formed. Terrestrial mines produce increasingly high proportions of waste, and the greatest amount of liability faced by terrestrial miners is typically the result of the large volumes of waste, and consequent mismanagement disasters. Typical problem areas such as acid mine drainage and waste dumps can be avoided in the marine environment.

Greenhouse advantages may also be recognised. Terrestrial mining operations are great consumers of fossil fuels and are already under pressure to cut emissions from the greenhouse lobby. A potential carbon tax will take a large sum off the bottom line of terrestrial operations, and increase the competitiveness of marine operations.

Because SMS deposits are not covered by sediment, any fine sediment produced in mining will comprise mostly of sulphide. Its high density will aid in rapid settling of silt particles, thus reducing the amount of fugitive silt. Compared with mining manganese nodules, where vast areas will be disturbed, SMS mining operations can be expected to be highly focused, simplifying the job of monitoring and remediating. SMS mines are in addition typically located in less than 40% of the water depth of manganese nodule deposits, simplifying the tasks of environmental management and monitoring.

The major concern of mining SMS deposits is that the active systems are teeming with marine life of extraordinary and stunning variety. Clearly mining these sites would be unacceptable if it threatens this unique biological assemblage, which is a valuable resource in itself (see section 12.5). However, a number of observations suggest that the environmental effects of mining this habitat may not be very harmful. The vent fauna normally tolerates an extreme environment, and the release of substances from mining will probably not harm the local biota. Most of the species typically survive and regenerate after natural catastrophes such as sudden cooling or where lava flows wipe out large numbers of individuals. The deep vent fauna depends primarily on the presence of heat, H_2S and fluid emissions, rather than the presence of the SMS mound. As long as the heat and fluid emissions continue to provide an oasis, life will return to it. However, it must be expected that the vent communities will be disturbed and partly destroyed during mining, and this environmental issue should therefore be especially considered. Cautious mining strategies could be to mine progressively up-current, to mine only parts of a deposit, or to mine only at dormant deposits. Deep Sea Minerals intends only to mine dormant deposits.

References:

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11 COOK – A TECHNICAL/ECONOMICAL ANALYSIS

11.1 Estimate basis

The consensus appears to be that a manganese nodule mine site should be able to sustain a 1 to 3 million tonnes per year for at least 20 years. In other words the total size of the deposit needs to be at least 30 million tonnes, preferably more. At the same time the average abundance of nodules required for a first generation mine site is assumed to be 10 kg/m^2, with a combined metal content of at least 2%. All of these factors are satisfied in the Cook Islands. It is estimated that the cobalt resource in the Cook Islands is about 32 million tons, the equivalent of 520 years of the current world demand.

The 1980s witnessed static low or declining metal prices. In the early 1990s increases in metal prices started to revive mining company interest in manganese nodules and a proposed French nodule project as well as the Becthel study of the Cook Islands reserve was projected as being profitable. It should, however, be noticed that the Base Case in the Bechtel report was done with a cobalt price of USD 25/lb, and a price of Nickel equal to USD 3.33 and USD 1 for Cu. With the current cobalt price of USD 15/lb the IRR would be only about 7%.

The proposed mining rate of 1,097,360 tons/year is a marginal production rate when compared with terrestrial mines requiring similar investment costs. Elasticity shows that with the estimated world demand growth, this production rate of 2500 tons cobalt per year (approximately 10% of the market) would not affect the prices, all other producers remaining constant. If other suppliers increase their production, prices could be severely depressed. Cobalt is a limited market and Bechtel therefore assumed that an additional production of 10% could be done without seriously affecting the market. If the production rate is increased to 20%, we would probably see drastically reduced metal prices, due to the oversupply.

The following economical analyses is therefore based on the same production rates of nodules as Bechtel proposed in their pre-feasibility study, i.e. 10 percent of the world cobalt market.

Harvested nodules (wet tons):	1.097.360
Harvested nodules (dry tons):	665.000
Transported nodules (nominal dry tons):	707.850

The minerals produced from the nodules are cobalt, copper and nickel.

Production capacity of Cobalt (tons/yr):	2652
Production capacity of Nickel (tons/yr):	1718
Production capacity Copper (tons/yr):	955

Cobalt price:	USD 15/lb
Copper price:	USD 1/lb
Nickel price:	USD 3.33/lb

The cobalt price has fluctuated extensively in the past decade as discussed in Chapter 3. The base case estimate is based on an average cobalt price for the project period equal to USD 15/lb.

The production system prices and surveying costs are taken from our own estimates, see Chapter 7 and 8.

The transport vessels have been estimated by Kristian Gerhard Jebsen Skipsrederi, see Chapter 8.

The processing and various costs are taken from the Bechtel report and have not been escalated (first quarter 1996 estimates). The cost for the processing plant is assumed not to have increased for the last five years due to improvements in technology and production methods. The Canadian company Hatch has also evaluated the Bechtel cost estimates and has expressed that the costs are in the right order of magnitude.

