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MANGANESE NODULE MINING AND ECONOMIC RENT

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The current negotiations on the law of the sea seem likely to answer partially the question of who owns the resources of the oceans. Ownership has been ambiguous since the days of Grotius. While the actual answer will differ for different parts of the oceans, the United Nations' Law of the Sea Conference is likely to decide that the international community owns the resources of the deep ocean, which will probably be defined as that part of the oceans beyond two hundred miles from shore or beyond the continental shelf, whichever is farther. In this area are found manganese nodules, which are currently attracting attention as a potential source of several hard minerals. As owner, the international community would be entitled to regulate the conditions under which the nodules might be exploited. Current positions of various nations differ on whether the regulations imposed by the international community for access to the nodules should demand some kind of payment (rent, royalties, or taxes), or whether the regulations should only limit access to the extent necessary to prevent ecological damage and interference with navigation.

From an economic viewpoint, the question whether a payment should be required depends upon whether economic rent would result from exploitation of the nodules. If there is economic rent, a second question is who should receive it. If the international community as owner feels entitled to some or all of the economic rent, a payment of some form should be assessed as a precondition for access to the nodules. This paper is an attempt to determine whether there would be economic rent created by nodule mining, and if so, roughly how much.

Economic rent exists only if the total value of an output exceeds its total costs by more than a "normal" profit.[1] Such a condition can

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1. The term "economic rent" is used here to mean a return to a factor above its opportunity cost. The opportunity cost of a nodule mining site is virtually zero because there is no alternative use for it. It is also true that the efficient price of a depletable resource is above cost plus "normal" profit by a royalty payment whose magnitude is related to the resource's scarcity and the cost of the next-best substitute. For a discussion of this in

only exist if the product in question is scarce relative to the demand for it. For economic rent to continue to exist in the long run, there must be a barrier to increasing the supply sufficiently to lower the price until the economic rent vanishes. Such a barrier could be limited endowment of the necessary raw materials for producing the output, as is the case with successful entertainers and some natural resources. Or, the barrier could come through the market structure of the industry (either a monopoly or an oligopoly).[2]

In the case of manganese nodules both kinds of barriers may exist. If commercially exploitable nodules are not a "free good" but are scarce, such scarcity could permit the creation of economic rent by miners. And if there exist barriers to entry into nodule mining, the conditions for increasing such economic rent would exist.

ARE NODULES A FREE GOOD?

Manganese nodules are small potato-like objects continuously being formed in the sediment processes of the oceans and located on the deep ocean bed. While they are found in numerous parts of the major oceans, the chemical composition and the density vary from place to place. The most important chemical elements from a commercial viewpoint are nickel, copper, cobalt, and manganese. For commercial viability (based on current prices), nodules should have at least 25 percent manganese, 1.25 percent nickel, 1 percent copper, and 0.22 percent cobalt.[3] Nodules with the highest percentages of nickel and copper (approximately 2 percent each) are found in parts of the Pacific Ocean. Wherever found, however, the relative amounts of the commercially valuable elements in nodules differ markedly from the relative quantities in world use of these elements. LaQue has shown, based on 1967 data, that if nodules were mined in sufficient quantity to have fulfilled the 1967 world use of manganese, nodules would also have provided 4 percent of the world's copper, 59 percent of its nickel and 453 percent of its cobalt.[4]

relation to oil see, Nordhaus, *The Allocation of Energy Resources* in 3 Brookings Papers on Economic Activity 531 (1973). In the case of the major mineral components of nodules, however, only the price of copper is likely to contain a significant royalty component. The other minerals are too abundant.

2. Monopoly profits form an economic rent to the entrepreneur created by his control over the market for his output. He may be able to increase them by monopsony power in the markets for his inputs. For convenience this paper talks only about the total economic rent resulting from nodule mining; it is not possible currently to sort out what share of that rent is attributable to each factor of production.

3. *Hearings on S. 1134 Before the Subcomm. on Minerals, Materials & Fuels of the Senate Comm. on Interior & Insular Affairs, Mineral Resourcs of the Deep Seabed*, 93d Cong., 1st Sess. 27 (1973) (Statement of Leigh S. Ratiner) [hereinafter cited as *1973 Hearings*].

