B. CURRENT RESEARCH AND DEVELOPMENT

I. International Development Organizations

1. Outline

Since the exploration cruise made in 1873-1876 by R/V Challenger, manganese nodules have been a subject of fundamental scientific research. However, they were not considered in business circles to be a commodity for commercialization, and were largely forgotten.

In the middle of the 1960s, however, it began to be recognized that there are limitations to metallic mineral resources on land, so that new supplies for the future needed to be found. Furthermore, from tne beginning of the 1970s, corporations in those countries that were eager to develop resources began striving towards full-scale technical development. As a result, it was seen that the development of manganese nodules required, even in the more technical stages, a supply of funds too massive for a single corporation. Furthermore, the risk was also too great for one corporation to bear.

Moreover, from the technical standpoint also, it was seen that a successful manganese ore project would require wide-ranging professional capabilities and experience. This judgement encouraged the corporations which had proceeded with separate development to form common-interest groups which pooled funds, technology, and know-how. Thus, international consortiums began to be formed, leading to serious research and development in exploration, mining and processing of manganese nodules.

2. International Consortiums

Reference Table B-1 lists these international consortiums. At present, they are so involved in resolving their conflicts over territorial claims that exploration and technical development have been suspended.

3. Conditions in Each Country

3.1 Japan

Through the Agency of Natural Resources and Energy, Ministry of International Trade and Industry, Japan is developing manganese nodules as a part of its national resources policy.

In 1974, with the support of the Ministry of International Trade and Industry, the Deep Ocean Minerals Association (DOMA) was established by those Japanese companies (currently numbering 39) interested in the development of manganese nodules. The Ministry has entrusted official exploration operations to the Metal Mining Agency of Japan (MMAJ) which itself has entrusted DOMA with the actual exploration cruises.

These cruises started in 1975 and even now a manganese nodule exploration vessel, the "Hakurei Maru No. 2", built in 1980, is engaged in this work approximately 250 days a year. The Deep Ocean Resources Development Co., Ltd. (DORD) was set up in September 1982 as the principal agency for applying for mining sites as provided for by the Law on Interim Measures for Deep Seabed Mining of July 1982, and to proceed with mining and development projects. DOMA's exploration cruises will be handed over to DORD in the near future. DORD is scheduled to take over completely the results obtained in explorations (reconnaissance surveys) from the Government, and also take charge of future government exploration while continuing to conduct the detailed explorations required by private interests.

Other government agencies now conducting research into manganese nodules include the Geological Survey of Japan and the National Research Institute for Pollution and Resources.

On the other hand, full-scale research and development concerning mining technology, which also began in 1968 with the development of the Continuous Line Bucket System (CLB), was reached with the commencement, in 1981, of the Research and Development of Manganese Nodules Mining System project worked out by the Agency of Industrial Science and Technology, MITI. This project is scheduled to develop a mining system in nine years up to 1989 at a cost of approximately ¥20 billion. Most of the actual research and development has been entrusted to the MMAJ and the Technology Research Association of Manganese Nodules Mining System comprising 19 private companies.

3.2 The United States

With the impetus from private corporations, the United States is playing the most active part and is regarded as the base for the activities of each international consortium. The Government, in particular the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, has conducted research into the environmental pollution caused by deep sea mining (generally known as the DOMES Project). It also energetically executes other research activities.

In the United States the government institutes conducting research on manganese nodules are NOAA (see above), the U.S. Geological Survey (USGS, Department of Interior) and the U.S. Naval Oceanographic Office (NAVOCEANO, U.S. Navy). The universities and university research institutes engaged in this research are the Lamont-Doverty Geological Observatory (LDGO, Columbia University), the Scripps Institute of Oceanography (SIO, California University), the Woods Hole Oceanographic Institute (WHOI), the Hawaii Institute of Geophysics (HIG, Hawaii University), Oregon State University (OSU), Washington State University (WSU), and others.

3.3 The Federal Republic of Germany

Manganese nodules research and development in the Federal Republic of Germany is implemented as a part of an overall plan for oceanographic research conducted by Bundes Ministerium fur Forschung und Technologie (BMFT). The agency actually conducting the research is the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). BGR has close relations with private enterprise and engages in the exploration and development of oceanic mineral resources. The Arbeitsgemeinschaft Meerestechnisch Gewinnbare Rohstoffe (AMR), however, is a private organization active in manganese nodule research and development. AMR was organized in 1974 by 3 companies, Metall gesellschaft AG, Preussag AG and Salzgitter AG.

Other research institutes include the University of Hamburg, Techniche Universität Clansthal, Niedersächsisches Landesant für Bodenforschung.

3.4 France

Manganese nodules research and development in France is led by government agencies. Private activities are not vigorous. The government-related organs are the Centre National pour l'Exploitation des Oceans (CNEXO) which plays an active leading role, the Commissariat a l'Energie Atomique (CEA) and the Bureau de Recherches Géologiques et Minières (BRGM).

In the private sector only two companies are involved la Société Métallurgique Le Nickel (SLM) and Chantiers de France Dunkerque (CFD), a shipbuilding company.

Furthermore, to investigate in detail the investment and the operating costs for manganese nodules development, the Association Française pour la Recherche et l'Exploitation des Nodules (AFERNOD) was established in 1974 by CNEXO, CEA, and Le Nickel. Later, CFD and BRGM also joined AFERNOD. At present, AFERNOD plays an active role in various fields of exploration, mining and processing.

3.5 The United Kingdom

The United Kingdom has no particular policy on manganese nodules development. The development of these nodules and deep-seabed mineral resources and the promotion of related scientific technology, however, are carried out mainly by the Department of Education and Science.

The leading agencies concerned with manganese nodules are the Natural Environment Research Council (NERC) and the Science Research Council (SRC). With financial subsidies from these agencies, London, Manchester and other Universities conduct research into manganese nodules. The private institutions concerned are listed in Reference Table B-1.

3.6 Belgium

The Belgian Government has no particular policy covering manganese nodules development. Research is conducted by the private Union Minière S.A. and its affiliate, Metallurgie Hoboken-Overpelt (MHO).

3.7 The USSR

The USSR belongs neither to any of the international consortia mentioned above nor to any other groups, but plays an active independent role. Until 1970, it had been mainly researching the technology of mining, but in that year it mined approximately 10 tonnes of manganese nodules from the deep seabed with an exploration vessel, the "Vityaz". The Moscow Mining Institute has established a laboratory to develop technology and equipment for smelting and refining manganese nodules.

3.8 India

India began exploration cruises specifically for manganese nodules in the early 1980s. This exploration is being conducted by the National Institute of Oceanography (NIO) located in Goa.

On the other hand, the Council of Scientific and Industrial Research and other institutes have started a project known as the All-India Coordinated Project. This project aims at developing technology for manganese nodules mining and processing with aid from the Department of Ocean Development of the Government of India. India is the first of the developing countries to start manganese nodule exploration.

3.9 China

China began exploration for manganese nodules near the equator in the central Pacific Ocean in 1976. In 1978 also, it investigated and mined manganese nodules on the seabed at depths of 4,200 to 5,500 meters. The gross amount of investment in manganese nodules is reportedly 80 million yuan of which 16 million yuan are exploration-related costs.

II. Exploration Technology

Exploration is a process of observation and evaluation accompanied by surveys of the locations and quantities of deposits from an economic point of view. That is, it examines the occurrence, distribution and characteristics of individual deposits and the geophysical factors affecting mining. Manganese nodules are distributed over wide areas of the seabed, so that marine exploration activites, unlike those on land, require a research vessel carrying special equipment. Furthermore, it is impossible to perform a detailed survey of an entire area in a short time. Therefore, the areas of the sea to be explored are generally selected beforehand on the basis of existing data, such as bathymetric information and sea and weather conditions, and operations concentrate on these selected areas. As it proceeds from a reconnaissance operation to a detailed study, a survey will gradually narrow the intervals between the latticework of survey lines or sampling points. Thus, a wide expanse of ocean is narrowed down to a group of areas likely to produce good yields. Reference Table B-2 lists the typical research vessels used in the world.

The equipments used for manganese nodules exploration depends upon the purpose of the exploration cruise and the precision of the survey. The eqiupment generally employed is as follows:

a. Geophysical exploration system

- o Precision depth recorder (12 kHz, 30 kHz)
  In a bathymetric survey, sound waves at 12 kHz and 30 kHz are emitted from the bottom of the ship towards the seabed and the water depth is determined from the traveling time taken for the reflected waves.

- o Air-gun system
  Highly-compressed air is released underwater with an air gun and the geological structure below the surface of the seabed is determined on the basis of the resulting seismic waves.

