SEABED MINING PATENT ACTIVITY: SOME FIRST STEPS TOWARD AN UNDERSTANDING OF STRATEGIC BEHAVIOR*

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ABSTRACT

Intellectual properties, such as patents, are an important source of information in the field of resource management and technology. Patent issues are one way to observe the behavior of private firms and government agencies at a formative stage in an industry's development when, for strategic reasons, these participants are careful about disclosing details of their activities. The seabed mining industry is a good example of an industry in its formative stages. This industry has been characterized in large part by the research and development (R&D) of technology to recover minerals from deep ocean polymetallic nodules and to process them metallurgically into metal products. The nearly 400 seabed mining patents that have been granted worldwide are a rough measure of this R&D activity. Patent issues can reveal several interesting aspects of an industry: (a) the identity of participants; (b) the generic type of technology; (c) the technological concentration of patent holders; (d) the technological integration of patent holders; and (e) the timing of inventive activity. In some cases, industrial motivations and strategies may be inferred from these aspects. Moreover, seabed mining might be subject to the cyclical fluctuations of markets for the metals contained in polymetallic nodules. Patent activity could provide some insight into the nature of a possible seabed mining industry cycle.

I. INTRODUCTION

A. Summary

Seabed mining, a formative industry directed at the recovery and metallurgical processing of metals from deep ocean polymetallic nodules, has been characterized in large part by research and development (R&D) activity. An indirect measure of the extent of this R&D to date is that at least 50 private firms and eight public agencies from several countries hold seabed mining patents. As measured by patent issues, R&D activity commenced in the 1960s, reached a peak in the early to mid-1970s, and continues today at a greatly reduced pace. Recently, much of the industrial activity in seabed mining has been discontinued because of inclement metal market conditions, pessimistic forecasts for those markets, and other important factors.

In the seabed mining industry a small amount of activity currently is directed at the clarification of access rights to exploration sites on the deep seabed. When the world's metals markets rejuvenate and if the legal regimes for seabed mining stabilize, one might expect a resurgence of activity in the industry. Ultimately such activity may be expressed through innovation (the commercial employment of previously-developed inventions) using knowledge generated in the first round of activity.

If seabed mining becomes a commercial reality, then the recent decline in seabed mining activity may represent the downside of the industry's first cycle. This cycle could be reflected through patent activity even before the industry enters into commercial production.[1] Cyclical fluctuations are characteristic of established markets for the metals contained in nodules: particularly those of nickel, cobalt, copper, and manganese.[2]

In some countries, concern for supplies of strategic materials may actually accelerate the commercialization of seabed mining. Japan, for instance, is sponsoring a nine year R&D project to develop a manganese nodule recovery system. The project

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is intended to culminate in 1990 when the preponderance of seabed mining patents worldwide will begin to expire. As patents expire, the technology that they describe can be manufactured, sold, or used without restriction. It is possible, therefore, that this increased availability of technology could spur a renewed industrial interest and reinforce any tendency for cyclical behavior in seabed mining activity.

This article describes the seabed mining industry in terms of data that have been abstracted from publicly-disclosed patent activity. Those firms that embody the industry as well as those firms and engineers that are potential participants or entrants into the industry are identified. Several of the seabed mining firms have joined together in ventures known as "consortia." The consortia are compared in terms of concentration in the number of patents held and in the number of claims made on these patents. Firms within each consortium also are compared in terms of patenting concentration, and the primary patenting firms (PPFs) are identified for each consortium. Relative emphasis, measured here by U.S. seabed mining patent activity as a percentage of total U.S. patent activity, is examined in the case of each PPF and is compared among PPFs. The timing of patent activity for each consortium is depicted graphically. The timing of patent activity for all firms or engineers may provide clues about the period of a cycle in the industry.

This article makes no real attempt at a qualitative comparison of patents, except to differentiate patents (including claims) into generic technological categories. Generic categories help describe the array of technological solutions to the two broad problems faced by seabed miners: recovery and metallurgical processing of polymetallic nodules. The spread of patent activity across generic technological categories is examined for the consortia and potential entrant firms to suggest the possibilities for vertical integration. Seabed mining firms may have tended to converge on a specific set of recovery technologies, although this convergence is not immediately apparent from observations of patent data. Furthermore, any useful qualitative comparison may have to await the actual commercial operation of seabed mining technology.

This article concludes with some inferences about possible motivations and strategies of firms and agencies in the seabed mining industry. Patents might provide insight into the behavior of these entities as they seek protection for their intellectual properties (patents and trade secrets). The motivations include the commercial development of new sources of minerals to supplement dwindling onshore sources; the protection of market position; the sale of ideas, experience, or technology; and entrance into a potentially successful industry. The strategies involve either patenting or keeping trade secrets: each may be employed to protect intellectual property.[3]

B. Methods

Patent data used in this article were obtained primarily through a search of the "Official Gazette" of the U.S. Patent and Trademark Office. The comprehensiveness of this search was checked and confirmed through a computer search of U.S. patents in the CLAIMS database. In addition to these searches, reference has been made to earlier patent searches. None of the former patent searches provide a current, comprehensive examination of patents related only to both seabed polymetallic nodule mining and processing.

The majority of seabed mining patents have been issued in those countries where private firms or government agencies have been the most active participants in the seabed mining industry: the United States, West Germany, Canada, the United Kingdom, the Soviet Union, Japan, and France. In many cases, firms have patented their inventions in more than one country to provide extra protection for that invention. Seabed mining patents granted in countries other than the United States were searched by three methods. First, foreign nodule recovery patents were searched at the Patent and Trademark Office files in Crystal City, Virginia, under the same classes and subclasses that U.S. patents were searched in the "Official Gazette." Second, both nodule recovery and metallurgical process foreign patents were discovered in publications. Third, a computer search of an international patent database, INPADOC, was conducted to locate both nodule recovery and metallurgical process patents.

From the data collected, it is evident that more seabed mining patents have been granted in the United States than in any other country. In fact, over two-thirds of all the seabed mining patents discovered in this study have been issued in the United States. West Germany, with less than one-sixth of all patents, is a distant second. It is probable that most seabed mining firms envisioned the United States as the primary location for the manufacture, use, or sale of seabed mining technology, and therefore patent rights were perceived as more valuable there.[4] This phenomenon may be an artifact of the search methods, however, since it has been much easier to locate U.S. patents in the United States. For example, preliminary results from a separate review of seabed mining patents in Japan revealed 27 patents held by Japanese nationals. Only ten of these were identified in manual searches conducted for this study, and none were identified through the computer search. This study, as in any patent search, cannot claim to be all-inclusive, and foreign patents have been especially difficult to search because of language barriers and differences in classification systems. Nevertheless, this is believed to be the most comprehensive and current collection of patent information available on the seabed mining industry. Any missing information should have a minimal impact on the conclusions of this study.