4. F. LaQue, Prospects for and from Deep Ocean Mining, *Hearing on the Law of the Sea*

In addition to varying metallurgically, manganese nodules also vary in the density with which they are found on the ocean floor. Unlike land-based ores, manganese nodule deposits have no significant vertical dimensions, consisting of a single layer on the surface of the ocean floor. The density can vary widely, with average densities ranging from 0.5 to 3.0 pounds wet per square foot. An average density of two pounds of wet nodules per square foot is held to be necessary for successful mining.[5]

There are several other requirements related to available mining equipment for an economically viable mine site. There are believed to be three methods of mining, each under development by a different commercial organization. One is a pneumatic lift system, developed and tested by Deep Sea Ventures, Inc., which is a subsidiary of Tenneco. This type of mining rig would have to be custom-built for each mining site, because elements of its design depend upon water depth, water velocity, and other characteristics of the mining site. The second is the continuous-line bucket system, invented by Mr. Yoshio Masuda of Japan. This system received extensive testing last summer, the results of which are not public. However, the rumor is that it was not successful. The third system is one developed by Hughes Tool. This is believed to be a hydraulic lift system and could be an outgrowth of oil drilling technology, a Hughes specialty.[6]

All of these technologies require a relatively unobstructed ocean floor on which to operate. It must not be strewn with boulder, nor can it be broken up by rifts and valleys. The sediment layer must not be too soft to support the mining equipment. In addition, the area of the ocean under which the mine is found must not have too rough surface conditions of weather and waves or the ships doing the mining will not be able to hold sufficiently to their courses.[7]

Together, all these requirements for successful mining indicate that despite the ubiquity of manganese nodules as a geological phenomenon, commercially valuble deposits will be very rate. Most companies that are known to be prospecting for them are concentrating their searches in a relatively narrow band of the Pacific Ocean lying roughly within the area bounded by 17°south, 17°north, 180°

& Peaceful Uses of the Seabeds Before the Subcomm. on Int'l. Organization & Movements of the House Comm. on Foreign Affairs, 92d Cong., 2d Sess. 67 (1972) [hereinafter cited as *1972 Hearings*].

5. *1973 Hearings, supra* note 3, at 185 (Statement of T.S. Ary).

6. More information about the technology of both mining and processing of manganese nodules can be found in Hammond, *Manganese Nodules (II): Prospects for Deep Sea Mining,* 183 Science 644 (1974).

7. J. Flipse, M. Dubs, & R. Greenwald, Pre-Production Manganese Nodule Mining Activities and Requirements, *1973 Hearings, supra* note 3, at 625.

west and the west coast of the American continents. In this region are found the nodules with the highest known concentrations of the commercially valuable minerals. Even within this area, however, the density and sea floor conditions vary widely.

The actual number of potential mining sites is unknown except perhaps to the companies considering the industry. It seems likely, however, that the total number of commercially viable sites are limited and that some of them are more valuable than others. The number of "best" sites is almost certain to be less than the number of potential miners, when it is considered that a single mine on such a site would have to cover about 8,880 square miles to yield enough nodules over a forty-year life.[8] This large size is required because nodule deposits, as noted above, have essentially no thickness, only surface area.

There is thus a likely scarcity of the best mine sites, although there is probably no shortage of sites that could be mined at lower profits. If there were perfect entry into the industry, the last miner (who would be working the "worst" of the exploited sites) would just earn a normal profit while operating at the lowest point on his long-run average cost curve. Economic rent would be accumlating from all the other mine sites, however, due to their superior grades of ore or topography. Thus, it seems clear that some economic rent will be generated from nodule mining no matter what the industry structure.

THE NODULE INDUSTRY

In fact the mining of manganese nodules is most unlikely to be a competitive industry. While there are currently more than 25 firms expressing an interest in mining, only a few are actually likely to mine. The number of mines will probably be even less, as some are likely to form consortia or joint ventures for this endeavor.[9] The major reason for such a contraction in numbers is the high capital costs of a mining venture.