- o Sub-bottom Profiler (SBP)
  Sound waves of 3.5 kHz are used to survey the geological structure of subsurface of the seabed.

b. Sampling equipment

The sampling equipment for gathering manganese nodules and seabed sediment are:
o Free-fall grab sampler
o Free-fall corer
o Box corer
o Spade corer
o Dredge bucket

c. Deep-sea camera and television system

These are used for direct observation of deep seabed areas and for surveys of nodules' coverage, type of sediment, etc. The camera itself is lowered from the ship to near the seabed with a coaxial cable.

d. Navigation system

The following system determine the precise position of a research vessel:
o Navy Navigation Satellite System (NNSS)
o Acoustic transponder positioning system
o Navigation buoy system

The exploration data obtained by the above research vessels and survey system is generally processed on board the ship and further processed, analyzed and evaluated ashore as follows:

a. Data processing on board

- o Map drawing
  Survey line maps, track maps, bathymetry maps, air-gun survey

analysis maps, SBP survey analysis maps, manganese nodules distribution maps, etc., are drawn.

o Data filing
o On-board grade metal analysis

b. Data processing, analysis and evaluation on land

o Data processing
- Data input, processing and selection
- Data table preparation
- Data file storage and management

o Data analysis
- Basic map drawing
- Standard statistical processing
- Manganese nodules distribution analysis
- Sedimentary layer analysis
- Bathymetric analysis, etc.

o Data evaluation
- Selection of the optimum exploration method
- Ore reserve calculation
- Deposit evaluation
- Claim evaluation, etc.

III. Mining Technology

Manganese nodules mining systems are generally classified as follows:

- CLB system
- Hydraulic dredging system
  - Collection methods
    - Self-propelled
    - Towing
  - Lifting methods
    - Pumping
    - Air lifting
    - Pressure-difference
    - Others
  - Others
- Container system
- Storage tank system
- Other systems

The continuous line bucket system (CLB) was invented in Japan. In this system, an endless rope fitted with numerous collection buckets spaced at fixed intervals runs from the mining ship down to the seabed, scoops up manganese nodules and brings them back up to the ship. Several prototype tests of this system were conducted and improvements were made to the system itself, the rope drawing method, on-board rope handling, the bucket shape, etc.

The hydraulic dredging system was invented in the United States. This system connects the seabed to the surface with a pipe and usually lifts manganese nodules with sea water as a medium. The system includes one of the following subdivisions: a pumping system, an air lift system, or a pressure difference system, according to the method used to bring nodules to the surface. The pumping system pumps manganese nodules suspended in sea water up into the ship.

The air lift system injects air into middle of the pipe and carries up the manganese nodules suspended in a stream of water and air. Both of these systems are at present considered to be suitable for large-scale commercial mining. The pressure difference system introduces an air space open to the atmosphere into the sea, connects this space to the seabed with a pipe and makes use of the difference in static pressure caused by the difference in altitude to force up the manganese nodules together with sea water.

The container system places the manganese nodules collected on the seabed into a container and transports this container from the seabed to the sea surface. Most of these systems are of the endless-rope circulation type, like the CLB system.

In the storage tank system, the nodules collected on the seabed are loaded into a tank, and when full, this is lifted to the mining ship. These systems are classified into the rope type, the buffer type, the flotation type and others.

Another system of manganese nodules mining is the self-powered shuttle vehicle system. This system shuttles the transporting vehicle itself between the seabed and the sea surface for the collection and raising of the manganese nodules. Reference Table B-3 compares the CLB system and the hydraulic dredge system. As the Table shows, the hydraulic dredge system is superior to the CLB system in two ways: in mining efficiency, a very important factor in actual operation; and in the controllability of the collector unit on the seabed. Reference Fig. B-1 indicates schematically the structure of the manganese nodules mining system.

IV. Processing Technology

The methods of manganese nodules processing being investigated are almost all hydrometallurgical processes. Even when a pyrometallurgical process is used, it is preceded by hydrometallurgical pretreatment. Furthermore, because of their special properties, manganese nodules cannot be concentrated with the usual dressing techniques, so that the entire volume of raw ore must be treated in the low-grade state. This is the greatest problem in manganese nodules processing.

The following aims have been set for developing and establishing a manganese nodules processing process:

a. High extraction of valuable metals
b. Establishment of metal recovery technology from pregnant solution, and its application
c. Use of existing plant in operation

According to published documents and other sources, the processing processes now being researched are the following:

Ref. No.

1) Smelting - leaching process
   1)-a Smelting to alloy - leaching
   1)-b Smelting to matte - leaching

2) Roasting - leaching process
   2)-a Chloridizing roasting - water leaching
   2)-b Reducing roasting - ammonia leaching
   2)-c Sulfatizing roasting - water leaching
   2)-d Segregation - ammonia leaching

3) Direct leaching process
   3)-a Sulfuric acid leaching
   3)-b Hydrochloric acid leaching
   3)-c Ammonia leaching
   3)-d Nitric acid leaching

Reference Table B-4 lists the above processing processes with their leaching rates. Reference Table B-5 shows the stages and recovery rates of the various processing processes; Reference Table B-6 compares the characteristics of the processing processes; and Reference Table B-7 summarizes the processing processes.

As a result of the above research, investigation in terms of the development targets given at the beginning of this report is focussed on the following highly feasible methods:

a. Reducing roasting - ammonia leaching [Ref. No. 2)-b]
b. Cuprion - ammonia leaching [" 3)-c]
c. High-temperature, high-pressure sulfuric acid leaching [" 3)-a]

d. Chloridizing roasting - water leaching [" 3)-b]
e. Smelting to alloy - conventional leaching [" 1)-a]

However, there is at present too little research data to give a detailed understanding of these methods. Nevertheless, the following are methods of interest for the future:

a. Segregation leaching [Ref. No. 2)-d]
b. Leaching with $FeCl_2$ or HCl
c. Leaching with a mixture of HNO_3 and HNO_2 acids
d. Ammonium carbonate leaching using a carbohydrate as a reducing agent
e. SO_2 reduction - ammonium carbonate leaching

Of all the above methods, the following are being studied as practical processing processes:

a. Kennecott Group methods
   o Reducing roasting - ammonia leaching - solvent extraction - electrowinning [Ref. No. 2)-b]
   o Reduction - ammonia leaching - solvent extraction - electrowinning (Cuprion/ammonia leaching process) [" 3)-c]

b. Moa Bay method
   o High-temperature, high-pressure sulfuric acid leaching - solvent extraction - electrowinning [Ref. No. 3)-a]

c. DVI method
   o Chloridizing roasting - water leaching - solvent extraction - electrowinning [" 2)-a]

d. INCO Group (OMI) method
   o Reducing roasting - smelting - sulfidizing - leaching - solvent extraction - electrowinning [" 1)-b]

Reference Table B-1 Outline of International Consortia
(Based on the U.N. document, Sea-bed Mineral Resource Development, 1982, and other data)

International Consortia	Participants	Parent companies	Country of origin of parent company	Share of participation (%)	Remarks
Kennecott Consortium (Unincorporated) Founded in Jan. 1974	Kennecott Corporation	Sohio	USA	40	A collector was tested in 1974 in sea 5,000 meters deep. No lifting test has yet been conducted. There have been a series of tests of lifting systems on land, covering both pump lift systems and air lift systems.
	RTZ Deepsea Enterprises, Ltd.	Rio Tinto-zinc Corporation Ltd.	UK	12	
	Consolidated Gold Fields, PLC	Same	UK	12	
	BP Petroleum Development, Ltd.	British Petroleum Company, Ltd.	UK	12	
	Noranda Exploration, Inc.	Noranda Mines, Ltd.	Canada	12	
	Mitsubishi Group	Mitsubishi Corporation, Mitsubishi Metal Corporation, Mitsubishi Heavy Industries, Ltd.	Japan	12	
Ocean Mining Associates (OMA) (Partnership registered in Virginia, USA) Founded in May 1974	Essex Minerals Company	United States Steel Corporation	USA	25	OMA conducted a mining test in Dec. 1978 in an area of the Pacific Ocean approximately 1,200 n.m. (2,200 km) southwest of San Diego using the Deep Sea Miner II. The designed capacity is 50 tonnes/hr.
	Union Seas, Inc.	Union Miniere S.A.	Belgium	25	
	Sun Ocean Ventures	Sun Company, Inc.	USA	25	
	Samin Ocean, Inc.	Ente Nazionale Idrocarburi (ENI)	Italy	25	
Ocean Management Incorporated (OMI) (Incorporated in USA) Founded in Feb. 1975	INCO, Ltd.	Same	Canada	25	From March to May, 1978, OMI succeeded in lifting a total of approximately 800 tonnes of manganese nodules using both the pump lift system and the air lift system, about 800 n.m. (1,480 km) south of Hawaii at a depth of approximately 5,000 meters. The manganese nodules mining ship handled approximately 30 to 65 tonnes/hr. This ocean mining test, conducted at approximatley one-fifth scale of full operational capacity, proved the feasibility of this mining system.
	AMR (Arbeitsgemeinschaft Meerestechnisch-gewinnbare Rohstoffe)	Metallgesellschaft AG, Preussag AG, Salzgitter AG	Germany, FR	25	
	SEDCO, Inc.	Same	USA	25	
	Deep Ocean Mining Company, Ltd. (DOMCO)	23 companies	Japan	25	

Reference Table B-1 (cont'd.)

