NATURAL RESOURCES JOURNAL

Volume 8
Issue 3 *Resources of the Sea*

Summer 1968

Deep Sea Manganese Nodules: From Scientific Phenomenon to World Resource

David B. Brooks

DEEP SEA MANGANESE NODULES: FROM SCIENTIFIC PHENOMENON TO WORLD RESOURCE

DAVID B. BROOKS*

Ten years ago the presence of manganese-bearing nodules on the floor of the deep ocean basins was known to but a few oceanographers. Today, their presence is known not only to geologists, but to mining men, to international lawyers, and—through numerous articles in popular news media—to many in the general public. This burst of attention comes with good reason, for what was once a scientific curiosity is being heralded as a potential source of manganese, nickel, copper, and other metals for the world's industries.

But the fact that a metal exists, even in very sizable quantities, is by no means sufficient to make it a resource in the sense it can be used commercially. Ocean water is a reservoir of all the metals occurring on earth, and one that is freely available to any coastal nation, yet except for magnesium, no primary metal is commercially recovered from sea water. Despite years of experimentation and hope, the oceans remain almost as intractable as they were to the alchemist. The distance from scientific phenomenon to world resource is indeed large.

Clearly, then, the first thing to ask about deep sea manganese nodules is whether there are any grounds for thinking that they might in the foreseeable future make the transition from phenomenon to resource. Anticipating a qualified but affirmative answer to this question, two other general questions follow: (1) what are the characteristics of deep sea mining likely to be, and (2) what sorts of institutional arrangements will such an operation need in order to operate equitably, efficiently, and without conflict? The latter two questions are interrelated, but they are distinguishable. Whereas one involves a sort of best guess about the kind of mining operation that is likely to emerge regardless of the international regime, the other involves the choice among those regimes and the influence that each may bear on the efficiency of production and the distribution of returns.

Of course, as stated, the three questions have technologic, economic, and political dimensions. My own limitations, even more than

* Chief, Division of Mineral Economics, Bureau of Mines, U.S. Department of the Interior, Washington, D.C. This paper was prepared while the author was on the faculty of Berea College, Berea, Kentucky.

those of time, preclude a discussion of all of them. In order to emphasize the economic dimension, let me delimit the questions as follows: Are deep sea manganese nodules likely to become a commercial resource? What economic characteristics are deep sea mining ventures likely to exhibit? What institutional arrangements are most likely to promote the economic efficiency of deep sea mining? These three questions correspond to the three main sections of this paper and are taken up in order.

Before proceeding to the questions, an additional prefatory comment is called for. Consideration of the second and third questions would be vital today even if there were only a low probability that the deep sea manganese would ever be exploited. I cannot agree with those who say that international law will not and should not be developed until a conflict situation has arisen, that is, until mining has actually begun. It is inconceivable to me that we cannot design institutions that will serve to guide development rather than to follow it. By waiting we may just be abstaining from choice in favor of letting the circumstances of the first few mining ventures determine the results. More seriously, we may be promoting conflict in a world already too burdened with it.

I

DEEP SEA MANGANESE NODULES AS A WORLD RESOURCE

A. What is a "Resource"?

There is no entirely satisfactory definition of the word *resource*. It does not, on the one hand, imply that a material must be producible at a profit today using present technology, nor does it, on the other hand, encompass all possible sources regardless of how lean or how deep in the earth. As generally understood, the term *resources* falls between these two extremes; it refers to a material that may someday be exploited given moderate changes in economic condition and/or reasonably expectable technologic advances.[1]

For our purposes it is convenient to propose a somewhat sharper definition. Let us say that a resource is a material that may or may not be exploitable with today's technology and at today's prices, but

1. Known sources of some metal that are producible at a profit today are called its *reserves* whereas all potentially recoverable sources of that metal constitute its *resource base*. This terminology, along with the broad use of the term *resources*, follows that proposed by Bruce C. Netschert and Hans H. Landsberg in The Future Supply of the Major Metals 3 (1961).

that is sufficiently close to exploitability that it exerts some influence on price. This added criterion is an attempt to be more specific about the time dimension of the future economic conditions or technologic advances that can make the material exploitable. The effect on price may be direct, as when prices of current sources are forced downward, or it may be indirect, as when business firms begin to consider the new resource in their decision making. Thus, atomic energy had a direct effect on fossil fuel prices long before it became commercial, and oil shale is currently having an indirect effect on the same market.[2] On the other hand, sea water (except for magnesium) and granite are not yet resources; exploitability is too remote.