II. SEABED MINING PATENT DATA

A. Seabed Mining Patent Assignees

A1. *Consortia.* Several of the world's largest private firms have entered into partnership arrangements or joint ventures for the purpose of seabed mining. These arrangements or ventures are referred to here as seabed mining consortia. The consortia are the mostly private groups: Ocean Mining Associates (OMA), the Kennecott Consortium (KCON), Ocean Management Incorporated (OMI), and Ocean Minerals Company (OMCO); and the mixed public-private groups: the As-

sociation Française pour l'Etude et la Recherche des Nodules (AFERNOD) from France and the Japanese Deep Ocean Resources Development Corporation (DORD). Figure 1 depicts the organization of seabed mining consortia firms. In many cases, only a few companies that participate in each consortium hold patent rights. With patent data, therefore, it may be possible to begin to unravel intraconsortium patenting (and perhaps R&D) strategies.

A2. *Potential entrants.* Several other large private firms have conducted seabed mining R&D and hold patent rights to seabed mining inventions. These firms have not joined with others to plan for or conduct seabed mineral development and are generally not considered active members in the industry. These firms, which include Bendix, Bethlehem Steel, Dow Chemical, General Dynamics, Global Marine, Union Carbide, Westinghouse, and others, are considered here as potential entrants to the seabed mining industry. Patents held by individuals or institutions in the Soviet Union have been included in this category as well.

A3. *Engineers.* Other small firms or individuals hold patents to seabed mining inventions. This group, referred to here as engineers, includes small engineering firms and patent development companies. In some cases, it may be inaccurate to distinguish between potential entrants and engineering firms. Some potential entrants may be in the engineering business, conducting R&D with the intention of selling experience or patent rights to more active firms. Some engineers may become involved in joint ventures. In fact, the Continuous Line Bucket Syndicate (CLB), an early noncommercial R&D and exploration venture, was organized primarily through the efforts of two engineers, Commander Yoshio Masuda of Japan and Dr. John Mero of the United States.

A4. *Who holds seabed mining patents?* Figure 2, parts A, B, and C, lists the firms, agencies, or individuals that hold

Figure 1

ORGANIZATION OF THE SEABED MINING CONSORTIA

CONSORTIUM MEMBER & SHARE	PARENT	NATIONALITY
OCEAN MINING ASSOCIATES (OMA): formed May 1974		
Essex Minerals Company (25%)	U.S. Steel Corporation	U.S.
Union Seas Inc. (25%)	(Union Mines, Union Miniere S.A.), Société Générale de Belgique	Belgium
Sun Ocean Ventures (25%)	Sun Company Inc.	U.S.
Samim Oceans Inc. (25%)	Ente Nazionale Idrocarburi (ENI)	Italy
Deepsea Ventures (Service Contractor for the Consortium)		
KENNECOTT CONSORTIUM (KCON): formed January 1974		
Kennecott Corporation (40%)	(SOHIO), BP	(U.S.), U.K.
RTZ Deepsea Mining Enterprises Ltd. (12%)	Rio Tinto Zinc p.l.c.	U.K.
Consolidated Gold Fields p.l.c. (12%)	Consolidated Gold Fields p.l.c.	U.K.
BP Petroleum Development Ltd. (12%)	British Petroleum Company p.l.c.	U.K.
Noranda Exploration Inc. (12%)	Noranda Mines Ltd.	Canada
Mitsubishi Corporation)	Mitsubishi Group (leader)	Japan
Mitsubishi Metal Corp.) (12%)	"	Japan
Mitsubishi Heavy Industries Ltd.)	"	Japan
OCEAN MANAGEMENT INCORPORATED (OMI): formed February 1975		
Inco Inc. (25%)	Inco Ltd.	Canada
SEDCO Inc. (25%)	SEDCO, Inc.	U.S.
Arbeitsgemeinschaft Meerestechnische Rohstoffe (AMR) (25%)	(Metallgesellschaft A.G.	F.R.G.)
	(Preussag A.G.	F.R.G.)
	(Salzgitter A.G.	F.R.G.)
Deep Ocean Minerals Company (DOMCO) (25%)	23 Companies led by Sumitomo	Japan
OCEAN MINERALS COMPANY (OMCO): formed November 1977		
Amoco Ocean Minerals Company (31%)	(Amoco Minerals), Standard Oil	U.S.
Lockheed Systems Company) (31%)	(Lockheed Corporation	U.S.
Lockheed Missiles and Space Company))	((Lockheed Corporation	U.S.
Billiton B.V. (31%)) Ocean Minerals Inc.	(Royal Dutch/Shell	Netherlands
B.K.W. Ocean Minerals B.V. (8%))	(Royal Boskalis Westminster	Netherlands
ASSOCIATION FRANCAISE POUR L'ETUDE ET LA RECHERCHE DES NODULES (AFERNOD): formed 1974		
Institute Française de la Recherche et l'Exploitation de la Mer (formerly CNEXO) (70%)	French Government	France
Commissariat à l'Energie Atomique (CEA) (20%)	French Government	France
Société Métallurgique le Nickel (SLN) (6%)	IMETAL, Elf Aquitaine	France
Chantiers du Nord et de la Méditerranée (CNM) (4%)	Schneider S.A.	France
DEEP OCEAN RESOURCES DEVELOPMENT CORPORATION (DORD): formed September 1982		
48 Companies (including the members of the Deep Ocean Minerals Association (DOMA)) that coordinate activities with MITI		Japan

A. CONSORTIUM MEMBERS OR AFFILIATES THAT HOLD SEABED MINING PATENTS

		Recovery	Processing	Total
OMA	Newport News Shipbuilding & Drydock	11	--	11
	Deepsea Ventures	15	39	54
	Union Miniere	3	--	3
	Metallurgie Hoboken-Overpelt*	--	1	1
	Technomare*	3	--	3
		32	40	72
KODE	Kennecott	4	50	54
	Bear Creek Mining*	2	--	2
	Mitsubishi Kainatsu K.K.*	2	--	2
		8	50	58
OAI	Kari & Wright*	1	--	1
	Howaldtswerke-Deutsche Werft*	4	--	4
	Inco	16	11	27
	Metallgesellschaft	1	1	2
	Preussag	6	2	8
	Salzgitter	3	--	3
	Sumitomo Metal Mining	5	1	6
		36	15	51
OMCO	Lockheed Missiles and Space	1	--	1
	Shell Oil*	2	2	4
	Baggermaatschappij Bos & Kalis*	1	--	1
		4	2	6
AFERNOD	CEA	11	4	15
	CNEXO (IFREMER)	1	--	1
	SLN	1	3	4
	CNEXO & SLN	3	--	3
	CNEXO, SLN, and Tetra Tech	2	--	2
		18	7	25
AMRO	AIST	1	--	1
	Mitsui Zosen	1	--	1
	Others	--	5	5
		2	5	7
CONSORTIA TOTALS		100	119	219

*(Not a consortium member, but related to a consortium member through a common parent firm).