International Consortia	Participants	Parent companies	Country of origin of parent company	Share of partici-pation(%)	Remarks
Ocean Minerals Company (OMCO) (U.S. partnership) Established in Nov. 1977	Amoco Ocean Minerals Company	Standard Oil of Indiana	USA	30.7	In Nov. 1978, the collector alone was tested in 1,800 meters deep. In Feb. and March 1979, an overall test was conducted in 4,700 meters deep.
	Lockheed Systems Company, Inc.	Lockheed Aircraft Corporation Lockheed Missiles and Space Company, Inc. (subsidiary of Lockheed Aircraft Corporation)	USA USA	30.7	Both the pump lift system and the air lift system were tested at sea. It is reported that there were some failures but finally technological data as well as some manganese nodules were obtained.
	Ocean Minerals, Inc.	Billiton B.V. (a Netherlands company of the Royal Dutch/Shell group)	Netherlands USA	30.7	The lifting system comprises an on-board system, a buffer established underwater, and a sea-bed collector. The underwater buffer, a special feature of this sytem, makes it possible to operate the collector, control the underwater hydraulic systems such as pumps, absorb oscillations from the ship, and also to store manganese nodules temporarily. Another characteristic of this system is that the collector is semi-automatically propelled by an Archimedes' screw.
		BKW Ocean Minerals B.V. (a Netherlands subsidiary of the Royal Bos Kalis Westminster Group, NV)	Netherlands	7.9	
AFERNOD (France) Established in 1974	Centre National pour l'Exploitation des Océans (CNEXO) Commissariat à l'Energie Atomique (CEA) Société Métallurgique Le Nickel (SLN) Chantiers de France-Dunkerque				The CLB system was first adopted for mining because of its low initial cost. Recently, however, research on the hydraulic dredge method is also underway. Furthermore, research is being conducted on the remote control shuttle system.

Reference Table B-2 Manganese Nodules Exploration Vessels

Name of vessel	Nationality	Length (m)	Width (m)	Depth (m)	Tonnage	Crushing speed (knots)	Main propulsion (HP)	Number of crew	Number of scientists	Completion (Year)	Remarks
Hakurei Maru	Japan	86.95	13.40	5.30	1,821 (Gross)	15	3,800	35	20	1974	Owned by MMAJ, mainly used by the Geological Survey of Japan
Hakurei Maru No.2	Japan	80.50	13.80	5.50	2,050 (Gross)	15	4,200	37	24	1980	Owned by MMAJ, used by DOMA
Prospector	USA	43.41	9.75	2.97	297.95 (Gross)	9.5	600	9	8	1964 (Remodeled)	Owned by DVI, used by OMA group
Governor Ray	USA	54.88	9.76	3.20	880 (Full load)	10	1,000(?)	17	14	1962 (Remodeled)	Used by OMCO grcup
Kana Keoki	USA	47.56	10.97	3.35	Approx. 300 (Gross)	11	1,800	15	15	1970 (Remodeled)	Used by HIG
Moana Wave	USA	52.44	10.98	3.53	299 (Gross)	10	1,600	11	9-11	1973	Used by HIG
Valdivia	Germany, FR	75.29	11.02	5.25	1317.72 (Gross)	11	2,160	25	19	1960	Used by OMI and AMR
Sonne	Germany, FR	86.5	14.2	6.5	2,607 (Gross)	13	4,000	25	23	1969	Used by OMI and AMR
Coriolis	France	37.60	8.00	3.75	450 (Displacement)	10	700	18	12	1963	
Le Noroit	France	50.55	10.66	4.32	870 (Displacement)	12	1,650	20	18	1971	
Vityaz	USSR	109.4	14.6	-	2,975 (Displacement)	-	-	-	-	-	
Gaveshani	India	68.33	12.19	4.93	1,900 (Displacement)	10	-	45	19	-	Owned by National Institute of Oceanography

Reference Table B-3 A Comparison of the Hydraulic Dredge System and the CLB System

Hydraulic Dredge System	CLB System
1) Movable underwater equipment (such as pipes, collectors, valvés, pumps and nozzles) is complex.	1) The only underwater moving parts are the ropes and buckets. Relatively simple facilities are adequate.
2) Mud (seabed sediment) is lifted together with manganese nodules, necessitating on-board ore-washing facilities.	2) Lifting washes away mud, so that on-board washing facilities are not required.
3) Preparation and removal are large, time-consuming tasks.	3) Preparation and removal are relatively easy and quick.
4) Limits on manganese nodule size necessitate a size-selection system on the seabed.	4) There is little limitation on manganese nodules size. Any nodules that fit in the buckets can be lifted.
5) If there is failure or breakage of the underwater equipment, repair work is very time-consuming.	5) Even if failures of the buckets or ropes occur underwater, repair work is relatively easy.
6) In the event of an underwater accident, the entire system is affected. In a serious accident, the entire undersection might conceivably be abandoned.	6) In the event of an underwater accident, the rope and buckets can conceivably be recovered by cutting the rope on one side.
7) Because of continuous collection and relatively high flow rate within the pipe, the quantity collected per hour of operation (mining efficiency) can be increased.	7) Because operation speed cannot be significantly increased, and because the manganese nodules are collected discontinuously, the quantity that can be collected per operating hour (mining efficiency) is limited.
8) The collection system is functional and reliability is relatively high.	8) Behavior of buckets and ropes moving underwater is arbitrary and not controllable. There is thus a great factor of uncertainty involved.

Reference Table B-4 Processing Processes and Leaching Rates

		Pre-treatment	Leaching Conditions									Pilot plant test		Similar plants operating		Company name
			Extraction %					Leaching solution concentration	Temperature °C	Pressure atm	Time Hrs.					
			Ni	Cu	Co	Mn	Fe					Yes	No	Yes	No	
1) Smelting - leaching process																
a. Alloy - leaching	1	Drying - smelting (1,400°C)						NH_3 100g/l, CO_2 25g/l				o		o		Kennecott
	2	Drying - roasting (1,425°C) - sulfidizing (1,370°C)	99	99	99		99	H_2SO_4 100g/l	110	105	2	o		o		Inco
2) Roasting - leaching process																
a. Chloridizing roasting - water leaching	1	Drying - chlorination (500°C)	97.4	96.1	97.6	94						o			o	Deep Sea Ventures
b. Reducing roasting - ammonia leaching	1	Drying - reduction (600°C)	98-37		95-12	85-22	77-0.5	NH_3 200g/l, CO_2 100g/l					o	o		Brooks
	2	Drying - reduction (350-550°C)	70-20	99-71		15.5-0.1	13.6-0.1	NH_3 6%, CO_2 4%	50-40	12			o	o		Okamoto
	3	Drying - reduction (350-750°C)	2.2-84.6	94.1-88.1	75.7-53.2			NH_3 11%, CO_2 6.2%	Room temp.	1	3	o		o		Kennecott
c. Reducting roasting - nitric acid leaching	1	Drying - reduction	58	50	60	25	25	NH_3 6.5N	50	1	0.5		o		o	California Univ.
d. Sulfatizing roasting - water leaching	1	Drying - sulfatizing (400-725°C)	73-12	77-12	99-37	95-57	15-1.4						o	o		Brooks
e. Segregation - ammonia leaching	1	Drying - segregation (850-950°C)	10.2-trace	100		0.3-trace	0.1-trace									Okamoto
3) Direct leaching process																
a. Sulfuric acid leaching	1		95-80	95-80	80-70			H_2SO_4 200-250g/l	200-240				o	o		Haenig
	2		60	40	10			H_2SO_4	100				o	o		Haenig
	3		95	87	80	5.2	2.5	H_2SO_4	180		3		o	o		Subramanian
	4		high	high	high	low	low	H_2SO_4	200	100	1		o	o		Han
	5	Pre-heating (100-720°C)	80	90	10			H_2SO_4 0.5N	90-30				o	o		Ito
	6		98-85	98-85	60-30	40-5	2	H_2SO_4	250-200				o	o		Ulrich
	7		96-90	96-90		low	low	H_2SO_4 200g/l	200		3					Neushütz
b. Hydrochloric acid leaching	1		94.9	86.3	89.5	78.1	91.1	HCl 3.4N	25				o		o	Ichijo
	2		2.22	32	0	0.7	0.7	HCl 2N, NH_4Cl 1M	50				o		o	Ichijo
	3		98-85	98-85	60-30	5	2	HCl	250-200				o		o	Ulrich
	4		89.8-4.6	100-73.9	13.1-0	5.90-0.41	43.8-13.7	HCl 0.5N	90-30		5-0.5		o		o	Ito
	5		83.8	80.6	67.8	91.1		HCl 4%, $FeCl_2$	80-40		14		o		o	Card Well
	6							HCl 2N, Fe^{2+} 75g/l	90							Ichijo

Reference Table B-4 (cont'd.)