It is my contention that deep sea manganese nodules are a resource in this sense of having a direct, or more likely an indirect, influence on price, and, conversely, that other alternative manganese-bearing materials are not resources. What is the evidence for such a position? In order to answer, we must investigate two things: the demand for manganese, including both present uses and possible substitutes, and the supply of managanese, including both current sources and potential alternative sources (of which deep sea nodules are only one). Each limb of manganese economics has numerous ramifications, but they must be treated in very summary fashion here.[3]

B. Manganese Demand

Consider demand first. The main use of manganese, accounting for some ninety-five per cent of its consumption, is as an additive metal in steelmaking. It serves primarily to reduce a kind of brittleless called hot shortness that is caused by excess sulfur. Common carbon steel contains about one half of one per cent manganese. Substitutes can be found for each of the functions manganese serves in

2. The active market and rising prices for privately held parcels of oil shale land in Colorado provide evidence of this indirect effect. As a matter of fact, despite their completely different geology and geography, the economic similarities between deep sea manganese and oil shale are marked. Both have been known for some time but neither has been successfully exploited; deposits of each can be delineated relatively easily so that greater uncertainty attaches to recovery methods than to the resources; and neither is likely to attract any but the largest firms. These common economic characteristics, which will be discussed below for the nodules, suggest that there may be similarities in the public policies applicable to oil shale and to deep sea manganese.

3. For a more complete discussion of these aspects of manganese economics, see D. Brooks, Low-Grade and Nonconventional Sources of Managanese (1966). This book represents a pilot study designed to see whether it was possible to clarify the concept of resources for the case of a single mineral commodity.

steel, but no other material does so much yet costs so little. Whereas manganese seldom costs more than four cents per pound, possible substitutes, such as the rare-earth metals and vanadium, cost upwards of one dollar per pound. Though it is possible that economies in use will cause the consumption of manganese *per ton of steel* to decline in the future, all projections indicate a continuing rise in the *total* demand for manganese because of growth in steel production around the world. Demand, then, looks favorable to the prospects of deep sea mining or of other alternative manganese resources.

C. *Manganese Supply: Current Sources*

Turning to the supply side, however, we find a different picture. Current sources of supply, *i.e.,* existing mines, appear quite adequate. Modern manganese mines contain vast quantities of high-grade, low-cost reserves; They can continue to produce at high rates for many years to come. In fact, the newer mines are really little more than earth-moving operations in which enormous beds of near-surface manganese ore are recovered by bulldozers and, after some concentration, are moved directly to a port. True, some of these mines have cost as much as 100 million dollars to bring into production, but they contain so much ore that it is doubtful whether the investment per ton of reserve is any higher than it was in the past. In sum, while the demand for manganese is strong, there is no present need to turn away from current sources of supply unless and until one of the alternative sources turns out to be as cheap as, or cheaper than, conventional mines.

D. *Manganese Supply: Alternative Source*

With these projections in mind, we are in a position to consider alternative sources. Generally speaking, there are two types of alternative sources for any mineral commodity. First, there are low-grade sources that are similar to deposits being mined today but in which the metal is less concentrated. Second, there are nonconventional sources from which metal has not in the past been commercially recovered. Low-grade sources of manganese in this country include deposits in Maine, South Dakota, Arizona, and Minnesota. There are also at least two nonconventional sources: manganese-bearing slags produced as a waste product during steelmaking, and the deep sea nodules.