FIGURE 2a

B. POTENTIAL ENTRANTS THAT HOLD SEABED MINING PATENTS

		Recovery	Processing	Total
U.S.	Bendix	1	--	1
	Bethlehem Steel	3	1	4
	Chevron Research	--	1	1
	Combustion Engineering	--	1	1
	Dow Chemical	--	2	2
	Ethyl Corporation	--	7	7
	General Dynamics	2	--	2
	Global Marine	5	--	5
	Mobil Oil	1	1	2
	Republic Steel	--	1	1
	Sherex Chemical	--	1	1
	Summa Corporation	2	--	2
	Tetra Tech	1	--	1
	Union Carbide	--	1	1
	UOP	--	6	6
	Westinghouse Electric	6	--	6
F.R.G.	Bayer and Duisburger Kupferhütte	--	1	1
	Deutsche Babcock & Wilcox	2	--	2
	Demag L.H.S.	1	--	1
	Friedrich Krupp	2	--	2
	Gesellschaft für Kernforschung	2	--	2
	Klein, Schanzlin & Becker	5	--	5
	Orenstein & Koppel	4	--	4
Canada	Sherritt Gordon Mines	--	1	1
Holland	Grupping A.W.J.	1	--	1
	IdC Holland	3	--	3
France	EMH	1	--	1
	SGCEM	3	--	3
	SOFREM	--	1	1
USSR	Gold Mining Institute	3	--	3
	Leningrad Mining Institute	1	--	1
	Moscow Mining Institute	3	--	3
	Ust-Kamenogorsk Nonferrous Institute	1	--	1
	Transportation Cons. Res. Institute	1	--	1
POTENTIAL ENTRANT TOTALS:		54	25	79

FIGURE 2b

C. ENGINEERING FIRMS AND ENGINEERS THAT HOLD SEABED MINING PATENTS

		Recovery	Processing	Total
U.S.	Anonymous	1	--	1
	Baird	1	--	1
	Beatmos	1	--	1
	Cato Research	--	2	2
	Dane	2	--	2
	Higgs	3	--	3
	Gardner	1	--	1
	Girdeo	1	--	1
	Gantert	2	--	2
	Haggard	1	--	1
	Hawaii Marine Research	3	--	3
	Interior Department	--	2	2
	Krutein	2	--	2
	Mero	1	1	2
	Nelson	2	--	2
	Rossfelder	1	--	1
	Scientia Corporation	1	--	1
	Stecnler	1	--	1
	Taylor	1	--	1
	University Patents	--	1	1
	Wanzenberg	4	--	4
	Williams (Nor-Am Resources Technology)	5	--	5
F.R.G.	Meixner	--	1	1
	Rauw	1	--	1
	Scheffler	--	1	1
	Tax	2	--	2
	Van Petegbem	--	1	1
	Walz	2	--	2
	Weinhands	3	--	3
U.K.	Anonymous	--	2	2
	Asotoff	--	1	1
	Cronjager	--	1	1
	Industry Secretary	1	--	1
	Sridnar et al.	--	1	1
Canada	Ball	1	--	1
	Canadian Patents & Development	--	2	2
	Lilis	--	1	1
	Roever	--	1	1
	Weston	--	4	4

FIGURE 2c

C. ENGINEERING FIRMS AND ENGINEERS THAT HOLD SEABED MINING PATENTS (Continued)

		Recovery	Processing	Total
France	Mouret	--	2	2
	Remlinger	1	--	1
	Tardivat	1	--	1
Japan	Masuda	4	--	4
	Nagoya	--	1	1
	Saito	2	--	2
	Toritani	1	--	1
	Tsutsumi	1	--	1
	Yoshishige	--	1	1
USSR	Andreev	1	--	1
	Geier	1	--	1
	Istoshin	1	--	1
	Lezgintsev	1	--	1
	Mamaeb	1	--	1
	Shevelev	1	--	1
Switzerland	Body	(see: Willums--U.S.)		
Norway	Thorsen	--	2	2
	Willums	(see Willums--U.S.)		
Belgium	Anonymous	--	1	1
South Africa	dervieu	1	--	1
ENGINEER TOTALS:		61	29	90
TOTALS FOR ALL SEABED MINING PATENT HOLDERS:		215	173	388

FIGURE 2c (Continued)

seabed mining patents. These entities have been classified as consortium members or affiliates, potential entrants, or engineers. Potential entrants and engineers are further separated by nationality. The total number of nodule recovery patents and metallurgical processing patents have been identified for each entity. Patents granted in the United States and in other countries have been included regardless of whether the same invention has been patented by the same entity in more than one jurisdiction.[5]

Figure 2, Part A lists firms or agencies that are members of or in some way affiliated with members of seabed mining consortia. Because there has been no examination of patent licensing agreements, some of the affiliations represented here may be tenuous. For example, Shell Oil is a subsidiary of Royal Dutch/Shell, which in turn is a parent of the OMCO consortium member Billiton. Although difficult to verify, this relationship may facilitate the licensing of patented seabed mining technology. Other affiliations are clearer. Deepsea Ventures Incorporated (DVI) is a service contractor for the OMA consortium; Newport News Shipbuilding and Drydock (NNS&D) spawned DVI in the late 1960s and holds no seabed mining patents after 1970. Earl & Wright, an engineering firm, is a subsidiary of OMI consortium member, SEDCO. Sumitomo Metal Mining and Mitsubishi are correctly represented as members of the OMI and KCON consortia, respectively. These two firms are also members of the Japanese consortium, DORD.

Potential entrant firms have been arranged in Figure 2, Part B in alphabetical order by nationality. Some of these firms may have been hired by or may have conducted joint research with the more active seabed mining firms. For example, Tetra Tech holds a joint patent with CNEXO and SLN, members of the French consortium. AFERNOD, which is led by French governmental agencies, has hired engineering firms to undertake feasibility studies on seabed mining. One of these firms, Alsthom-Atlantique, is a parent of patent-holder Société Générale de Constructions Eléctriques et Mécaniques (SGCEM). Several of the potential entrant firms are subsidiaries of firms that might be considered large enough to participate in seabed mining alone or as a consortium member. SGCEM falls into this category as well as Deutsche Babcock & Wilcox A.G., an affiliate of the U.S. marine construction company, McDermott, and Demag L.M.S., a subsidiary of Mannesmann A.G.

