Asian Pacific Marine Minerals and Industry Structure

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Abstract Eventual development of marine minerals potential in the Asian Pacific would likely draw on the technology, skills, and experience of the emerging international seabed mining industry. As a result of strategic behavior by its firms, this small-numbers industrial "strategic group" has created a level of capacity for seabed mining exploration and research and development (R&D) that far exceeds the near-term level of activity expected in seabed mining. The paper reports on the nature of preproduction industrial structure (or "protostructure") in seabed mining and draws implications for efforts to develop the resource potential of Asian Pacific marine minerals. Seabed minerals exploration and R&D services might be offered to Asian Pacific nations at bargain prices (below unit cost) by firms with first-starter advantages in the emerging industry. However, cautionary notes are included about constraints on the economic potential of the region's deep-sea minerals such as manganese nodules, polymetallic sulfides, and cobalt crusts.

The purposes of this paper are largely descriptive and interpretive. In the context of Asian Pacific marine minerals potential, I seek to describe the current organizational status of the emerging international seabed mining industry, with some reference to traditional industrial organization approaches to the understanding of already-

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mature industries. After a cautionary note on the limited economic potential of the region's deep-sea minerals, I offer an interpretation of how the current position of this embryonic industry might influence marine minerals development in the Asian Pacific.

Eventual development of nonfuel marine minerals potential in the Asian Pacific would likely draw on technology, skills, and experience of the emerging international seabed mining industry. This industry has developed over the past decade to the point where it may be able to provide valuable services and initiative for the development of potential offshore mineral resources. Because of the historical and economic context in which the industry finds itself, and not least because of its evolving structural features, these services might well become available at bargain rates (below unit cost). Aspects of the industry's structural evolution that lead to this conjecture are sketched in more detail below. The bad news for coastal states which seek economic return from new offshore mineral development is that the economic potential of several prospective offshore mineral targets, particularly deep-sea deposits, is severely limited.

Seabed Mining and the Asian Pacific

Since the early 1960s, a number of large international consortia, together with several national governments, have invested a total of several hundred million dollars in efforts to develop a capability to find and recover metal-rich manganese nodules on the ocean floor (Broadus and Hoagland 1984; Charles River Associates 1982; Barkenbus 1979; Leipziger and Mudge 1976). Until about 1980, these investments were directed mainly toward technological research and development (R&D) and exploration. Now most of that spending has stopped. Achievement of an international consensus on the legal regime established by the United Nations Conference on the Law of the Sea (UNCLOS) has been delayed primarily by objections from the United States and certain other industrial nations to the seabed-mining provisions of the treaty. Several major companies have either withdrawn altogether or have declined to make further expenditures. The economic prospects for seabed mining seem to be crumbling (Donges 1985; Broadus and Hoagland 1984; General Accounting Office 1983; Farr 1982; Burrows 1980; Vanney 1980).

Reduced commercial interest in manganese nodule prospects is reflected in the estimated combined spending profile for the commercial consortia shown as a dashed line in Figure 1. These spending estimates have been reconstructed from an extremely fragmentary published record together with spotty clues provided by confidential industry sources. Nonetheless, they give a general impression of the scale and time profile of industry efforts. As seen in Figure 1, estimated seabed mining expenditures reached appreciable levels in the early 1970s, rose rapidly in the mid-1970s to peak levels around 1978–79 of nearly $100 million (1982) per annum, and then fell dramatically to current token amounts. Estimated cumulative industry spending since 1962 equals $635 million (1982). Roughly the same pattern of activity is reflected in Figure 2 in the time profile of patent issuances, as revealed through a detailed patent search by Hoagland (1985).

Some observers see a rapid shift to Asia in the focus of international interest in deep-sea minerals (Spagni and Ford 1984). The dynamic Japanese effort alone might lead to such a conclusion. While a number of Japanese companies, most notably Mitsubishi and Sumitomo, are involved in international commercial seabed mining consortia, the Japanese government also sponsors a large

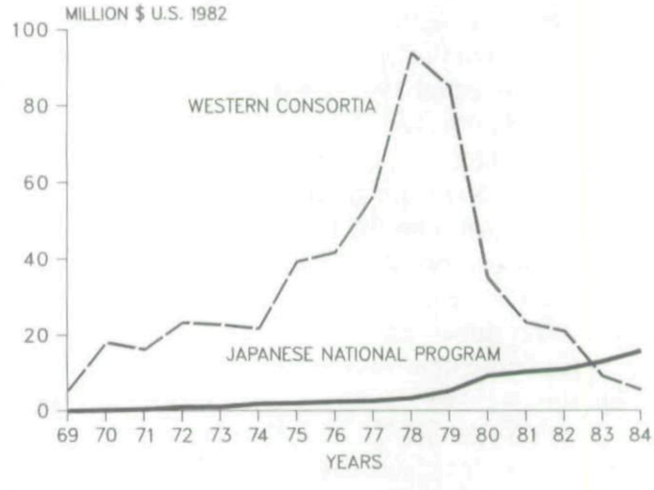

FIGURE 1. Estimated seabed mining expenditures by consortia, 1969–84 (million 1982 U.S. dollars).