		Pre-treatment	Leaching Conditions									Pilot plant test		Similar plants operating		Company name
			Extraction %					Leaching solution concentration	Temperature °C	Pressure atm	Time Hrs.	Yes	No	Yes	No	
			Ni	Cu	Co	Mn	Fe									
c. Ammonia leaching	1		88	89	92			$(NH_4)_2SO_4$ 1M, NH_3 5.9M, $MnSO_4$ 0.5M	60		4				o	Kennecott
	2		4	22	4			$(NH_4)_2SO_4$ 1M, NH_3 5.9M	60		4				o	Kennecott
	3							$(NH_4)_2CO_3$, NH_3, CO	200	50					o	Kennecott
	4		90	90	70			NH_3 100g/l, CO_2 25g/l, CO_2, cuprous ions	50	Norm pres.	2	o			o	Kennecott
	5		41	77		0.05	0.05	$(NH_4)_2SO_4$, NH_3, NH_4OH 5M	110		2					Brooks
	6		53	53	10.5	trace	trace	$(NH_4)_2SO_4$ 1.9M, NH_3 5M	80		6					Sherrit Gordon
	7		90-40	90-50	90-70	5.1-1.5		$(NH_4)SO_3$ 15ml, SO_3^{2-}, NH_3 5M	60		8		o		o	Okuwaki
	8		98-93	93-91	90-85	93-88	36-2.9	$(NH_4)Cl$ 100g/l, NH_3 7.5M, glucose 5g/l	120		0-6		o		o	Okuwaki
	9		89-87	91-81	71-68	3.8-2.9	7.3-1.5	$(NH_4)_2CO_3$ 5g/l, NH_3 7.5N, Glucose 5g/l	120		0-6		o		o	Okuwaki
d. Nitric acid leaching	1		49.6-2.1	51.9-13.0	0	0.8-0.2	7.9-0.1	HNO_3 1-2N	50-25				o		o	Murayama
	2		95.5	86.9	85	90.7		HNO_3 , HNO_2					o		o	Welsk

Reference Table B-5 Processing Processes and Recovery Rates (Estimated)

Process	Item	Unit	Reducing roasting - ammonia leaching process	Cuprion ammonia leaching process	High-temperature sulfuric acid leaching process	Chloridizing roasting - water leaching process	Smelting sulfidizing leaching process
1 Grinding	Grain size	cm	-2.25	-2.25	-2.25	-2.25	-2.25
		mesh	-200	-200	-325	-200	-325
2 Drying	Temperature	°C	175			175	175
3 Reduction or chlorination			Reduction	Reduction		Chlorination	Reduction
	Temperature	°C	625	50		500	650
	Reducing or chlorinating agent		CO 18.2%	CO		HCl(g) 100%	CO 18.2%
			CO_2 7.8%	Cuprous ion			CO_2 8.1%
			H_2 10.9%				H_2 9.4%
4 Smelting	Temperature	°C					1425
	Flux						Silica, limestone
	Recovery	% Ni					94.7
		Cu					86.9
		Co					85.9
		Fe					70
		Mn					1.5
5 Sulfidization	Temperature	°C					1370
	Flux						Gypsum
	Recovery	%					(little loss)
6 Leaching	Extraction	% Ni	90	90	95	97.4*	99
		Cu	90	90-80	94	96.1*	99
		Co	70	70	67	97.6*	99
	Temperature	°C	40	50-40	245	40	110
	Pressure	atm.	1	3.5-1	35		10.5
	Time	Hrs.	3	2	4		2

Reference Table B-5 (cont'd.)

				Reducing roasting - ammonia leaching process	Cuprion ammonia leaching process	High-temperature sulfuric acid leaching process	Chloridizing roasting - water leaching process	Smelting sulfidizing leaching process
(6 Leaching - cont'd.)	Leaching solution	g/l		NH_3 100 CO_2 50	NH_3 100 CO_2 50	H_2SO_4 200-250		H_2SO_4
	Concentration	g/l	Ni		10-5		9.5	40
			Cu		8-4		7.7	24
			Co				1.8	5
7 Solvent extraction	Leaching rate	%	Ni	99.9	99.9	99.5	99.5	99.5
			Cu	99.9	99.99	99.5	99.5	99.5
			Co				99.5	
	Solvent					Lix 64N	Lix 64N Lix 65N	Lix 64N
8 Stripping		%	Ni	98.8/0.001	98.8/0.001	98.8/0.9		98.8
			Cu	<0.004/87	<0.004/87	0.004/87		87
			Co	0.3/0.2	0.3/0.2	0.3/0.2		
9 Metal winning	Electro-winning	%	Ni	99				
			Cu	99.9				
	Precipitation with H_2S		Co					
10 Total recovery		%	Ni	87.9	87.9	92.4	94.7*	<92.1
			Cu	77.4	77.4-68.8	81.2	83.1*	<74.5
			Co	<70	<70	<67	<94.3*	<85
Reference No. to Reference Table B-4				2)-6	3)-c	3)-a	2)-a	1)-b

Reference material: NOAA

* Deep Sea Ventures

Reference Table B-6 A Comparison of Characteristics of Processing Processes

(E for evaluation: o, good; x, poor)

	Reduction-Ammonia Leaching	E	Cuprion - Ammonia Leaching	E	High Temperature Sulfuric Acid Leaching	E	Chloridizing Roasting - Water Leaching	E	Smelting - Sulfidizing - Leaching	E
1 Processibility at normal temperature and pressure	High temperatures required for drying (175°C) and reduction (625°C); atmospheric pressure	x	Reduction at 50°C and atmospheric pressure	o	Leaching at high temperature (245°C) and high pressure (35 atmospheres pressure)	x	High temperatures required for drying (175°C) and chlorination 500°C); atmospheric pressure	x	Numerous high-temperature processes: drying (175°C), reduction (650°C), sulfidizing (1,370°C).	
2 Processibility without removal of moisture	Drying required for removal	x	Removal not required	o	Removal not required	o	Drying required for removal	x	Drying required for removal	x
3 Low solvent cost or possibility of solvent recovery and recyling	NH_3 used as leaching solution inexpensive and recoverable for recycling.	o	NH_3 used as leaching solution inexpensive and recoverable for recyling.	o	H_2SO_4 used as leaching solution. Inexpensive but not recoverable or recyclable. Consumption: 280 kg/DMT	x	HCl used as leaching solution. Consumption: 585 kg/DMT. HCl reproducible from Cl_2 formed during leaching and H_2, but plant required for making H_2.	o	Little leaching solution is required, since matte is processed.	o
4 Energy consumption	Energy consumption for drying, reduction, stripping, and ammonia recovery: 160 kg of coal/DMT and 456 kWh of electricity/DMT.		No high-temperature operations but steam required for stripping and ammonia recovery Coal: 165 kg/DMT		Steam required for leaching, etc. Coal: 109 kg/DMT. Electricity: 45 kWh		High temperatures required for drying and chloridization; energy required for manganese recovery. Coal: 370 kg/DMT., Electricity: 610 kWh/DMT.	x	Many high-temperature operations; high energy consumption. Coal: 195 kg/DMT. Electricity: 454 kWh/DMT	x
5 High extraction of Ni, Cu and Co, and selectivity	Separation and recovery possible. Recovery: Ni, 88%; Cu, 77%; Co < 77% (estimated)	o	Separation and recovery possible. Recovery: Ni, 88%; Cu, 70-77%; Co < 70% (estimated)	o	Separation and recovery possible. Recovery: Ni, 92%; Cu, 80%; Co < 67% (estimated)	o	Separation and recovery possible. Recovery: Ni, 94.7%; Cu, 83.1%; Co < 94.3% (estimated)	o	Separation and recovery possible. Recovery: Ni, 92%' Cu, 74%; Co, 60% (estimated)	o

Reference Table B-6 (cont'd.)