Figure 2, Part C lists engineers, including small engineering firms and patent development firms, in alphabetical order by nationality. It is unknown to what extent any of these patents have been licensed to other firms or to the seabed mining consortia. Metallgesellschaft has cited the technologies patented by Demag (see potential entrants), James Ball, Jan-Olaf Willums, and Dieter Hody as potentially innovative.[6] Mero and Masuda were largely responsible for promoting early seabed mining fervor in the 1960s.

B. Patent Concentration

B1. *Patents*. Once the identities of patenting firms are known, a rough picture of relative inventive activity can be drawn by comparing the numbers of patents held by these firms.[7] Figure 3 reveals the "concentration" or the percent of total nodule recovery, total metallurgical processing, or total seabed mining patents held by consortia, potential entrants, or engineers. Seabed mining consortia firms as a group hold more of both nodule recovery and metallurgical process patents than either the potential entrants or engineers. Interestingly, potential entrants and engineers considered together hold more nodule recovery patents than the consortia as a group. Evidently, potential entrant firms and engineers have tended to emphasize recovery technology. In fact these firms rarely have patented both types of technology; only three firms or engineers have both nodule recovery and metallurgical process patents. The consortia have tended to emphasize both recovery and processing technology, which may reflect interests in achieving vertically integrated operations. The consortia hold over two-thirds of the metallurgical process patents indicating that this area may be technologically more complex.

In this comparison of patent concentration, OMA clearly holds the highest concentration with almost one-fifth of all seabed mining patents; Figure 3 shows OMA's primary position in nodule recovery and its secondary position in metallurgical processing. KCON follows OMA almost solely on the basis of its metallurgical processing patent concentration in which it holds 29 percent of all patents. OMI places third in the comparison with 13 percent of all seabed mining patents.

B2. *Claims*. Patent concentration is necessarily a rough picture of R&D activity and technological achievement, because it does not compare the actual inventions on a qualitative basis. Moreover, patent concentration does not measure the number of new technological concepts that together may describe and define a particular invention. In U.S. patents, individual "claims" are made on these new technological concepts as part of a description of an invention. Figure 4 shows the concentration of claims on U.S. patents only. Although this representation

PATENT CONCENTRATION

(Percent of All Seabed Mining Patents)

PATENTEE	NODULE RECOVERY		METALLURGICAL PROCESSING		TOTAL	
	No.	(%)	No.	(%)	No.	(%)
OMA	32	(15)	40	(23)	72	(18)
KCON	8	(4)	50	(29)	58	(15)
OMI	36	(17)	15	(9)	51	(13)
OMCO	4	(2)	2	(1)	6	(2)
AFERNOD	18	(8)	7	(4)	25	(6)
DORD	2	(1)	5	(3)	7	(2)
Consortia Total	100	(47)	119	(69)	219	(56)
Potential Entrants Total	54	(25)	25	(14)	79	(20)
Engineers Total	61	(28)	29	(17)	90	(23)
Industry Total	215	(100)	173	(100)	388	(99)

FIGURE 3

CLAIMS CONCENTRATION

(Percent of all claims made on U.S. seabed mining patents)*

PATENTEE	NODULE RECOVERY		METALLURGICAL PROCESSING		TOTAL	
	No.	(%)	No.	(%)	No.	(%)
OMA	430	(28)	614	(37)	1044	(33)
KCON	33	(2)	492	(30)	525	(16)
OMI	148	(9)	143	(9)	291	(9)
OMCO	110	(7)	19	(1)	129	(4)
AFERNOD	89	(6)	19	(1)	108	(3)
DORD	5	(0.3)	N.A.	(N.A.)	5	(0.2)
Consortia Total	815	(52)	1287	(78)	2102	(65)
Potential Entrants Total	283	(20)	221	(13)	504	(16)
Engineers Total	461	(28)	133	(8)	594	(19)
Industry Total	1559	(100)	1641	(99)	3200	(100)

*(Note: Claims data were available only for U.S. patents.)

FIGURE 4

INTRACONSORTIUM PATENTS AND CLAIMS CONCENTRATION

(Percent of patents and claims held by consortium member firms)*
(Primary Patenting Firms [PPFs] are underlined)

	Total Consortium Patents	Total Consortium Claims*	Consortium Member Firms	% of Own Consortium Patents Held	% of Own Consortium Claims* held by PPF
OMA	72	1044	AWI and MN&D	90	87
			Union Miniere	4	10
			Met. Hob.-Overp.	1	2
			Technomare	4	1
KCON	58	525	Kennecott	93	99.8
			Bear Creek Mining	3	--
			Mitsubishi K.K.K.	3	0.2
OMI	51	291	Inco	53	68
			Preussag	16	6
			Sumitomo M.M.	12	13
			Salzgitter	6	3
			Metallgesellschaft	4	--
			Earl & Wright	2	7
			How. Deut. Werft	8	1
OMCO	6	129	Lockheed	17	77
			Shell Oil	66	23
			Bag. Bos & Kalis	17	-
AFERNOD	25	108	CEA	60	68
			SLN	26	14
			CNEXO (IFREMER)	14	18
DORD	7	5	AIST	14	100
			Mitsui Zosen	14	--
			Others	74	--

*(Note: Claims data were available only for U.S. Patents.)

FIGURE 5

of R&D activity still cannot compare inventions qualitatively, it may provide a better measure of the number of new technological concepts that accompany seabed mining patents.

In this comparison of claims concentration, the consortia remain in almost the same positions as in the patent concentration comparison, with at least two notable exceptions. First, OMA has a greater number of metallurgical process claims than KCON. OMA actually averages over 15 claims per process patent while KCON averages only nine. Second, OMCO has surpassed KCON and AFERNOD in its concentration of nodule recovery claims. Lockheed made 99 claims on its one remote-control, bottom-crawler recovery system patent. With the exception of OMA member, Union Miniere, which has made 109 claims on two recovery patents, no other seabed mining patent comes close to Lockheed's in total number of claims. This may be an important indicator of patent strategy in the case of the OMCO group.

B3. *Intraconsortium patents and claims*. Concentration data indicate the relative importance of consortia patent activity, at least in the amount of activity, when compared to the patent activity of potential entrants and engineers. It may prove useful, therefore, to examine more closely the concentration of patents and claims within individual consortia. Figure 5 shows the percent of total patents and total claims on U.S. patents for the members of each consortium. The primary patenting firms (PPFs) in each consortium can thereby be identified. Deepsea Ventures (including eight patents held by Newport News Shipbuilding and Drydock) and Kennecott are overwhelmingly the lead patenting firms in their respective consortia. Because the OMA and KCON groups are the leaders in industrywide patent and claims concentrations, one might conjecture that Deepsea Ventures and Kennecott have been the most active firms in seabed mining R&D, with Kennecott clearly emphasizing metallurgical processing work. In the cases of OMI and AFERNOD, patent and claims activities are distributed among more of the member firms or agencies, although Inco and CEA are clearly the respective leaders. In OMCO's case, Lockheed holds only one of six total patents, but has made over three-quarters of the claims. The available evidence is insufficient to draw conclusions for DORD, but the Agency of Industrial Science and Technology (AIST), an affiliate of the Japanese Ministry of International Trade and Industry (MITI), has been conducting a large-scale manganese nodule R&D project with the assistance of about 16 private companies.