Various costs include next phase studies and test work (USD 11 mill for program management, owner's cost, metallurgical testwork, test harvesting, site selection, feasibility study update, contingency), development cost (USD 9 mill) and owner's costs (USD 19 mill for environmental impact statement, owner's project management, land acquisition, process license, utilities hook-up, staffing and recruiting, start-up and commissioning, training of operators, taxes and insurance, contingency) and has been adopted from the Bechtel estimate. Various operating costs of USD 6.5 million include maintenance labour and general administration (including all management, administration and technical personnel for the complete project. In addition are items such as office supplies, insurance on the land based fixed assets, marine insurance for the ocean based assets, travel, entertainment, computer services, miscellaneous contracts, equipment leases and rents, licenses, advertising, donations, dues and memberships, public relations, phone/fax, radio, local taxes, unscheduled overtime and the like also included). For further details see the Bechtel report.

11.2 Assumptions

Loan/ equity rate:	70/30
Loan interest:	8%
Loan repayment:	8 years
Cost of equity:	15%
OPEX escalation:	0 or 3%
Depreciation:	20 years

USD/NOK: 8.5

Investments over 3 years: 20, 50 and 30 percent
No escalation of product prices (various product prices are analysed in the sensitivity analysis)
Two shifts, 24 hours operation (12 hours on/12 hours off)
Two crews, 14 days on/14 days off

11.3 Capital and operating costs summary

	CAPEX; mill USD	OPEX; mill USD
Collector/subsea base/ROVs:	14.6	1.0
Riser/lifting system:	16.9	1.2
Surface vessel:	95.3	19.6
Total production system:	126.8	21.8
Transport vessels	54.0	7.0
Processing:	271.0	22.9
Various:	39.0	6.5

Survey costs include an initial survey estimated to USD 5 mill with a subsequent survey cost for the following years equal to USD 1.9 mill, see Chapter 7.

11.4 Result

With the figures and assumptions presented above the result is presented below. The spreadsheet model was especially developed for this study. All figures are included in current dollar values.

	NPV (USD)	*IRR%*
Base Case	-187 mill	2.7

NODULE PROJECT COOK ISLANDS - BASE CASE

All numbers in USD

Operating time (d/yr):	330			**Investment costs:**			**Operating costs:**	
Harvested nodules (wet tons):	1 097 360			Production system		126 800 000	Production system	21 800 000
Harvested nodules (dry tons):	665 000			Transport		54 000 000	Transport	7 000 000
				Processing		271 100 000	Processing	22 921 910
Revenues:				Various (owner & dev.cost)		39 000 000	Various	6 492 200
Prod. capacity Cobalt (tons/yr)	2 652	Cobalt price (USD/lb):	15,00	Total investment (CAPEX):		490 900 000	Operating expenses (OPEX):	58 214 110
Prod. capacity Nickel (tons/yr)	1 718	Nickel price (USD/lb):	3,33					
Prod.capacity Copper (tons/yr)	955	Copper price (USD/lb):	1,00	Loan:	70,00 %	343 630 000	Survey expenses:	1 900 000
Total revenues USD/yr	102 435 348			From equity:	30,00 %	147 270 000		
Escalation rate	0,00 %			Initial survey:		5 000 000		
Tax rate	10,00 %							
Cost of equity	15,00 %			Total equity:		328 221 712		

FINANCIAL STATEMENT ESTIMATES AND DISCOUNTED CASH FLOW VALUATION

	01	02	03	04	05	06	07	08	09	10	11
Total revenues				71 704 743	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348
Operating expenses (OPEX)	5 821 411	5 821 411	5 821 411	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110
Operating income	-5 821 411	-5 821 411	-5 821 411	13 490 633	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238
Survey expenses	0	0	5 000 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000
Depreciation				24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000
Interest	5 498 080	19 243 280	27 490 400	27 490 400	24 905 897	22 114 633	19 100 068	15 844 338	12 328 150	8 530 667	4 429 385
Taxable income	-11 319 491	-25 064 691	-38 311 811	-40 444 767	-7 129 659	-4 338 395	-1 323 831	1 931 899	5 448 088	9 245 571	13 346 853
Tax				0	0	0	0	193 190	544 809	924 557	1 334 685
Profit	-11 319 491	-25 064 691	-38 311 811	-40 444 767	-7 129 659	-4 338 395	-1 323 831	1 738 709	4 903 279	8 321 014	12 012 168
Loan cash flow	68 726 000	171 815 000	103 089 000	-32 306 292	-34 890 796	-37 682 059	-40 696 624	-43 952 354	-47 468 542	-51 266 026	-55 367 308
Depreciation				24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000
Free cashflow				-48 206 059	-17 475 454	-17 475 454	-17 475 454	-17 668 644	-18 020 263	-18 400 012	-18 810 140
Working capital			-106 255 719	48 206 059	17 475 454	17 475 454	17 475 454	17 668 644	18 020 263	18 400 012	18 810 140
Investment	-98 180 000	-245 450 000	-147 270 000								
Net equity cashflow	-40 773 491	-98 699 691	-188 748 530	0	0	0	0	0	0	0	0