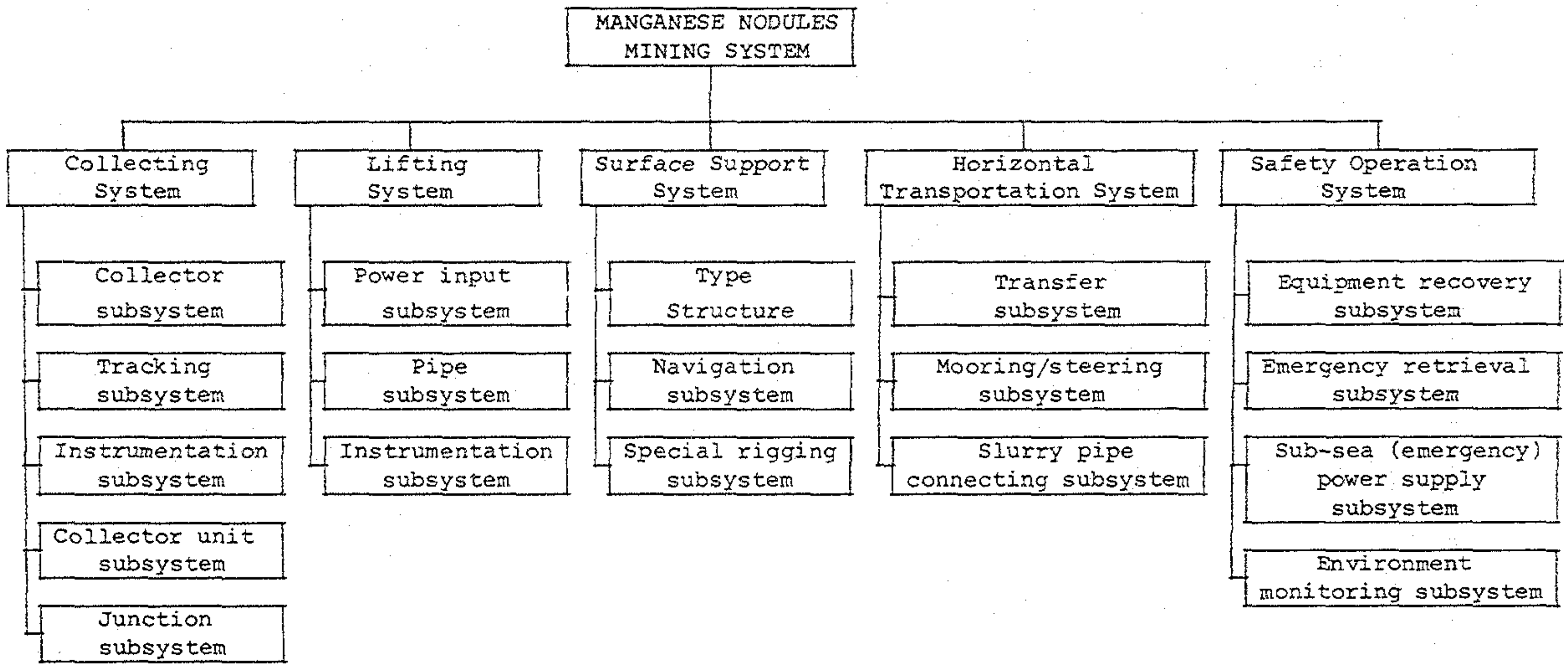
(E for evaluation: o, good; x, poor)

	Reduction-Ammonia Leaching	E	Cuprion - Ammonia Leaching	E	High Temperature Sulfuric Acid Leaching	E	Chloridizing Roasting - Water Leaching	E	Smelting - Sulfidizing - Leaching	E
6 Corrosion-resistant materials for equipment	Small amounts sufficient	o	Small amounts sufficient	o	Corrosion-resistant autoclave required	x	Corrosion-resistant material required, since HCl is a strong acid.	x	Small amounts sufficient	o
7 Toxicity of reagents	Slight	o	Slight	o	Slight	o	Toxic	x	Slight	o
8 Environmental pollution	Treatment of leaching residues required	x	Treatment of leaching residues required	x	Treatment of leaching residues required	x	Treatment of leaching residues required	x	Dry process facilitates slag treatment.	o
9 Possibility of manganese recovery							Recovery is possible; in fact, manganese treatment is the purpose of this process.	o	Recovery as ferromanganese is possible.	o
10 Similar plant with established technology now in operation	In operation on laterite ore using the Nicaro process	o	This process partly resembles the Nicaro process, but there is no reduction process at 50°C.	x	In operation on laterite ore using the Moa Bay process	o	Very few examples of plants using HCl exist.	x	This process is used on copper ores, garnierite, and laterite.	o
Reference No. to Reference Table B-4	2)-b		3)-c		3)-a		2)-a		1)-b	

Reference Table B-7 Summary of Processing Processes

			Reducting roasting - ammonia leaching	Cuprion leaching	High-temperature sulfuric acid leaching	Chloridizing roasting - water leaching	Smelting - sulfidizing - leaching
1 Mineral grade	%	Ni	1.26	1.26	1.26	1.26	1.26
		Cu	1.0	1.0	1.0	1.0	1.0
		Co	0.25	0.25	0.25	0.25	0.25
		Water	20-35	20-35	20-35	20-35	20-35
2 Recovery	%	Ni	88	88	92	94.7	92.1
		Cu	77	77-70	80	83.1	75
		Co	<70	<70	<67	<94.3	<85
3 Amount of nodules	10,000 DMT/year		300	300	300	300	300
4 Products	Ni cathode	T/year	33,264	33,264	34,776	35,796	34,814
	Cu cathode	"	23,100	23,100	24,000	24,930	22,500
	Co powder	"	5,250	5,250	5,025	7,072	6,375
5 Energy and process materials							
Coal		10,000 T/year	57	495	264	111	585
Electriciy		x 10^6 kWh/year	150		120	2,019	1,503
NH_3		T/year	2,910	3,180	1,740	120	
H_2SO_4		10,000 T/year			681		6.6
HCl		T/year				175.5	
H_2 STD		10,000 m^3/year	207	207	240	297	237
Reference No. to Reference Table B-4			2)-b	3)-c	3)-a	2)-a	1)-b

Reference Fig. B-1 Manganese Nodules Mining System



C. INTERNATIONAL CONDITIONS AFFECTING DEVELOPMENT

I. Present Status of the Convention on the Law of the Sea

The 3rd United Nations Conference on the Law of the Sea, whose deliberations started in 1973, adopted in its entirety the draft treaty and the related draft resolutions at its 11th session held in New York from March 8 to April 30, 1982, by a vote of 130 (Japan, France, Australia, New Zealand, Sweden and other northern European nations and most developing countries), to 4 (the United States, Israel, Turkey and Venezuela), with 17 abstentions (the United Kingdom, the Federal Republic of Germany, Holland, Belgium, Italy, Spain, Luxemburg, Thailand, the Soviet Union and the East European countries). The convention was thereafter adopted at the treaty-adopting conference by 117 countries, but 28 countries abstained from appending their signatures. It was then left open for 2 years for further signatures. If 60 countries ratify or join the treaty, the treaty will come into effect one year after the 60th country ratifies or joins it.

II. Legislation Covering Deep Seabed Resource Development

1. Outline

The new draft convention on the Law of the Sea defines the seabed outside national jurisdiction and its substructure as the Area, and states that the Area and the resources in the Area are a common heritage of mankind. In the words of the draft convention, "No state shall claim or exercise sovereignty or sovereign rights over any part of the Area or its resources nor shall any state or natural or juridical persons appropriate any part thereof. All rights in the resources of the Area are vested in mankind, as a whole, on whose behalf the Authority shall act. The minerals recovered from the Area may only be alienated in accordance with Part XI of the Treaty and the rules, regulations and procedures of the Authority."

As stated above, deep seabed manganese nodules are placed under the jurisdiction of the Authority. In order to conduct exploration and exploitation, only those who satisfy determined qualifications and requirements may apply to the Authority and they must operate under determined conditions. In this connection, the freedom of the high sea provided for in the Convention on the High Seas which was adopted at Geneva on April 29, 1958 has been amended.

2. Organization of the Authority

The International Seabed Authority is established as an international juridical person to be the administrative organization of the deep seabed and its resources. It consists of the following organs:

a. The Assembly - the highest decision-making organ, by which general policy decisions are made. All signatories to the Treaty are members.

b. The Council - the executive organ of the Authority, which decides specific policy. Determined numbers of members are elected in each of 8 categories, which have been categorized based on the special interests and geographical distribution. Total number of the constituent countries is 38.