C. Relative Emphasis

Concentration data reveal those firms and agencies that have been most active in patenting, and therefore possibly also in R&D, in the seabed mining industry. But concentration explains little about the emphasis *within* a firm or agency on seabed mining R&D. Figure 6 shows U.S. seabed mining patents as a percent of all U.S. patents granted to PPFs during 1969–80.[8] Data on four large potential entrant firms has been included for comparison. Again, Deepsea Ventures leads with over two-thirds of its total patent activity directed toward seabed mining. CNEXO and SLN follow with only one-quarter of their patent activity in the seabed mining area, and Kennecott takes a distant third with 15 percent of its total patent emphasis in seabed mining.

Several firms or agencies, including UOP, CEA, General Dynamics, Bethlehem Steel, and Inco, obtained many patents

RELATIVE EMPHASIS

(U.S. seabed mining patents as a % of all U.S. patents by PPF during 1969-80)

PPF	All U.S. Patents 1969-80	U.S. Seabed Mining Patents 1969-80	U.S. Seabed Mining Patents as a % of all Patents: 1969-80
DVI (and MNS&D) a/	54	38	(70)
CNEXO b/	6	1.5	(25)
SLN b/	6	1.5	(25)
Kennecott	223	33	(15)
Preussag	18	2	(11)
Inco, Inc.	446	13	(3)
Sumitomo Metal	N.A.	2	N.A.
Lockheed M&S	41	1	(2)
CEA	821	4	(1)
AIST c/	56	N.A.	N.A.
Potential Entrants			
Global Marine	84	3	(4)
Bethlehem Steel	408	4	(1)
General Dynamics	490	4	(1)
UOP, Inc.	2425	4	(0.2)

a/ 100% of DVI's relative emphasis during this period was spent on seabed mining patents. MNS&D has obtained some patents in other areas during this period.

b/ CNEXO and SLN have one joint and two separate U.S. seabed mining patents.

c/ AIST holds one 1983 U.S. seabed mining patent.

FIGURE 6

in different areas during this period, a good reflection of their extensive R&D capabilities. But, and perhaps not too surprising in light of the concentration data, these firms expended a very low percentage of their total patenting emphasis on seabed mining technology. Indeed, many consortium member firms expended relatively less emphasis on seabed mining patents than did potential entrants. One advantage in forming a consortium may be the allocation of responsibilities such that those firms with particular expertise in an area such as seabed mining R&D undertake the bulk of the work in R&D in patenting. Lockheed, Kennecott, and Deepsea Ventures may be examples of this kind of distribution of responsibility.

D. Timing of Patent Activity

The timing of patent activity is an important quantitative measure of the rate of invention in an industry. R&D usually is a prerequisite to invention. Therefore, the timing of patent activity may provide a rough measure of the timing of R&D activity. This is especially useful in an understanding of the seabed mining industry, because much of its efforts have been directed at R&D. If the seabed mining industry is cyclical in nature, a trait that generally is characteristic of mining industries, an examination of patent timing may help to describe the nature of the cycle.

The timing of patents for the entire seabed mining industry is depicted in Figure 7. (The numbers along the X-axis of the figure represent, on top, the years in which patents were granted

TOTAL SEABED MINING PATENTS WORLDWIDE 1965-1984

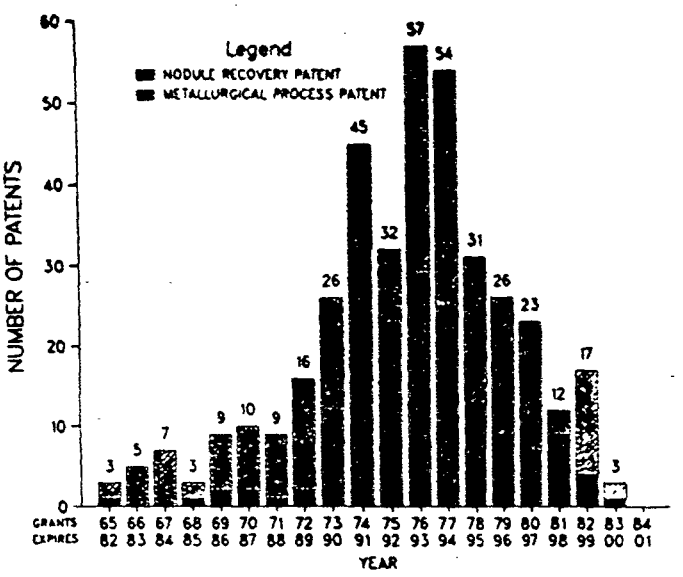

FIGURE 7

and, underneath, the years in which those patents will expire.) The first seabed mining patents were issued in the mid-1960s, and patent activity has continued from that date until the present. The preponderance of patents were granted between 1973 and 1978. Thus a period of patent protection exists for most seabed mining patents until 1990–95.

In the United States, the process of application for the issue of a patent on an invention takes an average of two years due to a tremendous backlog of patent applications and a limited examining staff at the Patent and Trademark Office. This rule-of-thumb holds true for seabed mining patents as well. (Figure 8 shows the cumulative number of U.S. seabed mining patent applications and grants at any moment in time and displays the approximate two year lag between applications and grants.) Because most seabed mining patents were granted between 1973 and 1978, it follows that applications for these patents most likely were filled between 1971 and 1976.

As roughly indicated by this timing pattern, most seabed mining R&D, which resulted in applications filed during 1971–76, must have taken place in the late 1960s and early 1970s. Although the lag structure for seabed mining R&D to economic conditions in the metals markets is unknown in this industry, a complex interaction of factors probably worked first to spur and then to slow seabed mining R&D. These factors may be related to economic signals, political events at the Law of the Sea Conference, and legal uncertainties associated with the status of exploration and exploitation sites. R&D accelerated during the early 1970s when economic conditions generally were bright. Subsequent to the time of the 1973–74 recession, which was precipitated by the energy crisis, seabed mining patent activity levelled-off and declined steadily thereafter. Thus, if a seabed mining R&D cycle exists, the period can be very crudely estimated at twenty years.