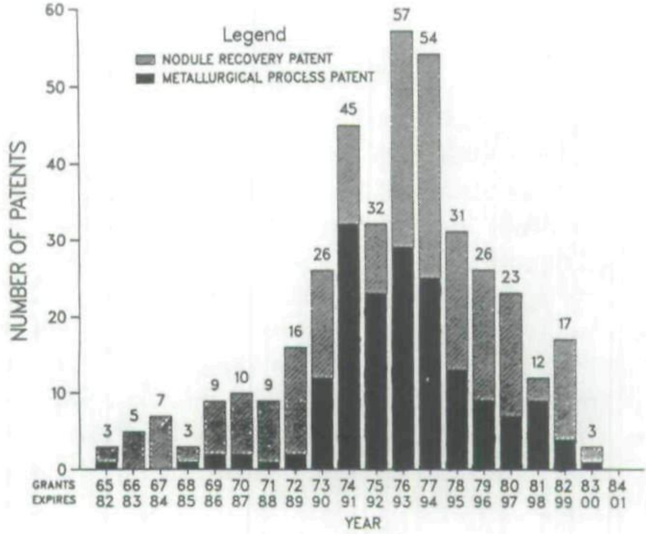

FIGURE 2. Total seabed mining patents worldwide, 1965–84. *Source:* Hoagland 1985.

domestic consortium. The national effort is focused through a joint government-industry firm, Deep Ocean Resources Development Company (DORD), formed in 1982 to promote nodule exploration and mining. Since 1981, development of a manganese nodule mining system has been designated as one of eight national "Large-Scale Projects," with a projected 1981–89 budget of around $86 million (Takahara et al. 1984; Agency of Industrial Science and Technology 1982). In Figure 1, the time profile of this Japanese national effort is contrasted with that of the commercial consortia. Programs to proceed with seabed mining R&D and exploration have been announced also by India, South Korea, and China (United Nations 1982). It must be recalled, however, that even in Japan, and much more so in less-developed nations, seabed mining investments are intended as much to catch up with the level of capability already achieved by the Western commercial consortia as they are to advance the state of the art.

Traditionally, East Asia has been the globe's major location for marine mining activity. Marine minerals deposits in the Asian Pacific probably are understood as well as any in the world, in part because of the work of the Committee for Coordination of Joint Prospecting for Mineral Resources (CCOP) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). Large amounts of tin have been dredged for many years off the Indonesian "Tin Islands," off the Thai island of Phuket, and offshore Malaysia. Offshore deposits now represent over half the tin reserves of Indonesia (Sujitno 1984), and Thailand appears to be experiencing similar growth in the relative importance of offshore tin deposits (Kulvanich 1984). Offshore sources of sand and gravel production also are familiar in East Asia, and Japan supports one of the world's most important offshore sand and gravel industries (Padan 1983). About 50% of Japanese consumption of fine aggregate for concrete comes from marine sands (Takata 1984).

Of course, discussions of marine nonfuel minerals potential must be limited to financial values that are several orders of magnitude smaller than those for offshore oil and gas. Offshore nonfuel minerals production generates global revenues of only about $500 million per year, less than one-third of a percent of the value of offshore hydrocarbon output. Offshore petroleum and gas prospects in the region have been attracting a great deal of international interest and are the subject of increasing exploration activity (Li and Valencia 1983). To some extent, the geological investigations employed in offshore oil and gas exploration may provide useful evidence on the distribution and disposition of offshore nonfuel minerals as well.

The manganese nodule prospects in the region, however, are not outstanding. A leading authority on the subject, G. P. Glasby, has reached the following conclusion from study of Southwest Pacific sites:

> It is almost certain that any nodules mining industry will concentrate on the equatorial North Pacific and perhaps a few other areas, and that known deposits of Southwest Pacific nodules, because of their low grade, will not be considered to be an economic resource within the foreseeable future. (Glasby 1981, p. 42)

Interest has turned recently toward other, more exotic deep-sea mineral prospects in the Asian region, marine polymetallic sulfides (MPS) and cobalt-rich ferromanganese oxide crusts (cobalt crusts).

MPS deposits are created as hydrothermal precipitates at tectonically active areas such as oceanic crustal spreading centers. Most studies of MPS deposits have focused on the midocean ridge, where the relatively high grades of zinc and copper in some samples have led to suggestions that the deposits are a potentially important source of valuable metals (Bischoff et al. 1983; Minerals Management Service 1983; Malahoff 1982). MPS deposits have been identified also in several different oceanic settings (Rona 1982, 1983a, 1983b), most importantly in the Red Sea brines (Mustafa et al. 1984; Amann 1983; Degens and Ross 1969). Many researchers also expect them to be found at other sites associated with volcanic activity, such as in the back arc basins and seamounts of the Western Pacific (Rona 1982; Lonsdale, Batiza, and Simkin 1982). The region abounds in submarine hot spots and potential hydrothermal activity. Young volcanoes are found all along the Western Pacific subduction zone.