At the risk of some oversimplification, the prospects for secondary recovery from slags and for mining low-grade deposits will be dismissed with just a few sentences. The possibility of secondary recovery arises because the open-hearth process of steelmaking is so inefficient in its use of manganese that slags may contain more than ten per cent manganese. Unfortunately, despite the fact that this source is found right at steel plants, the silicate metallurgy of a slag requires special refining procedures that significantly raise the costs of recovery. Moreover, the basic oxygen converter, to which steel makers are rapidly switching, is far more efficient in its use of manganese, and B-O-F slags rarely contain more than five per cent manganese. Much the same conclusion applies to the low-grade deposits. While a small manganese mining industry has existed in this country from time to time, largely as a creature of artificially high prices during war time or stockpiling programs, none of the low-grade deposits has ever produced on a commercial basis. In fact, cost of production data, based on many years of experimentation, are similar for the two sources. Using the cheapest of the tested processes, and allowing for further technologic progress, it would cost the United States about one dollar extra per ton of steel (an increase of more than one per cent) to turn either to domestic deposits or to slags for our manganese.[4] Thus, the cost of using strictly domestic sources of manganese would turn out to be a significant cost to the economy. Though a considerable sum was spent by the government to investigate slags and low-grade deposits, it was not because of any feared resource shortage, but from the security problem posed by our dependence on foreign manganese mines. For a number of reasons, the security problem carries less weight today. Thus an alternative source must prove itself commercially or not at all. In short, neither the low-grade deposits nor the slags appear to be resources in the sense defined above: their effect on manganese prices or on decision-making by manganese firms is nil.

What about deep sea nodules, then? Are they an alternative whose costs of production are close enough to high-grade onshore reserves that they can be considered as a manganese resource? In contrast to the situation just described, there are grounds for being less skeptical.

For one thing, the nodules are attracting considerable attention from industry, which was never true of the slags or low-grade deposits. Quite a number of American firms have already invested

4. *Id.* at 63-92, 111-13.

funds in research on the geology of the nodules and a few on possible mining techniques; others are studying processing techniques. Within the past year the existence of a "smooth, black pavement" of nodules on the Blake Terrace off the southeastern United States has been reported. *Aluminaut*, a deep-diving submarine, rode on its wheels along the deposits and recovered samples that were said to be better than the minimum commercial grade for manganese ore.[5] Other relatively high-grade nodules were recently discovered on the continental shelf only fifty miles northwest of Vancouver, British Columbia.[6] Another area of research suggests that separation of the various metallic constituents of the nodules may not be as difficult as was once supposed. Studies by Furstenau, for example, give grounds for hope that relatively simple processes may make a multiproduct operation feasible.[7]

Of course, few of the firms supporting research on the nodules are really potential deep sea miners, but this is not the point. Deep sea manganese *is* beginning to figure into their decision making. Moreover, firms in other countries, notably Japan, Australia, the United Kingdom, and the Soviet Union, are conducting similar studies.

I would also maintain that the very fact that conflicting opinions are expressed about the value of deep sea nodules indicates that they must be taken seriously. If someone suggested mining the moon, it is doubtful that anyone would respond with figures on the adequacy of conventional reserves. Such responses, which abound for deep sea nodules, are generated only for reasonably possible alternative sources. Almost from the original publication of engineering cost estimates by John Mero in 1959, the feasibility of deep sea mining has been a matter of controversy.[8] While the quality and quantity of metalliferrous material in deep sea nodules is enough to make any landlubber-miner green with envy, simple comparisons neglect the

5. 167 Engineering and Mining Journal 156 (1966).

6. 19 *Mining Engineering* 20 (1967).

7. D. Furstenau, A. Herring, and M. Hoover, *Leaching Manganese Nodules from the Ocean Floor*; paper presented to 1967 Annual Meeting of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME), Los Angeles, Calif. *See also*: 166 Engineering and Mining Journal 112 (April 1965).