Interestingly, if this period should persist, the next upswing would occur in the early 1990s. This coincides with the be-

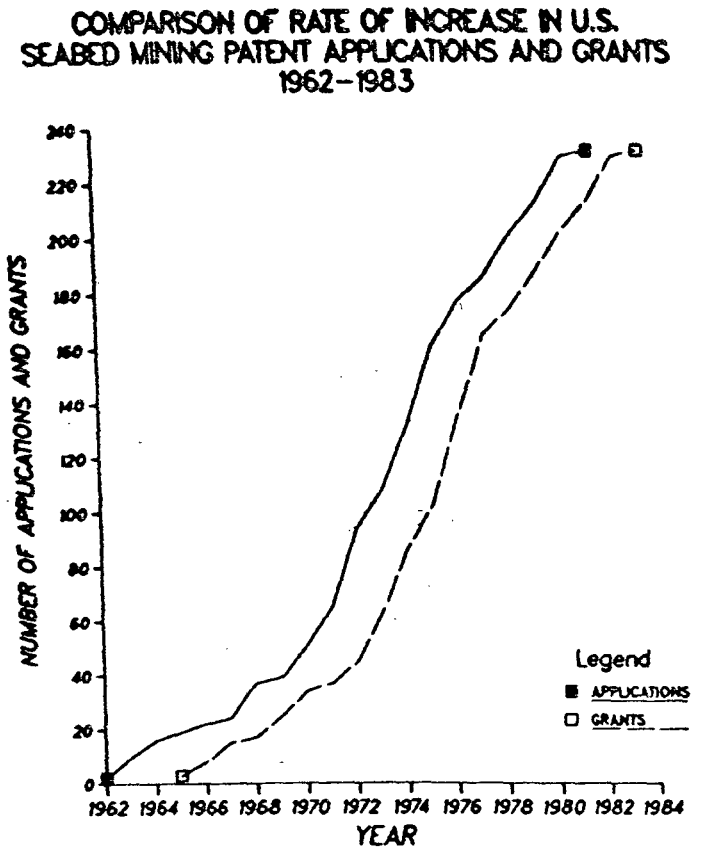

FIGURE 8

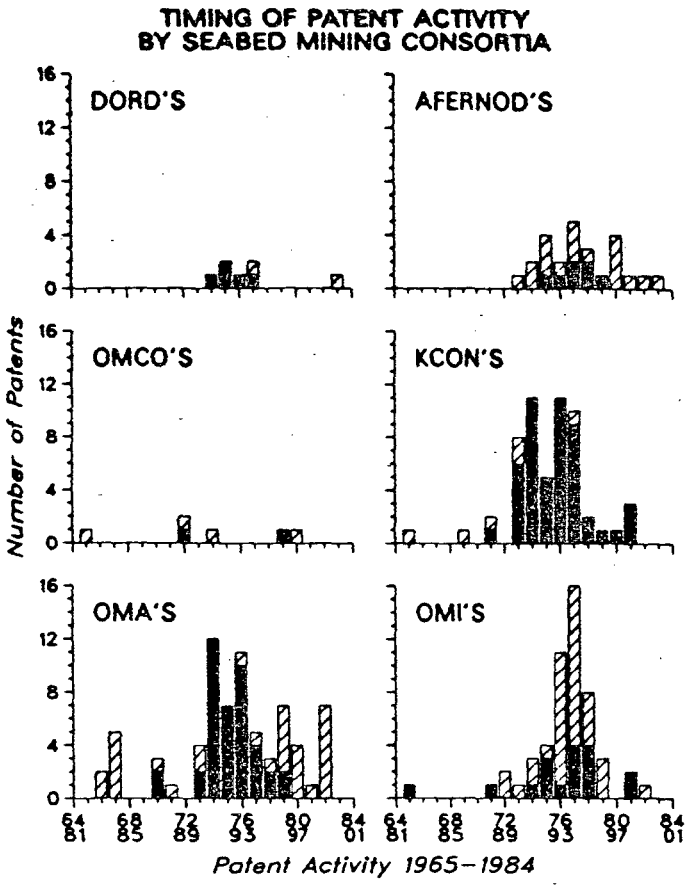

FIGURE 9

ginning of the expiration dates for the bulk of the seabed mining patents. As these patents expire, the technology that they describe can be manufactured, sold, or used without restriction. This increased availability of technology might then enhance a renewed industrial interest and reinforce any tendency for cyclical behavior in seabed mining activity.

It is known that the consortia had constructed timetables for their R&D programs. When their programs had been completed, the consortia decided not to continue seabed mining R&D. It is possible, therefore, that the individual strategies of the seabed mining consortia may have been important factors in shaping this round of patent activity. The timing of patents for the individual consortia is depicted in Figure 9. The consortia, OMA, OMI, KCON, and AFERNOD, show a large increase in patent activity at approximately the same time as they were formed. The technological groundwork which preceded the patent activity may have helped contribute to the formation of these consortia. Some of the patents that preceded consortia formation may have been sought to advertise technological capability and attract partners or customers. The primary patenting firms may have sought patents in part to protect themselves from their prospective partners (otherwise, they would have to reveal unprotected know-how). As the consortia were formed, additional know-how protection could be written into their joint venture agreements. Once the first round of R&D had occurred, and patents had been obtained, the technology was protected for a seventeen year period. While envisioning a diminishing rate of return on additional research in the absence of immediate commercial development, patent holders could then afford to back off on R&D and await more favorable economic conditions before commercial utilization of their technology.

E. Spread of Patent Activity

The production of metals from seabed nodule ores involves two broad problems: the recovery of nodules from the deep seabed and the metallurgical processing of those nodules. Each problem can be separated into several generic categories of technology. The recovery of nodules from the deep seabed consists of collection, lift, surface support, and transportation technologies. The metallurgical processing of nodules consists of reduction, extraction, and electrowinning of nickel and copper, and the beneficiation of other metals like cobalt or manganese. Figure 10 shows how the patent activity of consortia and potential entrants is spread across generic categories of seabed mining technology.[9]

The spread of patent activity may have important implications for the vertical integration of firms in an active industry. The extent to which a firm has the ability to recover and metallurgically process seabed nodule ores reveals its technological position within an industry and may have some importance with regard to its eventual commercial success. As depicted in Figure 10, in general, the consortia are more vertically integrated than individual potential entrant firms. Two