The region may also be a relatively good hunting ground for cobalt crusts. Unlike the MPS deposits, which were only recently discovered, ferromanganese oxide encrustations have long been recognized as one form of the deep-sea ferromanganese oxide concretions that also include the abyssal manganese nodule deposits (Cronan 1977). Knowledge of these variable occurrences dates to the H.M.S. *Challenger* samples of 1873–76. In the last five years, as economic interest in the manganese nodules has dwindled, marine scientists have begun to tout the potential of the cobalt-rich crusts found on seamounts (Clark et al. 1985). There is some evidence that the thickness and cobalt grade of the crusts increases with the age of the seamount on which they are found (Commeau et al. 1984). The Pacific ocean floor increases in age in a westerly direction, so that some of the oldest seamounts might be expected just to the east of the western subduction zone.

If promising marine minerals deposits are found in the region, there is a good likelihood that they will be within the exclusive economic zone (EEZ) of an Asian nation. The EEZs of the region show extensive coverage of the regional seas, as can be seen in Figure 3. Finding and developing new resources, however, is costly; and currently little is known about the true resource potential of MPS and cobalt crusts (Broadus and Bowen, 1986; Clark et al.

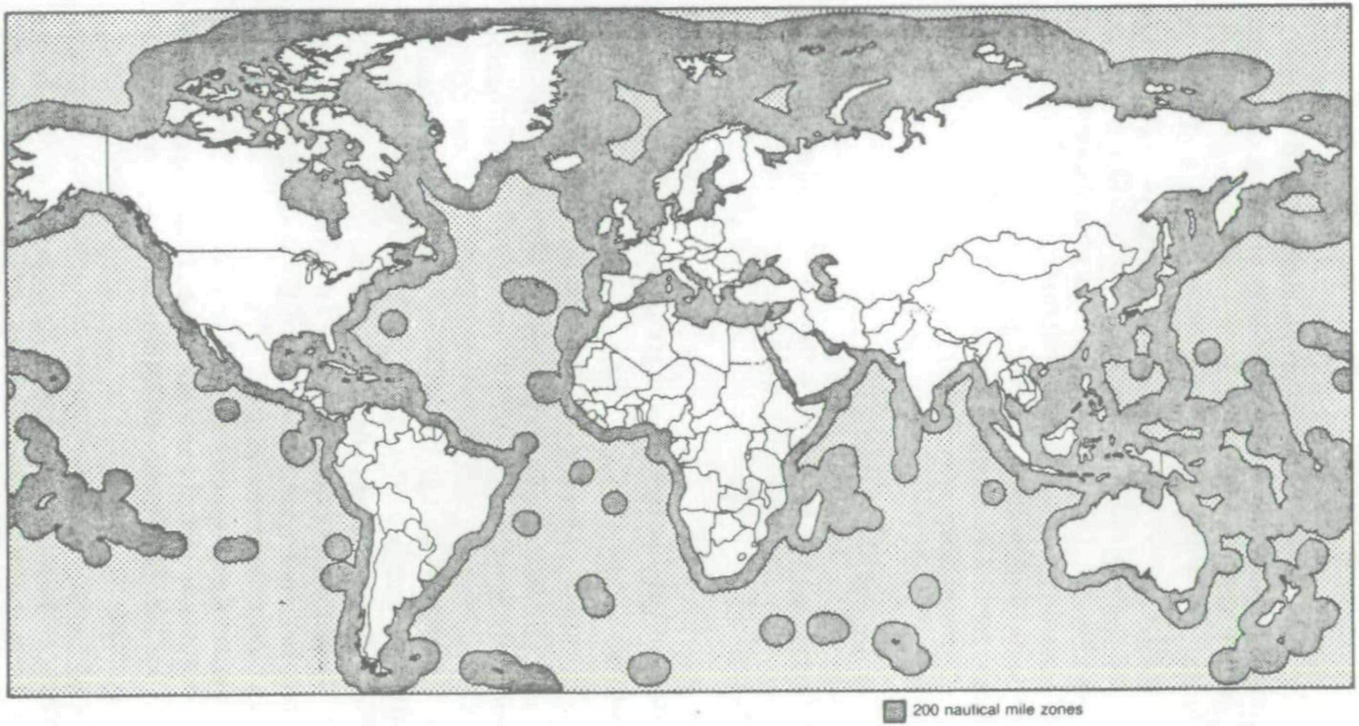

FIGURE 3. General characterization of areas of potential extended jurisdiction 200 nautical miles off the coasts. *Source:* National Advisory Committee on Oceans and Atmosphere, *The Exclusive Economic Zone of the United States: Some Immediate Policy Issues* (National Advisory Committee on Oceans and Atmosphere: Washington, D.C. 1984).