The capital costs of a mining venture depend in part upon the form of processing to be employed. Processing nodules involves at least partially new techniques because nodules are both physically and chemically unlike land-based ores. Several different methods have been studied using different materials to leach out the desired elements. The process chosen determines the minerals recovered.

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8. *1973 Hearings, supra* note 3, at 186 (Statement of T.S. Ary).

9. For a partial listing of the companies including some already members of consortia, see A. Rothstein & R. Kaufman, The Approaching Maturity of Deep Ocean Mining–The Pace Quickens, *1973 Hearings, supra* note 3, at 202.

Kennecott, and perhaps Hughes, are experimenting with a process using ammonia which is similar to a process used for nickel recovery from land-based ores. It yields copper, cobalt, and nickel, along with much smaller quantities of several other minerals. Apparently it also can yield manganese oxide, but it is unclear whether the managanese will be utilized. In general, the Kennecott process if referred to as a three-metal recovery system. A method using hydrogen chloride, referred to as a four-metal recovery system, was developed by Deep Sea Ventures and has been used successfully at a pilot plant. It reportedly yields 98 percent recovery of minerals and yields manganese as a pure metal. Moreover, according to testimony submitted in June 1972, this method can yield marketable quantities of zinc, molybdenum, and vanadium.[10]

While estimates have varied in the past there seems to be an emerging consensus on maximum capital costs and size of operation: $250 million or $400 million for mining operations yielding either 1 million or 3 million tons of nodules per year.[11] The larger tonnage is for an operation that does not recover manganese. Such an operation apparently requires several ocean installations for each processing plant.

Although the capital cost is high, the estimates of the rate of return on that investment also appear to be high, as shown below. The precise revenue and cost figures of individual companies depend upon actual mine sites and are corporate secrets. However, it is possible to calculate the range in which the actual figures are likely to fall.

Estimates released recently by representatives of the companies involved in nodule mining indicate that operating costs per ton are declining over the range of tonnages under consideration.[12] For output of one million tons of nodules, Rothstein and Kaufman show operating costs ranging from $55 to $73 per ton. For output of three million tons per year, they estimate operating costs to be between $35 and $54 per ton. The estimate of a Kennecott spokesman was between $21 and $30 per ton for a venture mining three million tons of nodules per year.[13]

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10. *Hearings on Development of Hard Mineral Resources of the Deep Seabed Before the Subcomm. on Minerals, Material & Fuels of the Senate Comm. on Interior & Insular Affairs,* 92d Cong. 2d Sess. 74 (1972) (Statement of N. Freeman). For more discussion of processing methods see Hammond, *supra* note 6.

11. *1973 Hearings, supra* note 3 at 45 (Statement of Leigh S. Ratiner). All capital cost estimates include search costs as well as development costs.

12. Rothstein & Kaufman, *supra* note 9, at 217.

13. Address by Marne Dubs, Conference of Marine Technology Annual Session, Sept., 1973.

REVENUE AND MARKET IMPACT

Costs are only one side of any profitability calculation; revenue is the other. Revenue considerations must start by looking at prices. Any impact of nodule mining upon price depends in part upon the total tonnage mined. The order in which the markets would be affected as tonnage increased is cobalt, mangaese, nickel, and copper. A good case can be made that only the cobalt and manganese markets would be significantly affected.[14] Such a conclusion is based on two considerations. One is the difference between the relative quantities of the minerals in the nodules and in current world consumption. The other is the structure of the future nodule industry. The yield and revenue, assuming no change in prices, from one ton of nodules composed of 25 percent manganese, 1.25 percent nickel, 1 percent copper and 0.22 percent cobalt is shown in Table 1. This table assumes a 98 percent recovery rate.