8. John L. Mero's work and projections are most fully presented in his book, The Mineral Resources of the Sea (1965). For a more recent "progress report" by Mero, see: *The Future of Mining the Sea*, Oceanology International, pp. 73-78 (October 1966). Two of the best statements that question the prospects for deep sea manganese are as follows: C. Ensign, Jr., *Economic Barriers Delay Underseas Mining*, Mining Engineering 59 (Sept. 1966), and T. Walthier, paper presented at the 1967 Annual Meeting of the AIME, Los Angeles, Calif.

many problems that must be overcome before production is technologically, to say nothing of economically, feasible. Depth of overlying water of course tops the list. Despite their high grade in many places—they run up to fifty per cent manganese, plus several per cent copper, cobalt, and nickel—the richest nodules tend to occur in the deepest water. There is no proven technique for recovering large quantities of material from such depths. We have had only limited experience with hydraulic dredging, the most commonly suggested technique, and still less with the thousands of feet of hose and problems of postioning that full-scale mining would entail. Nor, even given the studies noted above, is the technology available to cope with the fine grain size and intimate mixture of metals within a nodule.

Despite all of these qualifications, investigation of as much cost information as I could obtain led me to conclude that deep sea manganese nodules are the only potential resource that might be exploited in the near-to-middle-term future, and that to a considerable extent they already influence business decisions.[9] This does not mean that recovery of manganese from the oceans is today competitive with recovery from high-grade ore deposits of the conventional type. Until deep sea mining is actually attempted, the question of competitive standing must remain unresolved. However, it does mean that research on the possible exploitation of deep sea nodules has gone far enough to make them the lowest cost alternative manganese resource of any size, and hence far enough to put a firm ceiling on the long-run price of manganese—and perhaps of cobalt and nickel as well. The price cannot rise higher than the cost of production of the nodules. Indeed, future prices could well be lower than today's prices if deep sea mining becomes a reality.

II
ECONOMIC CHARACTERISTICS OF DEEP SEA MINING

The second of our three questions asks about the economic characteristics of an ongoing deep sea mining industry. While we cannot pretend to clairvoyance, enough is known about the problems and the opportunities to derive some tentative but important conclusions. Let us consider first those aspects related to a single operation, and then those that will become important when competition develops for deep sea sources of supply.

9. D. Brooks, *supra* note 3, at 93-108, 120-22.

A. The Deep Sea Mining Firm

So far as each individual mining venture is concerned, the foremost consideration is the high initial investment. Figures ranging from 30 to 300 million dollars have been suggested as the amount necessary to bring a deep sea mining operation, plus associated onshore processing facilities, into production. The appropriate figure is probably in the neighborhood of 100 million dollars.[10] Certainly this is high, but neglecting any risk premium, the large volume of material that would be available to a single ship means that the investment per ton of reserves is no greater than that for an onshore mine. Moreover, it does not appear that investment cost is very sensitive to scale; a 2,000 ton per day operation is not much cheaper than one designed for 5,000 to 10,000 tons per day. In fact, indications are that investment per daily ton is still declining at 10,000 tons per day.[11]

In partial compensation for the high initial investment, a deep sea mining operation should entail relatively low operating costs. Indeed, given the initial investment and the risk, a mining system will have to promise low operating costs if it is even to be considered. Again, published estimates are highly controversial, but two factors stand out. First, unit operating costs at all stages of production go down with increases in output. For example, the cost per ton of moving solids through a hose, as from the ocean bottom to a ship, decreases sharply over considerable ranges of throughput. Second, unit operating costs for the more likely recovery systems increase only slowly with depth. Mero has estimated that direct mining costs for a hydraulic dredge will range from about two dollars and twenty-five cents per ton in 1,000 feet of water to four dollars and twenty-five cents per ton in 15,000 feet.[12]

The twin factors of high investment cost and low operating cost suggest strongly that each deep sea mining venture will have to be relatively large in scale. Only at high rates of production can such investments be amortized in an acceptable length of time. Typical rates will almost surely not be less than 2,000 tons of nodules per day, and they could be 10,000 tons per day. Some 20 to 50 per cent

10. *Id.* at 99 and references cited there.