1985; Broadus 1984; Commeau et al. 1984; Halbach and Manheim 1984). Technologies for their commercial-scale recovery from water depths of hundreds or thousands of meters do not exist (Department of the Interior Panel 1983; Rona 1983b), and a number of technological advances are required before they can even be systematically and reliably sampled (Ballard and Bischoff 1983; Craig, Andrews, and Meylan 1982). In view of the abundance of more conventional onshore deposits of the contained materials (Barsotti in press; Broadus 1984), the economic prospects of these exotic deep-sea deposits must be seen as extremely limited.

If Asian nations choose to pursue these prospects further, they must do so with care. If they seek to develop or host full-fledged seabed mining capabilities, they would have to muster substantial exploration and research efforts. The effectiveness of such efforts would depend at least in part on the state of the art achieved by and the availability of technology from the international seabed mining industry.

Organization and Industrial Protostructure in Seabed Mining

It is likely that some basic technological requirements for recovery of polymetallic sulfides or cobalt crusts will be different from those for manganese nodules. Firms that have already invested heavily in nodule R&D, however, may have substantial "first-starter" advantages for other deep-sea hard minerals. Such advantages include operational R&D and ocean exploration skills and organization, as well as knowledge of legal uncertainties, partners, and rivals. Experienced skepticism might reduce the false starts and wrong-headed enthusiasm that seem to be part of the costs of any major new resource development process.

Different types of actors are involved in efforts to develop the capability to mine and exploit metals in seabed manganese nodules. These are (1) seabed mining enterprises, including (a) private companies and commercial organizations, such as the major international seabed mining consortia, and (b) state enterprises, organs of national governments directly investing in exploration and development similar to consortia efforts; and (2) the national governments themselves. The organization, activities, and current status of the major seabed mining enterprises are summarized in Tables 1 and 2.

Aside from underlying technology, consumer preferences, and the nature of the resource base, industry structure is probably the most important factor shaping the scale and direction of industry operations and its performance over time (Dasgupta, Gilbert, and Stiglitz 1982). The expected influence of industry structure on conduct and performance is fairly straightforward and well understood for mature industries in the limiting cases of monopoly and pure competition. Seabed nodule mining, however, is an example of a potentially major industry in its embryonic stage.

It is important to emphasize that seabed mining is not a well-defined industry in the conventional sense. Rather, seabed mining represents a potential avenue for entry into or expansion within larger and already-established industries that produce and sell the contained metals, such as nickel and cobalt. As "structure" is a term of art referring to such features as the number and size distribution of firms and the conditions of entry and exit in a well-defined operating industry, it might more appropriately be denoted as "protostructure" in the present context of an embryonic industry only poorly distinguished from larger incumbent industries. In the broader metals market, seabed mining consortia can be seen as a "strategic group" (Porter 1979; Newman 1978; Caves and Porter 1977) spanning existing industry boundaries with joint ventures that contain a mix of incumbent players and potential entrants. Two of the most important decision parameters for producers in a mature industry, production costs and market price, are hazy or nonexistent for players in this embryonic industry. Therefore, investment policies, affiliation, and legal tactics take on added significance. The industry's international composition and muddled legal setting are further complications.

To gain a clearer appreciation of the relative position of the various players in this strategic group's preproduction game of jockeying for pre-entry advantage and position, it is useful to examine protostructural features as if this were a well-defined, mature industry. This process involves attention to such measures as market share and concentration, barriers to entry and exit, and strategic

Table 1
Corporate Interests in Seabed Mining

Consortium Member and Share	Parent	Nationality	Parent's Annual R&D, 1980–81 (millions of dollars)	Estimated Spending to Date[a] (millions of dollars)
Kennecott Consortium (KCON): formed January 1974				87.9
Kennecott Corporation (40%)	(SOHIO), BP	(U.S.), U.K.	30.3	
RTZ Deepsea Mining Enterprises Ltd. (12%)	Rio Tinto Zinc p.l.c.	U.K.	22.1	
Consolidated Gold Fields p.l.c. (12%)	Consolidated Gold Fields p.l.c.	U.K.	25.7 (1982)	
BP Petroleum Development Ltd. (12%)	British Petroleum Company p.l.c.	U.K.	201.0	
Noranda Exploration Inc. (12%)	Noranda Mines Ltd.	Canada	6.0	
Mitsubishi Corporation (12%)	Mitsubishi Group (leader)	Japan	[b]	
Mitsubishi Metal Corp. (12%)		Japan	[b]	
Mitsubishi Heavy Industries Ltd. (12%)		Japan	[b]	
Ocean Mining Associates (OMA): formed May 1974				158.0
Essex Minerals Company (25%)	U.S. Steel Corporation	U.S.	74.0	
Union Seas Inc. (25%)	(Union Mines, Union Minière S.A.), Société Générale de Belgique	Belgium	5.5	
Sun Ocean Ventures (25%)	Sun Company Inc.	U.S.	50.0	
Samim Oceans Inc. (25%)	Ente Nazionale Idrocarburi (ENI)	Italy	162.0	
Ocean Management Incorporated (OMI): formed February 1975				69.2
Inco Inc. (25%)	Inco Ltd.	Canada	30.9	
SEDCO Inc. (25%)	SEDCO, Inc.	U.S.	12.4	