SPREAD OF PATENT ACTIVITY ACROSS GENERIC TECHNOLOGICAL CATEGORIES

	RECOVERY				METALLURGICAL PROCESSING			
	Collection	Lift	Surface Support	Transport	Reduction	Extraction	Electrowinning	Recovery of Other Metals
CONSORTIA								
OMA	•	•	•	•	•	•	•	•
KCON	•	•	•		•	•	•	•
OMI	•	•	•	•	•	•	•	•
OMCO	•	•	•			•		•
AFERNOD	•	•	•		•		•	•
DOMD	•	•	•		•	•		
POTENTIAL ENTRANTS								
Bayer					•	•		
Bendix	•	•	•					
Bethlehem Steel	•	•	•	•	•			
Chevron Research					•			
Combustion Engineering					•			
Deut. Babcock & Wilcox	•							
Demag L.M.S.	•	•						
Dow Chemical					•	•		
Duisburger Kupferhutte		(see Bayer)						
EMH		•	•					
Ethyl Corporation					•			
Friedrich Krupp	•	•						
General Dynamics	•	•	•					
G. für Kernforschung	•	•						
Gold Institute (USSR)	•	•	•					
Grupping A.W.J.	•	•						
IHC Holland		•						
Klein, Schanzlin & Becker		•						
Leningrad Mining Inst.	•							
Mobil Oil	•	•	•		•			
Moscow Mining Inst.	•							
Orenstein & Koppel	•							
Republic Steel					•			
Sherex Chemical						•		
Sherritt Gordon Mines					•			
SGCEM	•	•	•					
Summa Corporation	•	•	•					
SOFREM					•			
Tetra Tech	•	•						
Union Carbide							•	
UOP					•	•	•	
Transp. Cons. Inst.	•	•						
Ust-Kamenogorsk Nonferrous		•						
Westinghouse Electric	•	•	•					

FIGURE 10

consortia, OMA and OMI, have patented technology in each generic category and appear more vertically integrated than the other consortia. The spread of patent activity reaffirms the conclusion drawn earlier from the concentration data that potential entrants have tended to focus on either recovery or processing technology. In very few cases, such as Bethlehem Steel and Mobile Oil, potential entrants have patented both nodule recovery and metallurgical processing technology.

Generic categories of technology can be further subdivided into specific technologies. For example, at least six specific technologies compose the generic category of collection: sampler, CLB bucket, towed sledge, hybrid bucket/sledge, robot crawler, and autonomous shuttle. The generic categories of recovery and metallurgical process technologies have been subdivided in Figure 11 by consortia. Patent activity across specific technological solutions within a generic category may have important implications for technological performance relative to rivals. For instance, AFERNOD members hold patents on four out of the six collection technologies, including the autonomous shuttle, which is radically different in concept from technologies patented by other firms. AFERNOD's diversification within this generic category reveals a flexibility that eventually might allow it to operate with the most commercially successful specific solution to the collection problem.

Under conditions of commercial operation, and especially after patent protection expires, one might expect operators to converge upon the most effective technology.[10] If specific categories are broad enough to allow more than one patent on each specific technology, i.e., substitutes, as appears to be the case in many seabed mining technologies, then convergence could occur even before the industry becomes commercial. The spread data show that several consortia have patented components of hydraulic systems: towed sledges, robot crawlers, waterpumps, and airlifts, among others. In fact, hydraulic systems are the purported technology of OMI, OMA, KCON, and OMCO.[11] The Japanese are conducting a large-scale R&D project directed at developing a hydraulic system. Recently, the French have indicated their intentions to move away from

SPREAD OF CONSORTIA PATENT ACTIVITY ACROSS SPECIFIC TECHNOLOGICAL CATEGORIES
(Recovery and Metallurgical Processing)

	OMA	KCOR	UNI	OMCO	AMAX	KOMO
COLLECTION						
Sampler	•	•	•	•	•	•
Bucket (CLB)					•	•
Towed Sledge	•		•		•	•
Hybrid Bucket/Sledge						
Robot Crawler		•	•	•		
Autonomous Shuttle					•	
LIFT						
Wire Rope					•	•
Water Pump	•		•	•	•	
Airlift	•	•				•
Moonpool	•			•		•
Gimballed Derrick	•			•		
Pipe Handler	•			•		
Shuttle					•	
SURFACE SUPPORT						
Ore Carrier	•					
Semisubmersible					•	
Drillship			•	•		
Vertical Vessel						
Other Vessel	•	•	•	•	•	•
Navigation				•		
TRANSPORT						
Ore Carrier	•		•			
Docking System			•			
Loading System			•			
REDUCTION						
Comminution	•	•	•		•	
Acid Leach	•	•	•	•	•	
Ammoniacal Leach	•	•	•			
Acid Halide Leach	•	•				
Smelting	•	•	•		•	
Caprion		•				
Gaseous	•	•	•		•	
Other	•	•				
EXTRACTION						
Nickel	•	•	•	•	•	
Copper	•	•	•	•	•	
Cobalt	•	•	•	•	•	
Manganese	•		•			
Other	•	•			•	
ELECTROWINNING						
Nickel	•	•			•	
Copper	•	•	•		•	
Cobalt	•		•			
Manganese	•					
OTHER RECOVERY MEANS						
Cobalt	•	•		•	•	
Manganese	•	•	•			
Molybdenum	•	•	•			
Zinc	•				•	
Others	•					

FIGURE 11

the autonomous shuttle concept and towards the hydraulic system.[12] Thus convergence upon a perceived most effective technology is possible even before commercial operations. But, because patents have been granted on many kinds of technology, this convergence is not immediately apparent from observations of patent activity.

III. CONCLUSIONS

Because patents afford the patent holder the right to exclude others from the manufacture, use, or sale of inventions, patents are an important part of the strategies of firms and agencies as they operate within an industry.[13] In a formative minerals industry that has focused primarily on R&D, observations of patent activity are one way to uncover and examine the behavior of participating firms and government agencies.

As might be expected, those firms or government agencies that have ventured together as seabed mining consortia hold the greatest concentration of seabed mining patents or seabed mining patent claims. This is a clue to one possible strategy. Firms or government agencies have ventured together in order to spread the risks of investment in seabed mining R&D. Because seabed mining is a formative industry that has not yet reached commercial proportions, and because there is plenty of room for further technological developments, the risks for a single firm are quite large.

The large risks involved in seabed mining are underscored when one looks more closely at the emphasis, in terms of patent activity, of individual firms on seabed mining versus other fields of technological development. Within each consortium, one primary patenting firm (PPF) usually holds the great bulk of patents and claims. However, most of the industry's PPFs have not emphasized seabed mining R&D. Here is another strategy which is closely related to the first one. Even those consortia firms with the lead responsibility for technological development and patenting have reduced their exposure to risk by diluting their R&D efforts over many areas of research.

Another broad strategy can be uncovered through information gathered on the kind of technology that has been patented. The spread of patent activity across generic categories of technology is an indicator of the scope of the efforts of firms and government agencies in solving the problems of producing metals from seabed ores. In terms of patent activity, the consortia hold more patents in the different generic categories than do the potential entrants or engineers. Once again, it appears that it is very costly for single firms to spread their technological development activities across the many generic categories of technology. This observation suggests that the consortia have positioned themselves to achieve fully integrated operations and thus to capture the entire value of a refined metal product.