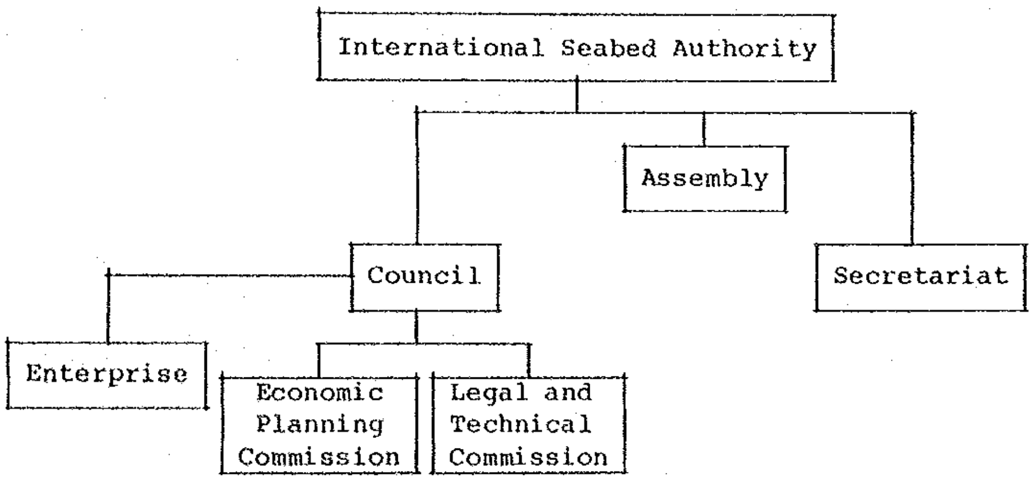
c. The Economic Planning Commission

d. The Legal and Technical Commission

e. The Secretariat

f. The Enterprise - which conducts by itself exploration, mining, transportation, processing and comercialization.

g. Organization chart



3, System of Exploration and Exploitation

Manganese nodule exploration and development are directly executed by the Enterprise under the control of the Authority or by the member countries of the Treaty themselves or by natural or juridical persons having the nationality of one or more of the member countries or effectively controlled by the member countries or their nationals.

In order to initiate and implement such activities, proposed plan of work must be submitted to the Authority, reviewed by the Legal and Technical Commission and approved by the Council. When the operator is a country, a natural or juridical person, this proposed plan of work shall be in form of a contract. The Authority must exercise the necessary control to secure compliance with the Treaty, its annexes, the rules, regulations and procedures of the Authority and the approved plan of work and the member countries must assist the Authority to do so. Even after the conclusion of an exploration and exploitation contract with the Authority, the commercial production shall not be undertaken until the operator has applied for and has been issued a production authorization which may not be applied for or issued more than five years prior to the planned commencement of commercial production.

The important duties of the contractor are as follows:

a. Reservation of sites —— The contractor shall offer an area for development by the Authority that has the same estimated commercial value as the area claimed for his own exploration and exploitation.

b. Transfer of technology —— The contractor shall make available to the Enterprise the same technology as he uses for his own operation so that the Enterprise's operation may be implemented at the same pace as operations in a non-reserved area.

c. Financial arrangements of contract —— The contractor shall pay a kind of royalty to the Authority.

d. Production Policy - From the standpoint of the protection of producers on land, certain ceiling is imposed on the output of nickel from manganese nodules. In principle, however, the adjustment between supply and demand is pointed at a future conclusion of commodity agreement.

e. Selection of applicants for production authorizations —— Although the applicants must obtain production authorization a maximum of 5 years before the planned commencement of commercial production, a limit is placed on the amount of nickel that may be produced. If the number of applicants is excessive and results in exceeding the production ceiling, selection is carried out on the basis of specific criteria.

4. Protection of Pioneer Investors

In order to protect the existing investors, the Authority grants exclusively to those pioneer investors that satisfy certain requirements listed below the right to apply to the preparatory commission for registration of a claimed area, which would give them priority on the acquisition of claimed areas and simultaneously grant a de facto preference in the application for production authorization mentioned above. In parallel with the grant of such priority, the Authority imposes on investors the obligation to explore under commercial conditions, by contract the reserved areas tendered by the investors themselves, and the obligation to undertake to transfer the technology before the entry into force of the Treaty.

Pioneer investors qualified for priority are divided into the following 3 categories:

a. France, Japan, India, the Soviet Union or a State enterprise or one natural or juridical person of each of those States; provided, however, that the countries concerned sign the Treaty, and the States or State enterprise or natural or juridical persons have expended, prior to January 1, 1983, an amount equivalent to at least $US 30 million in pioneer activities and has expended no less than 10% of that amount in the location, survey and evaluation of the claimed area.

b. Four entries whose components being natural or juridical persons possess the nationality of, or are effectively controlled by, one or more of the following countries: Belgium, Canada, West Germany, Italy, Japan, Holland, United Kingdom and the United States, or their nationals, provided that the certifying State or States sign the Treaty and the entity concerned has expended the level of expenditure and for the purpose stated in a. above.

c. Any developing state signatory of the Treaty or any State entity or natural or juridical person which possesses the nationality of such State or is effectively controlled by it or its nationals, or any group of the foregoing which, prior to January 1, 1985, has expended the levels of expenditure and for the purpose stated in a. above.

5. Production Policies

According to the Convention on the Law of the Sea, the annual production during the interim period shall be decided by computation employing a linear regression of the logarithms of the actual nickel consumption for the most recent 15-year period. The Authority, however, may not authorize production exceeding 46,500 tonnes of nickel per year under any plan of work.

Furthermore, the production of copper, cobalt and manganese may not exceed the amounts recovered at the time when the maximum amount of nickel is produced.

Reference Table C-1 shows an extract of the Convention on the Law of the Sea which covers production policies: "Part XI The Area, Section 3 Development of Resources of the Area, Article 151 Production Policies."

6. Countermoves of the Governments of Various Countries

The first session of the 3rd United Nations Conference on the Law of the Sea was held in 1973. Research and development, however, had been conducted prior to this conference by the western countries. Particularly in the United States, whose research and development were at an advanced state, domestic bills were introduced every year in Congress demanding the protection of existing investments and the safety of future investments because of the uncertainly of when the Treaty might be concluded and of what it might contain. The Government of the United States, however, had been consistently opposed to such legislation because of the fact that the discussion of the Convention on the Law of the Sea at UNCLOS was under way and because of its assumption that the conference would be concluded soon. Nevertheless, the contents of the UNCLOS draft treaty concerning the deep seabeds were becoming more and more unfavorable to the interests of advanced countries. Accordingly, in West Germany, the United Kingdom, France, Italy, Belgium, Holland and Japan, whose companies had joined the international consortia, demands for such national legislation became strong.

As a result, the govenments of various countries began investigations with a positive attitude. With this background, the United States first took the bold course of legislation on June 28, 1980. Then, in August of the same year, West Germany also enacted legislation.

Since their legal interpretations include manganese nodule mining under the concept of the freedom of the high seas stipulated by the Convention on the High Seas concluded at Geneva on April 29, 1958, the United States and West Germany authorize by law their own nationals to operate in specific sea areas and to prevent, at the time of authorization, overlapping of the sea areas operated. This legislation thus secures that exclusiveness of areas of operation that is indispensable for mining, at the same time avoiding the direct creation of mining rights such as exist on land and refraining from claiming national sovereignty over the beds of the high seas themselves. This method, however cannot prevent overlapping with other nations. Therefore, the legislations stipulate to conclude the reciprocating states agreement among the like minded countries in order that the operating areas shall be mutually recognized.

These two countries regard their laws as temporary measures until the realization of the international treaty itself. They intend to levy royalties of 0.75 percent of metal content value on the manganese nodules mined and to return it to the international community, thus giving recognition to the concept of the common heritage of mankind.

In January 1981, the new President of the United States, Mr. Ronald Reagan, announced that Part XI of the draft Convention on the Law of the Sea was not consistent with the national interests of the United States and that it was necessary to review it. He then demanded a drastic amendment at the 10th session of UNCLOS. As a result, the success or failure of the treaty itself came into question and the spring session came to an end with no visible progress. This situation has led to the decision that the eight countries now participating in the development of manganese nodules should hold a conference aiming at concluding the reciprocating states agreement mentioned above. On the other hand, the United Kingdom enacted legislation in July 1981 and France followed suit in December.

Of the eight like-minded countries, the United States, the United Kingdom, West Germany and France now have national legislation in this connection. Consequently, these four countries, calling themselves the inner four, conducted a four-state conference apart from the eight state conference and made repeated efforts towards the conclusion of an reciprocating state agreement. There have been tingconsiderable difficulties in the discussions concerning mutual agreement on the size of claimed areas and on the criteria and procedures for settling claims on overlapping areas. The agreement therefore remains unconcluded, awaiting the results of the 11th session are awaited. On the other hand, apart from the question of this international agreement, a private arbitration agreement (including arbitration rules) concerning the settlement of overlapping claims among the existing five international consortia has been negotiated. This agreement was first concluded in February among the 4 consortia to which American companies belong, and a French consortium joined the agreement in May.