Arbeitsgemeinschaft Meerestechnische Rohstoffe (AMR) (25%)	Metallgesellschaft A.G.	F.R.G.		
	Preussag A.G.	F.R.G.	51.6[c]	
Deep Ocean Minerals Company (DOMCO) (25%)	23 Companies led by Sumitomo	Japan	[b]	
Ocean Minerals Company (OMCO): formed November 1977				169.0
Amoco Ocean Minerals Company (31%)	(Amoco Minerals), Standard Oil	U.S.	150.0	
Lockheed Systems Company (31%)	Lockheed Corporation	U.S.	100.0	
Lockheed Missiles and Space Company (31%)	Lockheed Corporation	U.S.		
Billiton B.V. (31%) Ocean Minerals Inc.	Royal Dutch/Shell	Netherlands	568.8	
B.K.W. Ocean Minerals B.V. (8%) Ocean Minerals Inc.	Royal Boskalis Westminster	Netherlands	4.0	
Association Française pour l'Étude et la Recherche des Nodules (AFERNOD): formed 1974				70.8
Centre National pour l'Exploitation des Océans (CNEXO) (70%)	French Government[d]	France	62.7	
Commissariat á l'Energie Atomique (CEA) (20%)	French Government	France	N.A.	
Société Métallurgique le Nickel (SLN) (6%)	IMETAL, Elf Aquitaine	France	3.3 (SLN)	
Chantiers du Nord et de la Méditérranée (CNM) (4%)	Schneider S.A.	France	132.2 (1982)	

(continued)

Table 1 *(continued)*

Consortium Member and Share	Parent	Nationality	Parent's Annual R&D, 1980–81 (millions of dollars)	Estimated Spending to Date[a] (millions of dollars)
Deep Ocean Resources Development Company (DORD): formed September 1982				80.1[e]
48 companies (including the members of the Deep Ocean Minerals Association [DOMA]) that coordinate activities with MITI[b]		Japan	61.8 (1982)[b]	

[a] Estimated total spending in 1982 dollars based on Ocean Industry (1983), U.S. Congress (1981), and company sources.

[b] Japan's Ministry of International Trade and Industry (MITI) has made loans to Japanese companies participating in the multinational seabed mining consortia. For example, in 1976–78, approximately $9.25 million was loaned by MITI. MITI's affiliate Agency of Industrial Science and Technology (AIST) has initiated the development of a seabed minerals recovery system as a "large-scale project." AIST's total 1982 Large-Scale Project Budget (seabed mining and all other projects) is shown in the Parent's Annual R&D column for DORD.

[c] The figure is the 1982 budget for West Germany's Federal Ministry of Research and Technology (Bundesministerium für Forschung und Technologie, or BMFT). BMFT has supported about 50% of AMR activities since 1975.

[d] CNEXO has merged with the French fisheries agency, ISTPM, to form a new agency called Institute Française de la Recherche et l'Exploitation de la Mer (IFREMER).

[e] Estimated nodule R&D spending by the Metal Mining Agency of Japan (MMAJ) in 1976–81 (General Accounting Office 1983).

Table 2

Consortium Activities in Seabed Mining

Consortium	General Scope of Parents' Operations	Technological Focus	Status and Comments
Kennecott Consortium (KCON)	Petroleum production and trading; minerals production and metals trading (especially copper and gold); transportation; shipbuilding.	Metallurgical processing (led by Kennecott): "cuprion and ammoniacal leach" process; have tested a towed "vehicle" on a wire; holds patent on a self-propelled "tractor" and airlift system.	Virtually inactive since 1976. Have filed for two exploration licenses in both the United States and the United Kingdom for 191,000 km^2. BP controls Kennecott through SOHIO.
Ocean Mining Associates (OMA)	Petroleum production and trading; refined petroleum products; minerals production and metals trading (especially copper, lead, zinc, and others); steelmaking; other energy sources.	Deepsea Ventures (service contractor) has focused on a "towed dredgehead with rake" hydraulic recovery and "reduction and hydrochloric acid leach" process.	Successful prototype tests. Most active through 1982. Now curtailing sharply (60% staff cut in past year). Mining vessel scrapped, exploration ship laid up. Holds NOAA exploration license for 156,000 km^2.
Ocean Management Incorporated (OMI)	Minerals production and metals trading (especially nickel and others); contract offshore drilling and support operations; steelmaking; construction machinery; banking; engineering; general trading; wire-rope manufacturing.	Inco, West German, and Japanese companies have focused on towed sledge hydraulic recovery; Inco has focused on a "smelting and sulfuric acid leach" metallurgical process.	Completed planned feasibility study. Proved recovery technology, 1978. Curtailed work since 1979. Salzgitter withdrew from AMR group in 1984. Inco, SEDCO inactive. Holds NOAA exploration license for 135,000 km^2. AMR has filed separately in Federal Republic of Germany