Table 1
Revenue from the Contents of One Ton
of Minimum Grade Manganese Nodules at Current Prices[15]

	lb.	$/lb.		$/ton
Manganese	490	0.3125	=	153.13
Nickel	24.5	1.53	=	37.49
Copper	19.6	0.68	=	13.33
Cobalt	4.4	3.20	=	14.08
Total				218.03

A. *Manganese*

While manganese would seem to be the most important revenue source, the figure is misleading. There has been much uncertainty about the form that manganese recovery from nodules would take. Most manganese in use today is used either as ore or as ferromanganese, and almost all is used in the production of steel. Only a small amount of pure manganese metal (electrolytic manganese) is produced and used: in 1970 consumption of manganese metal amounted to about 2 percent by weight of all manganese consumed. The processes for extracting manganese from nodules will yield manganese either as metal or an manganese oxide. Manganese oxide

14. All figures on mineral use are from 1 Bureau of Mines, U.S. Dep't. of the Interior, Mineral Yearbook (1971), unless otherwise noted.

15. All Prices except manganese from Bureau of Mines, U.S. Dep't. of the Interior, Commodity Data Summaries (1974). Manganese price is from the Mineral Yearbook, *supra* note 14.

would be a substitute for manganese ore in steel production. The four-metal mining system yields manganese metal, the three-metal system, manganese oxide. However, it is unclear whether the production of manganese oxide is economical, and most discussions of the revenue potential of a three million ton per year recovery system do not include it.

The manganese metal output from one-million-ton nodule mining operation would be ten times the 1970 U.S. consumption of manganese metal. Clearly, the price would fall from the 1970 level. According to Wayne Smith, manganese metal can successfully substitute in some steel production for high carbon ferromanganese and yield a slightly better steel.[16] The substitution is not likely to be pound for pound, that is one pound of pure metal replacing one pound of ferromanganese. Because the total manganese content of the steel would not be changed, the substitution is likely to be one pound of pure metal for one pound of contained manganese in ferromanganses. As ferromanganese averages about 75 percent manganese, the substitution would be roughly one pound of pure metal for 1-1/3 pounds of ferromanganese. On this basis, the output from a million tons of nodules would amount in use to 21 percent of the 1970 U.S. consumption of high-carbon ferromanganese. The implication is that the price of manganese metal relative to that of ferromanganese would fall, perhaps to a level reflecting merely the differences in manganese content. Moreover, the price of high-carbon ferromanganese might fall slightly due to the greatly expanded supply of it and manganese metal.

B. Cobalt and Nickel

The other price that would be certain to fall once commercial nodule mining begins is the price of cobalt. This price decline, like that of manganese metal, would reflect the changed supply relationship. The cobalt extracted from one million tons of nodules would be 33 percent of 1970 U.S. consumption of cobalt. Cobalt is a close substitute for nickel in some steel production. What restrains its use is its price which has been as much as double that of nickel in the past. The total cobalt production from a one-million ton operation would equal roughly 1.4 percent of 1970 U.S. consumption of nickel, and 1.3 percent of 1970 U.S. consumption of nickel and cobalt combined. The impact of such cobalt supply increases is thus likely to remove the price difference between nickel and cobalt, but

16. W. Smith, Economic Consideration of Deep Sea Mineral Resources, (Woods Hole Oceanographic Institution, 1972).

it is not likely to have any impact upon the price level of nickel. What happens to that level depends only on the impact of the nickel content of the nodules.

The impact of nodule mining on nickel prices depends upon two things: the number of mining operations and the response of the existing nickel suppliers. A million ton mining operation would yield roughly 8 percent of the 1970 U.S. consumption of nickel. It would yield roughly 2 percent of 1970 world production. With proper planning and cooperation, a cartel could keep the number of mining operations by 1980 and beyond to the number able to fulfill increases in demand since 1970 without changing prices. This could mean mining only 4 to 6 million tons of nodules by 1980.[16] However, such a situation depends also upon both the expansion plans of the existing nickel industry and its price response to new entrants. The nickel industry is an oligopoly dominated by INCO and the price set by that firm. Assuming that INCO does not respond to new entrants by lowering the price, and assuming that only a few mining operations are established (a realistic assumption in view of the high capital cost), then the price of nickel will probably not fall.

C. Copper

Copper is the fourth major commercial ingredient of the nodules, but it would form only a minor part of the copper market. A million ton nodule operation would yield only 0.6 percent of 1970 U.S. consumption and only 0.1 percent of 1970 world production. Thus, it would be unlikely that the price of copper would change due to nodule mining.