The 11th session of UNCLOS opened on March 8. As has already been mentioned, the United States was opposed to the Treaty, Japan and France were in favor of it, and the other 5 countries abstained from voting. None of the demands by the United States for amendments concerning the content of the Treaty were adopted, but the

United States was guaranteed a seat in the Council. Thus, the existing scheme was left as it was.

The Soviet Union and Japan took into consideration the draft resolution for the protection of pioneer investors which had been adopted together with the text of the Treaty, and enacted national legislation in April and July, respectively.

On the other hand, the United States, the United Kingdom, West Germany and France, (earlier known as the "inner four",) concluded "the Agreement Concerning Interim Arrangements Relating to Polymetallic Nodules of the Deep Seabed, on September 2. The planned economy countries and the G-77 developing countries criticized the illegality of this agreement at the United Nations, partly because it was regarded as a secret agreement. Its substance, however, is not the earlier reciprocating states agreement but provides, on the basis of the respective national laws, indirect aid or support to be given to the settlement of overlapping claims now promoted independently by private circles, and does not agree any new legal regime.

Even on the basis of the resolution to protect pioneer investors stipulated in the Treaty, overlapping claims had to be settled prior to application to the preparatory commission. On the other hand, this agreement prohibits the respective countries from issuing licences based on their own national laws and from concluding reciprocating states agreements until January 1983. This means that the agreement is not at all inconsistent with the contents of the Convention.

The attitude of the eight countries at the conference for the adoption of the Convention is shown by the fact that only France and Holland signed it. Of the six countries that did not, the United States declared that it will not sign, and it seems likely that West Germany will not sign. Now that signatures have been obtained from 117 countries, the preparatory commission will start in the spring of 1983. The reactions of the various countries involved will be attracting attention.

Reference Table C-1 United Nations Convention on the Law of the Sea
Part XI The Area
Section 3 Development of Resources of the Area

Article 151
Production policies

1. (a) Without prejudice to the objectives set forth in article 150 and for the purpose of implementing subparagraph (h) of that article, the Authority, acting through existing forums or such new arrangements or agreements as may be appropriate, in which all interested parties, including both producers and consumers, participate, shall take measures necessary to promote the growth, efficiency and stability of markets for those commodities produced from the minerals derived from the Area, at prices remunerative to producers and fair to consumers. All States Parties shall co-oeprate to this end.

(b) The Authority shall have the right to participate in any commodity conference dealing with those commodities and in which all interested parties including both producers and consumers participate. The Authority shall have the right to become a party to any arrangement or agreement resulting from such conferences. Participation of the Authority in any organs established under those arrangements or agreements shall be in respect of production in the Area and in accordance with the relevant rules of those organs.

(c) The Authority shall carry out its obligations under the arrangements or agreements referred to in this paragraph in a manner which assures a uniform and non-discriminatory implementation in respect of all production in the Area of the minerals concerned. In doing so, the Authority shall act in a manner consistent with the terms of existing contracts and approved plans of work of the Enterprise.

2. (a) During the interim period specified in paragraph 3, commercial production shall not be undertaken pursuant to an approved plan of work until the operator has applied for and has been issued a production authorization by the Authority. Such production authorizations may not be aplied for or issued more than five years prior to the planned commencement of commercial production under the plan of work unless, having regard to the nature and timing of project development, the rules, regulations and procedures of the Authority prescribe another period.

(b) In the application for the production authorization, the operator shall specify the annual quantity of nickel expected to be recovered under the approved plan of work. The application shall include a schedule of expenditures to be made by the operator after he has received the authorization which are reasonably calculated to allow him to begin commercial production on the date planned.

(c) For the purposes of subparagraphs (a) and (b), the Authority shall establish appropriate performance requirements in accordance with Annex III, article 17.

(d) The Authority shall issue a production authorization for the level of production applied for unless the sum of that level and the levels already authorized exceeds the nickel production ceiling, as calculated pursuant to paragraph 4 in the year of issuance of the authorization, during any year of planned production falling within the interim period.

(e) When issued, the production authorization and approved application shall become a part of the approved plan of work.

(f) If the operator's application for a production authorization is denied pursuant to subparagraph (d), the operator may apply again to the Authority at any time.

3. The interim period shall begin five years prior to 1 January of the year in which the earliest commercial production is planned to commence under an approved plan of work. If the earliest commercial production is delayed beyond the year originally planned, the beginning of the interim period and the production ceiling originally calculated shall be adjusted accordingly. The interim period shall last 25 years or until the end of the Review Conference referred to in article 155 or until the day when such new arrangements or agreements as are referred to in paragraph 1 enter into force, whichever is earliest. The Authority shall resume the power provided in this article for the remainder of the interim period if the said arrangements or agreements should lapse or become ineffective for any reason whatsoever.

4. (a) The production ceiling for any year of the interim period shall be the sum of:

(i) the difference between the trend line values for nickel consumption, as calculated pursuant to subparagraph (b), for the year immediately prior to the year of the earliest commercial production and the year immediately prior to the commencement of the interim period; and

(ii) sixty percent of the difference between the trend line values for nickel consumption, as calculated pursuant to subparagraph (b), for the year for which the production authorization is being applied for and the year immediately prior to the year of the earliest commercial production.

(b) For the purposes of subparagraph (a):

(i) trend line values used for computing the nickel production ceiling shall be those annual nickel consumption values on a trend line computed during the year in which a production authorization is issued. The trend line shall be derived from a linear regression of the logarithms of actual nickel consumption for the most recent 15-year period for which such data are available, time being the independent variable. This trend line shall be referred to as the original trend line;

(ii) if the annual rate of increase of the original trend line is less than 3 percent, then the trend line used to determine the quantities referred to in subparagraph (a) shall instead be one passing through the original trend line at the value for the first year of the relevant 15-year period, and increasing at 3 percent annually; provided however that the production ceiling established for any year of the interim period may not in any case exceed the difference between the original trend line value for that year and the original trend line value for the year immediately prior to the commencement of the interim period.

5. The Authority shall reserve to the Enterprise for its initial production a quantity of 38,000 metric tonnes of nickel from the available production ceiling calculated pursuant to paragraph 4.

6. (a) An operator may in any year produce less than or up to 8 percent more than the level of annual production of minerals from polymetallic nodules specified in his production authorization, provided that the over-all amount of production shall not exceed that specified in the authorization. Any excess over 8 percent and up to 20 percent in any year, or any excess in the first and subsequent years following two consecutive years in which excesses occur, shall be negotiated with the Authority, which may require the operator to obtain a supplementary production authorization to cover additional production.

(b) Applications for such supplementary production authorizations shall be considered by the Authority only after all pending applications by operators who have not yet received production authorizations have been acted upon and due account has been taken of other likely applicants. The Authority shall be guided by the principle of not exceeding the total production allowed under the production ceiling in any year of the interim period. It shall not authorize the production under any plan of work of a quantity in excess of 46,500 metric tonnes of nickel per year.

7. The levels of production of other metals such as copper, cobalt and manganese extracted from the polymetallic nodules that are recovered pursuant to a production authorization should not be higher than those which would have been produced had the operator produced the maximum level of nickel from those nodules pursuant to this article. The Authority shall establish rules, regulations and procedures pursuant to Annex III, article 17, to implement this paragraph.

8. Rights and obligations relating to unfair economic practices under relevant multilateral trade agreements shall apply to the exploration for and exploitation of minerals from the Area. In the settlement of disputes arising under this provision, States Parties which are Parties to such multilateral trade agreements shall have recourse to the dispute settlement procedures of such agreements.

9. The Authority shall have the power to limit the level of production of minerals from the Area, other than minerals from polymetallic nodules, under such conditions and applying such methods as may be appropriate by adopting regulations in accordance with article 161, paragraph 8.

10. Upon the recommendation of the Council on the basis of advice from the Economic Planning Commission, the Assembly shall establish a system of compensation or take other measures of economic adjustment assistance including co-operation with specialized agencies and other international organizations to assist developing countries which suffer serious adverse effects on their export earnings or economies resulting from a reduction in the price of an affected mineral or in the volume of exports of that mineral, to the extent that such reduction is caused by activities in the Area. The Authority on request shall initiate studies on the problems of those States which are likely to be most seriously affected with a view to minimizing their difficulties and assisting them in their economic adjustment.

D. THE OUTLOOK FOR FUTURE DEVELOPMENT AND ITS EFFECT ON NICKEL, COBALT, COPPER AND MANGANESE MARKETS

I. Outlook for Development

The principal factors affecting future development are the legal system, technology and economic efficiency.