(continued)

Table 2 *(continued)*

Consortium	General Scope of Parents' Operations	Technological Focus	Status and Comments
Ocean Minerals Company (OMCO)	Missiles; space; electronics; aircraft manufacturing; petroleum production and trading; refined petroleum products; offshore dredging; pipelines.	Lockheed has patented a "remote-controlled, bottom-crawling" hydraulic recovery system; a "high-temperature, sulfuric acid leach" metallurgical process has been examined.	Billiton withdrawing. Bos Kalis inactive. Recovery system failed to deliver nodules in at-sea test, 1978–79. Holds NOAA exploration license for 166,000 km^2. Lockheed now promoting R&D for other marine minerals.
Association Française pour l'Étude et la Recherche des Nodules (AFERNOD)	Oceanography; nuclear power; metallurgy; minerals production and metals trading (especially nickel and cobalt); shipbuilding.	AFERNOD has spread its focus: CLB, towed-sledge hydraulic, and the remote-controlled autonomous shuttlecraft (PLA). GEMONOD now focusing on hydraulics.	AFERNOD inactive except in area claims. Holds exploration license under French law. R&D on PLA continues through GEMONOD, a new public group composed of CEA and IFREMER.
Deep Ocean Resources Development Company (DORD)	General trading; steelmaking; shipbuilding; transportation; ferrous and nonferrous metallurgy; industrial machinery; chemicals; metals trading; cable manufacturing; pump manufacturing.	DORD companies focused earlier on Masuda's CLB. Most recently under MITI's large-scale project, they have been developing a towed sledge, hydraulic recovery system. Metallurgical process unknown.	Most active group. Holds exploration license under Japanese law. R&D through MITI/AIST "large-scale project." Projected 1982–90 budget approximately $80–90 million. KCON and OMI Japanese members included.

elements of the involvement of certain organizations. It is important, however, to proceed with caution and to recall that the analytic approach was developed for application to well-defined, operating industries.

Consider first the broader industries that would be entered by seabed mining consortia. In both the cobalt and nickel industries there is good reason to believe that sufficient market power exists among the incumbents to create monopoly rents (Stollery 1983; Rafati, 1982a, 1982b). Table 3 shows that, in spite of severe supply disruptions in Zaire in 1979, that nation still accounted for 56% of 1979–80 cobalt output. The four-firm concentration ratio for cobalt production was 76% (with the top two producers having nearly 70%), and the eight-firm figure was 84%. Concentration in nickel sales, seen in Table 4, is less extreme (with a four-firm ratio of 60.6% and an eight-firm ratio of 64.6% in 1976), but that market has been dominated historically by the leading firm, Inco, which had a 27% share in 1980. It is noteworthy that enough entry has occurred in nickel over the past quarter century to cut Inco's share from nearly two-thirds in the early 1960s to closer to one quarter today. The presence of monopoly rents, of course, provides a signal and incentive for new entry. The relatively large minimum efficient scales, large venture risks, and sunk costs that characterize both

Table 3
Concentration in Cobalt Production, 1979–80

Source	Percent Share	Concentration Ratio
Zaire	56	
Zambia	12	
Inco (Canada)	4	
Morocco (SMBAG)	4	
Four-firm		76
Freeport Queensland (Australia)	3	
Metals Exploration Queensland (Australia)	3	
Falconbridge (Canada)	1	
Sherritt-Gordon (Canada)	1	
Eight-firm		84

Source: Rafati (1982b).

Table 4
Concentration in World Nickel Sales, in Percent

	1950	1955	1965	1970	1974	1976	1980
Inco	80.0	67.1	61.1	43.9	39.1	35.0	27.0
Four-firm	—	88.1	82.1	63.7	62.3	60.6	—
Eight-firm	—	92.9	85.2	69.3	66.6	64.6	—

Source: Rafati (1982a).

these industries, however, act to discourage entry and to buffer the incumbent's market positions.