Deep Sea Ventures has testified that it would also retrieve small quantities of vanadium, molybdenum and zinc from the nodules with its processing techniques.[18] These are most likely the same minerals that are mentioned as being produced as by-products with the three-metal recovery system. No figures have been given as to the concentrations of these minerals in the deposits Deep Sea Ventures has explored. However, John Mero gives a series of mineral compositions for nodules dredged up in scientific voyages.[19] The maximum concentrations of these three minerals for Pacific Ocean nodules were 0.11 percent vanadium. 0.08 percent zinc, and 0.15 percent molybdenum. These figures would translate into 2.2 pounds of vanadium, 1.6 pounds of zinc, and 2.9 pounds of molybdenum per

17. The Secretary General, Possible Impact of Sea-Bed Mineral Production in the Area Beyond National Jurisdiction on World Markets, With Special Reference to the Problems of Developing Countries, A Preliminary Assessment, at 50, U.N. Doc. A/AC. 128/36 (1971).

18. *1973 Hearings, supra* note 3, (Statement of T.S. Ary).

19. J. Mero, The Mineral Resources of the Sea 180 (1965).

ton of nodules mined. The impact of the amount of the three metals that can be extracted from a million tons of nodules is likely to be imperceptible in their respective markets. Only in the case of vanadium is the likely quantity a significant proportion of U.S. consumption or production, but it would amount to only 6.7 per cent of total 1970 world production.

On the basis of the above discussion it is possible to estimate revenue more accurately than is done in Table 1. Table 2 gives this calculation, assuming that the price of manganese metal falls to $0.11/lb. (the 1970 price for the manganese content of high-carbon ferromanganese), that the price of cobalt equals the price of nickel, and that all other prices remain unchanged.

Table 2

Revenue Potential From One Ton of Nodules at Revised Prices

	lb.	$/lb.		$/ton
Manganese	490	0.11	=	53.90
Nickel	24.5	1.53	=	37.49
Copper	19.6	0.68	=	13.33
Cobalt	4.4	1.53	=	6.73
Vanadium	2.2	1.50	=	3.30
Molybdenum	2.9	1.72	=	4.99
Zinc	1.6	0.21		0.34
Total				120.08

Without selling manganese the total revenue per ton of nodules would be $66.18. Revenue from a four-metal recovery operation mining one million tons per year would be $120,080,000. A three--metal recovery operation mining three million tons per year would earn $198,540,000 (if the average ore content were as above).

Note how important both the assumed ore content of the nodules and the prices are to these revenue estimates. It has been stated that the percentages used above (25% Mn, 1.25% Ni, 1% Cu, 0.22% Co) are minimums for commercial viability. If McKelvey's percentages (28.4% Mn, 1.47% Ni, 1.43% Cu, 0.29% Co) are used instead, the total revenue for seven-metal recovery from one million tons of nodules would be $141,680,000.[20] Revenue from three-metal recovery, mining three million tons per year, would be $241,350,000, with a per ton revenue of approximately $80. This

20. *1972 Hearings, supra* note 4, at 91 (Statement of Vincent E. McKelvey).

revenue estimate is similar to the reveue estimate of $85 to $90 per ton from a three-metal recovery system mining three million tons of nodules a year given by a representative of Kennecott Copper.[21]

PROFITABILITY

It is possible to combine the various estimates of capital costs, operating costs, and revenue to obtain estimates of the rate of return before taxes. Tables 3 and 4 show some of these estimates for the

Table 3

Estimated Rates of Return for a Four-Metal Recovery System Mining One Million Tons Per Year, Assuming No Change in Nickel Price

Capital Cost ($ million)	Operating Cost ($/ton)	Revenue ($/ton)	Return on Investment (%)
110	55	120	59
110	74	120	42
170	74	120	27
250	74	120	18
250	74	142	27

Table 4

Estimated Rates of Return for a Three-Metal Recovery System Mining Three Million Tons Per Year