	12	13	14	15	16	17	18	19	20	21	22	23
Total revenues	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348	102 435 348
Operating expenses (OPEX)	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110	58 214 110
Operating income	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238	44 221 238
Survey expenses	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000	1 900 000
Depreciation	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000
Interest												
Taxable income	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238	17 776 238
Tax	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624	1 777 624
Profit	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614	15 998 614
Loan cash flow												
Depreciation	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000	24 545 000
Free cashflow	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614
Working capital	0	0	0	0	0	0	0	0	0	0	0	0
Investment												
Net equity cashflow	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614	40 543 614

NPV:	-186 953 187

Internal rate of return IRR:	2,7 %	ROE

11.5 Sensitivity analysis

A sensitivity analysis was conducted to determine the economic impact of changes in the assumed values of selected project assumptions. This analysis tests the relative impact of changes in individual assumptions using NPV and IRR/ROE as indicators of the project sensitivity to each particular assumption.

Based on our understanding of the project economics the following sensitivity estimates were prepared:

SENSITIVITY FACTORS	*NPV (USD)*	*IRR%*
Cobalt price changed to USD 20/lb	-81 mill	9.6
Cobalt price changed to USD 25/lb	23 mill	16.5
Cobalt price changed to USD 30/lb	127 mill	23.0
Cobalt price changed to USD 10/lb	-300 mill	-
Capital cost reduced by 25%	-109 mill	5.6
Capital cost increased by 25%	-267 mill	0.7
Operating cost reduced by 25%	-128 mill	6.2
Operating cost increased by 25%	-248mill	-
Income tax increased to 20%	-190 mill	2.3
Processing costs reduced to USD 100 mill (CAPEX), USD 12 mill (OPEX) according to the analysis in Chapter 9	-34 mill	11.6
Future scenario: Cobalt price USD 25/lb and processing reduced as above	174 mill	30.8

If OPEX is escalated with 3% IRR and NPV will be further reduced.

These results indicate that the project's economics are relatively more sensitive to changes in product prices than to changes in the capital and operating costs. The results imply that the project's economics could be significantly improved by securing higher product (cobalt) prices and would benefit less from comparably reduced costs. The analysis of the cobalt price indicates that prices of USD 10-15/lb is the most likely range in the near to intermediate future, although the market has been very volatile in the past decade. Changes in the nickel and copper prices have relatively limited effect.

The change in processing away from pyrometallurgy has a significant effect on the project economics. With the current cobalt price of USD 15/lb, the project is, however, still not economically viable with an IRR of 11.6% and a NPV equal to USD –34 mill.

A future scenario might be that the alternative processing methods as described in Chapter 9 become available, while at the same time the cobalt price increases to USD 25/lb. In such a case the project will be economically viable.

11.6 Risk Analysis

The following risk elements have been identified as the most important:

1) Market prices

Cobalt will account for over 90% of the revenues from the Cook Islands resource. As shown in Chapter 4 the cobalt market is the smallest and most volatile of the metal markets related to nodule mining. This may seriously affect the risk of the project.

Conclusion: High risk

2) Availability

Must verify weather data, to ensure that our logistical assumptions are correct. Must verify that technology and designs are viable for these water depths and operations.

Conclusion: Moderate to high risk

3) Estimation of costs

We consider this estimate to have an average accuracy of 30-35%, based on the fact that Bechtel's estimates have a stated 25% accuracy.

Conclusion: Moderate risk

4) Environmental issues

Environmental issues may affect the project, as international environmental groups will try to stop the project.

Conclusion: Moderate risk

Political risks are considered to be very low due to the fact that there is a stable political situation in the Cook Islands.

11.7 Waste material disposal

Recent work has shown that 75% of the environmental problems associated with marine ferromanganese operations will be with the processing phase of the operation, particularly the disposal of the waste material (Wiltshire, 2000). Traditionally the waste material is dumped in a pond and left there. Current work with manganese nodule tailings have shown them to be a resource in its own right as applications in a range of building materials as well as in agriculture. The tailings could also serve as an excellent filler for certain classes of resin cast solid surfaces, tiles, asphalt, rubber and plastics and has also been used as a weighting agent in drilling mud in the Baku fields. It has also been found that nodules can absorb up to 200% of their weight of sulphur dioxide, a common gaseous effluent in power plants. Thus they may find applications in the control of gaseous emissions as a stack gas decontaminant. The effect of using mineral tailings for these secondary applications could enhance the profitability of marine mining operations by a small but important margin.

References

Wiltshire J.C, 2000, Innovations in marine ferromanganese oxide tailings disposal, in D.S. Cronan, Handbook of Marine Mineral Deposits, CRC Press, London, 281-305.