In the strategic group of seabed mining consortia, there can be little question of monopoly profits because no product is produced and marketed in this preproduction phase. Rivalry in the group has instead centered on investment to obtain effective seabed mining capabilities, including development of skills, techniques, mine sites, and equipment. Assuming for the moment that all investment dollars have been equally effective in creating both tangible and intangible seabed mining capacity, shares of estimated cumulative spending provide a proxy for competitive position within the group and a measure of group concentration. Thus, Figure 4 shows the OMCO group in a strong position with 27.5% of total estimated cumulative spending (1982 dollars), followed closely by OMA with 25.5%. Using this approach, the four-firm concentration ratio is

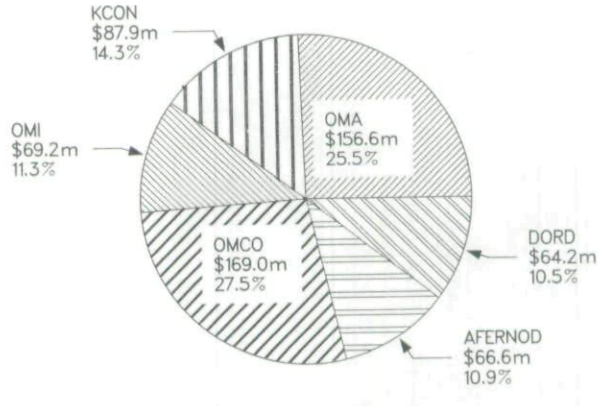

FIGURE 4. Consortia shares: estimated cumulative spending, 1962–83 (million 1982 U.S. dollars).

78.6%, and only six consortia hold 100 percent of existing capacity (because recent spending by national programs has not been included).

Of course, it is unrealistic to treat all spending on seabed mining as equally productive. Furthermore, shares calculated on constant dollar spending tend to inflate the value of early spenders' capacities even though the early spenders may be holding obsolescing "capital." Finally, the estimated cumulative spending of some groups is based on very fragmentary evidence and is thus only a rough approximation.

An alternative protostructural universe for relative position in seabed mining capacity, and one that is more directly observable than spending behavior, consists of patents and patent claims (a single patent may include several "claims" of original contribution). By this measure, as seen in Table 5, OMA is the leader with 50% of claims and 36% of patents, followed by KCON with 24% claims and OMI with 14% of claims (Hoagland 1985). In part because of a decision to patent an entire recovery system in a single patent rather than separately patenting individual components, OMCO holds only 6% of seabed mining patent claims. With patent claims as a universe, four-firm concentration is 94%.

Although these figures suggest a high degree of concentration in seabed mining "capacity," they do not permit us to conclude that the consortia are removed from competitive pressures in seabed mining. No matter how high barriers to entry might be for a producing seabed mining industry (estimated initial capital costs of more than $1.5 billion are not overwhelming, but minimum efficient scales of 3 million metric tons per year throughput could swamp the market quickly) preproduction entry into the strategic group need not be especially difficult. Perhaps the greatest barrier to entry will be in the regulatory assignment of prime mine sites to qualifying "pioneers" and later ceilings on output from operating mines. Even these pioneer mine sites might well become marketable assets, however, depending on how the unresolved legal and regulatory system finally is structured. OMA's transfer of technology and assignment of equity to ENI for a negotiated entry fee (reportedly less than $30 million) demonstrates that entry can be effected through the existing consortia.

Table 5

Seabed Mining Consortia Patent Activity
(Percentage of Patents and Claims by Consortium)[a]

	Recovery		Processing		Total	
	Patents	Claims	Patents	Claims	Patents	Claims
OMA	39	53	34	48	36	50
KCON	9	4	41	37	29	24
OMI	27	18	13	11	18	14
OMCO	6	13	2	1	3	6
AFERNOD	17	11	6	1	10	5
DORD	3	1	4	0	4	1
Total[b]	101	100	100	98	100	100

[a] Includes all U.S. and foreign patents. Claims data have been collected only on U.S. patents.
[b] Totals may not equal 100% because of rounding error.

It seems clear from the evidence of Figure 4 and Table 5, however, that this is a small-numbers and relatively concentrated industry. There is mutual recognition among the consortia and sufficient concentration to facilitate at least the coordination of efforts to shape the regulatory environment (Oster 1982). In addition to the strategic elements of its position toward the broader metals industries, each consortium will also expect its behavior in this concentrated industry to be observed and responded to by the other consortia. The importance of strategic behavior (Spence 1979) is thus established.

A striking feature of the embryonic seabed mining economy that adds further to its strategic orientation is the mixed-form character of the groups assembled to develop and conduct the activity. Most of the seabed mining enterprises have at least some participation by national governments or state companies, and some are largely or entirely governmental operations. The first column of numbers in Table 6 shows the approximate equity stake held by national governments in each of the consortia. Weighting this share in each consortium by the consortium's share of estimated cumulative spending (in the next column) gives us the government-held "market share" of each consortium. In total, governments appear to account for almost a third of the cumulative spending by the commercial seabed mining consortia. In most cases, governmental sponsorship

Table 6
Approximate Governmental Shares in the Seabed Mining Industry, in Percent

Consortium	Equity-Weighted Government Share	Consortium "Market Share"	Government "Market Share"
DORD	>95.0	10.5	10.0
AFERNOD	>90.0	10.9	9.8
OMA	<25.0	25.5	6.4
OMI	21.3	11.3	2.4
KCON	5.3	14.3	0.8
OMCO	0	27.5	0
Total			29.4

appears to have been motivated more by interest in exploration of alternative sources of long-run materials supply than by prospects for commercially generated profits from the production and sale of metals.