Individual strategies of the seabed mining consortia may have been important in shaping the first round of patent activity. In several cases, the dates of patent applications and grants reveal an increase in patent activity at approximately the time when the consortia were officially organized. Because a patent is a piece of property, or an asset, patent activity might have occurred either to advertise technological capability or to attract partners or customers. The technological groundwork incorporated into these patents certainly helped to facilitate consortia formation by providing a knowledge base and a direction for future research and development. Initially, PPFs may have sought patents in part to protect themselves from their prospective partners so that they would not have to reveal unprotected know-how or trade secrets. As the consortia were formed, further protection may have been written into their joint venture agreements.

Some additional individual strategies may be contained within the data on patent activity, but these will not become evident until the industry is operating on a commercial level. Hidden within the patent data is a relatively recent tendency for the consortia to converge on an hydraulic type of recovery system. Conversely, some patents may have been "fenced-in". This occurs when one firm or agency patents many similar inventions that are only slight variations on an original. In this way, technological breakthroughs can be protected from other firms

or agencies that seek a portion of the patent monopoly by patenting their own similar inventions or substitutes. The real test for fencing-in is whether or not each patented invention is actually employed or left to "sleep" over the seventeen year patent life. In a formative, noncommercial industry like seabed mining, such a test might never occur.

For reasons related to a number of interdependent economic, political, and legal factors, seabed mining patent activity for all firms and agencies commenced in the late 1960s, peaked in the mid-1970s, and has fallen today to a reduced rate. This pattern is a rough representation of R&D activity in seabed mining and may indicate the possibility of a seabed mining industry cycle. From an international perspective based upon patenting activity, one might very well expect to see a renewed industrial interest in seabed mining before the turn of the century.

The degree to which patent protection remains an important component of firm strategy in seabed mining today is unclear. It is clear that further technological research and development must take place if recovery and metallurgical processing systems are to be upscaled to the commercial level. R&D and patent activities will continue through the life of the industry as competitors seek new, less costly methods of producing metals from deep ocean polymetallic nodules. If and when another surge of seabed mining activity occurs, the technological information contained in the early patents undoubtedly will facilitate progress toward innovation and thereby speed the rate of eventual commercialization.

FOOTNOTES

(1) J.M. Broadus, Social Scientist, Marine Policy Center, Woods Hole Oceanographic Institution, several personal communications, from February 1983 through May 1985. The cyclicality that one might expect from observations of patent activity or from R&D is different from what is generally known as the "business cycle." One normally would expect to see an increase in inventive activity in the early stages of the life of an industry. Contrary to immediate impressions, however, inventive activity in an industry does not necessarily terminate once everything necessary to accomplish the industry's productive tasks has been invented. Cost-reducing refinements to innovative technologies are one obvious continuation of inventive activity. Strategic behavior in an industry, such as the invention of substitute technologies, also may act to continue inventive activity. (See generally: M.E. Porter, *Competitive Strategy*, New York: The Free Press, 1980, pp. 156–174.) In the particular case of the formative seabed mining industry, significant problems, which will require additional inventive activity before commercial operation, still exist. At the very least, these problems will involve scaling-up recovery and metallurgical processing systems to the commercial level.

(2) M.E. Slade, "Cycles in Natural-Resource Commodity Prices: An Analysis of the Frequency Domain," *Journal of Environmental Economics and Management* 9 (1982): 138–148; J.B. Tilton, *The Future of Nonfuel Minerals* (Washington: The Brookings Institution, 1977), pp. 64–79. See also: L.L. Fischman, Project Director, *World Mineral Trends and U.S. Supply Problems*, Research Paper R-20 (Washington: Resources for the Future, 1980), pp. 25–33.

(3) Patent strategies are thoroughly discussed by F.M. Scherer, *Industrial Market Structure and Economic Performance*, 2nd edition (Chicago: Rand McNally College Publishing, 1980).

(4) One observer has noted that large firms usually patent in only those countries that are known for "technological capabilities and strong markets." It would be unreasonable to patent a technology "where there is little or no demand for it or insufficient capability to produce it." J.D. Frame, *International Business and Global Technology* (Lexington, Mass.: D.C. Heath and Company, 1983), pp. 107.

(5) To the extent that inventive activity, or even R&D, is measured by patent activity, the inclusion of all patents obtained by a company in a counting exercise may overestimate inventive activity.

(6) Metallgesellschaft A.G., "Manganese Nodules—Metals from the Sea," *Review of the Activities*, Edition 18 (Frankfurt am Main, West Germany: 1975): 27–35.

(7) It is assumed that the patent searches conducted for this study were comprehensive enough to provide a meaningful comparison of patent activity. No search, however, can claim to be fully comprehensive. A further difficulty is encountered in measuring R&D by patent activity, since clearly R&D could be conducted without patenting. Patents are a better measure of the rate of invention and, when used with care, may indicate R&D trends. J. Balderston et al., *Modern Management Techniques in Engineering and R&D* (New York: Van Nostrand Reinhold Company, 1984): 201. The relationship of R&D to patent activity may also vary with other factors, especially the size of the firm, research expenditures, and the number of employees. J. Bound et al., "Who Does R&D and Who Patents?," Z. Griliches, ed., *R&D, Patents, and Productivity* (Chicago: The University of Chicago Press, 1984): 21–54.

(8) U.S., Department of Commerce, National Technical Information Service, *Industrial Patent Activity in the United States*, Part 2, NTIS Patent Information Series (Washington: April 1981). This document is a listing of entities that received at least three U.S. patents during the period 1969 to 1980.

(9) These categories of technology are explained in detail in P. Hoagland *Patent Activity in the Seabed Mining Industry*, Woods Hole Oceanog. Inst. Tech. Rept., WHO I-85-20.

(10) See generally: P.B. Grote and J.Q. Burns, "System Design Considerations in Deep Ocean Mining Lift Systems," *Marine Mining* 2 (1981): 357–383. Active firms ideally would select the most effective specific tech-

nology within a generic category for use in seabed mining. If patent protection already exists for that technology, however, then firms either would obtain a license on that technolgy or choose the next most effective unprotected substitute. This could contribute to a convergence upon one specific technology.

(11) See, for example, U.S., Department of Commerce, National Oceanic and Atmospheric Administration, Office of Ocean Minerals and Energy, *Deep Seabed Mining Draft Environmental Impact Statements on Issuing Exploration Licenses to OMA, OMI, OMCO, and KCON*, 4 Vols., (Washington: May 1984).

(12) P. Le Gouellec et al., "Bilan Global des Activités Françaises dans l'Exploitation des Nodules: Objectifs du Programme Gemonod," Presented at *2nd International Seminar on Offshore Mineral Resources*, Brest, France: Centre Océanologique de Bretagne, March 1984.

(13) The histories and possible strategies of each individual consortium, and the efforts of the Soviet Union, potential entrants, and engineers are discussed in Hoagland, n. 9.