1. Legal System

As has been indicated above, there is confusion about what type of legal system will govern future manganese nodule development activities. Since the contents of the Convention on the Law of the Sea are very unfavorable for future operators, the representatives of the existing consortia, at least, are doubtful about whether or not they can ever implement development under the Convention. Furthermore, the development under any reciprocating states agreements between nations concluded under national laws can expect to be criticized by developing countries, thus this method cannot be expected to be a stable legal system.

Since manganese nodules which are an object of development lie in the high seas, and from the nature of mining, the exclusive mining site is indispensable, the precondition for the development of manganese nodules should be the establishment of common legal regime which is universally recognized by each country of the world.

At present, the existing five consortia have already applied to their own countries for exploration licences on the basis of the national laws of the United States, the Federal Republic of Germany and France, and are negotiating independent settlement of overlapping mining areas. Nevertheless, it is not yet certain how they will settle overlapping with India, the Soviet Union, Japan and other pioneer investors not included in the 5 consortia, whether or not completed settlements of overlapping claims are linked with the Convention, and whether or not the exploration can be implemented merely with licences based on national laws. Under such circumstances, the respective consortia have now suspended their exploration activities.

2. Technology

Three of the existing five consortia have formally reported success in deep-sea experiments, but they have no actual experience of continuous long-range operations. Furthermore, the scale of these experiments was reportedly 1/x to 1/y of commercial scale. Consequently, even if technology is established conceptually, the confirmation of the durability of the system and equipments for commercial production must depend upon future research and development.

3. Economic Efficiency

The biggest problem affecting the outlook of future development is economic efficiency. From the 1960s to the 1970s, the development of laterite nickel ores on land expanded, and the ratio of sulfide ore to laterite ore has become 60 to 40. One of the main reasons for this expansion is that laterite ore is mainly found in the developing countries and obtained by open pit mining, and so labor costs are low. On the other hand, sulfide ore is mainly found in advanced countries and is obtained by underground mining. Consequently, rising labor costs in the advanced countries are now on a par with the high cost of energy for smelting laterite ore. Laterite ore has thus become competitive with sulfide ore. After the oil crisis of 1973, however, the price of oil has risen by a factor of 15; too great an increase to be compensated for merely by lower labor costs.

In considering the cost of nickel derived from manganese nodules, it is necessary to note that, since manganese nodules are also an oxide ore, and from the nature of oxide ores, the processing method is similar to that used for laterite ore rich in iron. At the present time, when there is no actual commercial production of manganese nodules, and development is in the research and development stage, there are no reliable cost estimates available. Nevertheless, the following qualitative conclusions can be drawn:

a. The acquisition of nickel from manganese nodules cannot compete in terms of cost with the increased production of nickel from sulfide ore mined on land by the expansion of existing plants or the construction of new mine.

b. The acquisition of nickel from manganese nodules cannot compete with increased production by the expansion of existing laterite mines.

c. The acquisition of nickel from manganese nodules would be competitive with that of nickel from newly opened laterite mines in case the situation which requires the development of low grade laterite ores emerges in the future.

The following are the reasons for the above:

a. Flotation method can be applied to sulfide ore to produce sulfide concentrates. Consequently, the smelting cost is low.

b. One advantage of manganese nodules is that the processing plant can be located where the infrastructure is already prepared and electricity is cheap. The effect of the some extra increase of distance on marine transportataion costs is not as great as that on land transportation costs. On the other hand, mines and processing plants on land are increasingly being sited in remote hinterlands, so that enormous expenditure is required for infrastructural preparation. However, the above advantage of manganese nodules disappears where the infrastructure already exists in cases where expansion of the existing plant is to be carried out.

c. The existing plants were built in the days before the oil crisis, when construction costs were low. Since the oil crisis, construction costs have risen by a factor of two to three but metal prices have barely increased at all. Consequently, it is difficult for new plants to compete in price with existing low-cost mines and plants and their expansion.

d. In the case of competition with a new laterite mine, the rising cost of construction applies equally. Compared with the mining of laterite in the open pit with power shovels and bulldozers, it is obviously costly to mine 14,000 wet tonnes per day of manganese nodules by operating two mining ships of tens of thousands tonnes displacement and employing pumps of 30,000 horsepower.

e. The average grade of manganese nodules in future commercial production is thought to be:

Nickel :	approximately	1.3%
Cobalt :	"	0.25%
Copper :	"	1.0%
Manganese:	"	25.0%

The average grade in terms of nickel equivalent is approximately 2.3 percent although this percentage will differ according to estimates of the respective metal prices. In view of the grade, this is adequate for competition with the 1.5 to 3 percent of nickel from land mine laterite ore.

In the mining industry, the most effective way to reduce the unit cost, particularly the mining cost, of metal production is to mine high-grade ore. In the case of manganese nodules, however, no particularly high-grade deposits have yet been discovered. Furthermore, the reduction in cost from the development of new processing technology would apply to land mine laterite ore as well. Thus, such cost reduction would not be accompanied by any relative reduction of manganese nodule production cost. It is thus conceivable that if the time comes when the demand expands so much that the present excess of capacity is eliminated, and further that additional capacity becomes necessary, and if the cost handicap of manganese nodules is reduced by the gradual decline of ore deposits and grades in land mines, the possibility of commercial production of manganese nodules could be realized, although this depends on how each country approaches the maintenance of a long-term stable supply of metal resources.

It is difficult to estimate the production cost of manganese nodules since there has been no actual commercial production, and the production technology is still in the development stage. Documents published concerning production costs are as follows:

- o MIT [1], A Cost Model of Deep Ocean Mining and Associated Regulatory Issues, 1978
- o ADL [2], Technological and Economic Assessment of Manganese Nodules Mining and Processing, 1977

The construction costs and production costs mentioned in these reports are too low to be realistic and cannot be used.

II. Effect on the Markets for Nickel, Cobalt, Copper, and Manganese

1. Effect on Markets

The economic scale of manganese nodule production is at present considered to be 3 million dry tonnes per year. The average grade is said to be:

Nickel :	1.40%
Copper :	1.10%
Cobalt :	0.21%
Manganese:	28.00% (percentage by weight)

Accordingly, the quantity of metals that would be produced is estimated to be:

Nickel	(cathode) :	37,700 tonnes
Copper	(cathode) :	29,300
Cobalt	(cathode) :	4,410
Ferro-manganese	(Mn content):	238,000

(assuming that of the 3 million dry tonnes of manganese nodules, only 1 million dry tonnes are used for the production of ferro-manganese.)

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1) Massachusetts Institute of Technology
2) Arthur D. Little, Inc.

	A. World consumption; Annual average from 1974 to 1978 (1,000 tonnes)	B. Manganese nodules; Annual production per project (1,000 tonnes)	B/A (%)
Nickel	664	37.7	5.7
Copper	8,572	29.3	0.3
Cobalt	27	4.4	16.2
Manganese ore	21,801	2,112.0	9.7
Ferro-manganese	5,610	238.0	4.2

Note: The quantity of manganese ore per manganese nodule project is the quantity of primary slag (manganese grade: 35-38%). The quantity of ferro-manganese indicates ferro-manganese (Mn 85%) produced by using one third of the primary slag.

The effect of one manganese nodule project is indicated above. The influence on copper markets would be slight but that on cobalt markets would be great. The effect on finished ferro-manganese markets would also be fairly large. The possibility of manganese nodule ore being used as an alternative to ferro-manganese ore for iron production needs to be researched, with reference to the impurities contained in the manganese slag. Apart from the comparison of production costs, the quantity of 37.7 thousand tonnes of nickel matches the overall production of one big land mine.

What should be pointed out here, however, is the issue of the production ceiling stipulated by the Convention on the Law of the Sea. Even if the production costs of metals derived from manganese nodules were to gain an advantage over that of metals produced by land mines, as long as the production is implemented under the Convention there will be production restrictions on manganese nodules. They can therefore compete with land production only within the given limits. Accordingly, there is naturally a limit to the influence on land mines.

2. Beginning of Commercial Production

At present, the market conditions of non-ferrous metals in general are extremely aggravated due to a drastic decline in demand. In particular, operating rates for nickel and cobalt in the western countries remain as low as 50 to 60 percent and no future growth in demand can be expected. The outlook therefore is for the supply-demand gap to continue for a considerable period. Consequently, new development of laterite mines with which nickel and cobalt derived from manganese nodules could compete from the standpoint of cost is likely to be postponed for a considerable time. Furthermore, production technology for manganese nodules has not yet been established. Besides, in relation to the existing supply-demand situation and to the Law of the Sea, technical development has slowed down drastically.

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