Implications for Asian Pacific Marine Minerals Development

The behavioral implications of the preproduction status and orientation of the seabed mining industry are complicated and beyond the scope of this brief overview. Several simple possibilities for marine minerals development in the Asian Pacific, however, do seem clear.

The international seabed mining industry has created a level of capacity for seabed mining exploration and R&D that far exceeds the near-term level of activity expected in the industry. The creation of this capacity has resulted from the strategic behavior of consortia in the industry: through preemptive investment, to discourage entry and protect incumbent advantage in existing metal markets; or through strategic positioning, to threaten entry with seabed mining into those markets or to stake contingent claims on future rents from seabed mining (Amacher and Sweeney 1976).

Sunk costs, the tangled regulatory status of exclusive mine-site entitlements, and the constraining terms of some of the consortia joint-venture agreements make exit somewhat difficult. Although first-starter advantages gained by early entry into the preproduction game may depreciate rapidly over time, they still represent assets to be shepherded by the pioneer groups. The apparently limited number of rich natural mine sites and institutional barriers to later entry imposed by UNCLOS are further incentives for firms to cling to their positions. Government subsidies and noncommercial governmental goals of long-term commodity supply diversification lead further to a reluctance of firms to withdraw (Spencer and Brander 1983). Indeed, governmentally sponsored efforts to "catch up" to the positions achieved by the commercial consortia might even induce renewed R&D activity by some groups, as might, to a lesser degree, diligence requirements in the regulatory licenses to exclusive mine sites.

The implication for Asian Pacific marine minerals development seems clear. There is a great deal of idle seabed mining exploration and R&D capacity in the world, gathering rust as research teams are dispersed and research vessels mothballed or scrapped. At the same time, because of the state of strategic play in the industry, there are incentives for firms to seek to maintain their capacity and to protect their preproduction positions. If any means to generate current revenues from this capacity could be developed, even if those revenues only covered variable operating costs and failed to cover costs already sunk or the cost of depreciating technology, firms might choose to pursue them.

One immediately obvious way to employ and maintain existing capacity to generate current revenues is through the sale of technology and services. Seabed mining groups might thus become technology vendors and service contractors, particularly for other marine mineral targets. Along this line, a U.S. General Accounting Office study of the industry concludes that "eventual development of polymetallic sulfides may result in venture capital 'leapfrogging' nodules to reach the next generation of seabed minerals" (1983, p. 31). Already, in fact, OMA and Lockheed reportedly have sought to market their seabed mining services for related applications. There is some indication that Pruessag may also be doing so, and there can be little doubt that Japan's DORD will seek to sell services to interested nations once it has achieved a certain level of capacity.

In short, because of the strategically induced but commercially premature early rush to develop seabed mining capacity, and because of the current lull and strategic consolidation in industry activity, seabed mining technological services and spinoff applications might be available at distress prices to Asian nations interested in developing their marine mineral prospects. Competitive pressures in this prospective "market" might be exerted by other marine technology and service vendors, such as firms experienced in offshore oil and gas activities, and perhaps by sophisticated dredging firms, such as some of those already operating in the region. The structure of these industries and their relationship to seabed mining and offshore minerals development must await further study. However, some overlap with the seabed mining industry is readily apparent at least in the cases of Lockheed, ENI, BP, Sun, Amoco, Billiton, Bos Kalis, and Sedco.

Summary and Prognosis

Briefly summarized, the situation with marine nonfuel minerals potential in Southeast Asian seas is this: Coastal nations in the region have gained substantial increases in their potential marine mineral resources through the international institution of 200-nautical-mile exclusive economic zones. Most of this additional coverage, however, pertains to exotic deep-sea prospects, such as marine polymetallic sulfides and cobalt crusts, rather than to economically proven nearshore minerals such as tin. As prelude to the institution of EEZs, several international industrial consortia and national research programs have developed considerable expertise in deep-sea minerals exploration and recovery techniques. Evidence from the preproduction "protostructure" of this embryonic industry and its associated strategic behavior suggest that access to this expertise might well be available over the next few years at "bargain" prices (below unit cost). Because the economic prospects of these deep-sea mineral targets are severely limited, however, national investments in this area must be seen as highly speculative and subject to eventual failure.

The potential availability of a "bargain" price for investment in seabed minerals development does not assure Asian nations that they would be getting very much value for their money. The fact is that the economic prospects of most marine minerals are very dim, particularly those of the exotic deep-sea deposits of polymetallic sulfides and cobalt crusts. Expenditure of valuable national resources to explore the potential of such exotic prospects might well prove to be an extravagant exercise that leads nowhere.

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