Capital Cost ($ million)	Operating Costs ($/ton)	Revenue ($/ton)	Return on Investment (%)
220	35	66	42
220	54	66	16
350	35	66	27
350	54	66	10
400	54	66	9
400	21	66	34
400	30	66	27
400	30	85	41
400	30	90	45

two different types of recovery systems. Both tables attempt to show the lower possible rates of return, namely those that would result if the highest estimates of capital and operating costs turned out to be correct, and if the lower estimates of revenue also turned out to be correct. Clearly, if the content of the important minerals from a

21. *1973 Hearings, supra* note 3, at 45 (Statement of Leigh S. Ratiner).

mine site is higher than the values used here, the revenue will be greater and so will the rate of return. To the extent that these rates of return are higher than the normal profit for industries with similar risks, there is economic rent.

The importance of the price assumptions can be seen by examining the impact upon these revenue estimates of changing the prices of nickel and copper. If the price of nickel were to fall, it would carry with it the price of cobalt. The estimates of Table 2 show nickel and cobalt revenues to be 37 percent of the total revenue of a four-metal operation, 67 percent of the total revenue of a three-metal operation. Tables 5 and 6 show the effect of a 40 percent fall in nickel prices. Deep Sea Ventures is the only company that has

Table 5

Estimated Rates of Return for a Four-Metal Recovery System Mining One Million Tons Per Year, Assuming 40% Fall in Nickel Price

Capital Cost ($ million)	Operating Cost ($/ton)	Revenue ($/ton)	Return on Investment (%)
110	55	102	43
110	74	102	25
170	74	102	16
250	74	102	11
250	74	120	18

Table 6

Estimated Rates of Return for a Three-Metal Recovery System Mining Three Million Tons Per Year, Assuming 40% Fall in Nickel Price

Capital Cost ($ million)	Operating Cost ($/ton)	Revenue ($/ton)	Return on Investment (%)
220	35	49	19
220	54	49	–
350	35	49	12
350	54	49	–
400	54	49	–
400	21	49	21
400	30	49	14
400	30	N.A.	N.A.
400	30	N.A.	N.A.

expressed the intention to mine for four major metals; the other companies seem interested in a three-metal recovery system.

The importance of the price of nickel to the revenue and profitability of the operation is expected to provide another barrier to entry into the industry. Most observors of nodule mining assume that freedom of entry into the mining industry will bring only two or three miners by 1980, with further additions roughly matched to expected growth in the demand for nickel. Under the demand assumptions prepared by the United Nations, this would mean an additional operation every two to three years.[22]

The effect of changing copper prices could change limitations on entry. Assuming only three miners by 1980 is reasonable not only on grounds of not disturbing the nickel market, but also because too few firms have done the necessary development work to enable more than that number to begin mining by that date. Even if all three hypothetical miners in 1980 were recovering only three metals from the nodules, meaning that each would mine three million tons a year, this would amount to only 0.9 percent of 1970 world copper production and an even smaller percentage of presumed 1980 production because the demand for copper has been growing. Copper looks like one of the next commodities whose producing countries might succeed in putting together an effective cartel (CIPEC), perhpas raising prices dramtically. If CIPEC is a effective as OPEC, the price could rise to around $2.00/lb. In this event, the copper revenues from a million-ton operation would come to $39,200,000. Such an increase in the price of copper would permit more companies to mine nodules, as long as the increased supply of nickel did not lower the price below $0.63/lb. At this price the companies would have the same revenue picture as before the change in either the price of copper or the price of nickel.

NODULE MINING, ECONOMIC RENT, AND THE INTERNATIONAL COMMUNITY

The analysis above indicates that there is a substantial proportion of economic rent in the profits to be made mining manganese nodules. Moreover, the economic rent occurs because of both the scarcity of suitable mine sites and the barriers to entry into the industry. It is not possible, however, to sort out how much of the rent is due to each factor.

To the extent that there is a shortage of the best mine sites, efficiency would be served by requiring those who want to mine

22. *See* note 14, *supra.*

them to bid for them in competition with others who also wish to mine. If the international community as owner were to put up fewer sites each year than there are potential miners, most of the economic rent due to the shortage of sites would go to it, not the companies. This also could have the effect of allocating the best sites to the most efficient companies, assuming no collusion among the bidders.