11. Based on data given by J. Mero, *supra* note 8, at 268-70.

12. *Id.* at 290. The assumed production rate is about 4,000 tons per day. *See also*: H. Hess, *The Ocean: Mining's Newest Frontier*, 166 Engineering and Mining Journal 95 (August 1965).

of this tonnage will be recoverable metal, which places each deep sea mining operation at the scale of the largest onshore mines.

Under these conditions it is impossible to ignore the effect of scale on the prices of the outputs. Estimates based on current consumption rates in the United States indicate that a ship with an output of even 500 tons per day would cause the price of cobalt to fall and that at rates of 2,000 to 5,000 tons per day the prices of nickel and manganese would also have to fall in order to clear the market.[13] Without going into detail, the implication is that gross revenue will be considerably less than if current prices could be assumed to remain constant after deep sea mining begins. Of course, the price effect of any one deep sea mining venture would diminish over time as consumption rates increased; on the other hand, pressure on prices would increase if this one venture proved successful and competitors entered the field.

To some extent the potential price effect may moderate the tendency to build large-scale mining systems. However, it is less likely to moderate a tendency to use fully whatever capacity is available. Near-capacity rates of production are typical of systems characterized by high investment and low operating costs, particularly if unit operating costs continue to decline over most of the range up to full capacity. The object is to recover more of the investment in any time period by taking advantage of the low cost of additional units of output. Such action can be carried so far that markets are totally disrupted and the resource is quite incompletely recovered. Of course, profits are apt to be minimal under these conditions, but as Christy has pointed out, even if prices are depressed because of overproduction, the anticipation of future returns might well be sufficient to induce nations to establish claims and operate them even though present returns were unsatisfactory.[14] While it is not difficult to develop institutions to prevent a race to acquire claims on the ocean bottom, this does little to control overcapitalization of

13. D. Brooks, *supra* note 2, at 103-07. Specifically, the estimate was that a single ship recovering 2,000 to 5,000 tons per day of nodules containing 35% manganese, 0.5% cobalt, and 2% each of nickel and copper (a relatively rich nodule but one that might be representative of the first type mined) would force manganese prices down to about 2½¢ per pound, cobalt to $1.00 per pound, and nickel to 65¢ per pound. These estimates were based on the price-consumption relationships as they existed about 1964. They resulted in a one-third reduction in annual gross revenue.

14. F. Christy, *Alternative Regimes for the Minerals of the Sea Floor* (to be published), Proceedings of the American Bar Assn. National Institute on Marine Resources, June 8, 1967.

and overproduction from the claims that are acquired. This difficulty almost inheres in the nature of the resource.

B. Competition Among Deep Sea Mining Firms

Turning now to the broader economic conditions that will develop if deep sea mining proves successful, we can identify a number of important corollaries to the points just discussed, corollaries that relate both to considerations of economic efficiency and to those of income distribution. Largely because of the high investment cost and large scale, we can assume that the number of mining operations will be limited, at least initially. Certainly rapid expansion into deep sea mining itself, as distinct from simply asserting the right to mine, is improbable. Moreover, only firms in the most highly developed nations will have the combination of technical ability and financial capacity to mount a deep sea mining venture. Even there, joint ventures to increase capability and reduce risk are to be expected. Oligopoly, if not monopoly, will be the rule, and the resulting concentration of economic power must raise anew all of the old questions about the balance between gains in the efficiency of production and losses in the force of competition. It is unclear where the balance can or should be struck, though it is obvious that it will be far from that which currently obtains for the fishing industry.

Actually, in terms of the producing firms, all of this will entail just a continuation of past trends. Most of the metals recoverable from deep sea manganese nodules are recovered today by a relatively small number of concerns from the advanced countries: western world nickel production is dominated by a single firm, and cobalt and copper production by a dozen or so; manganese production has also tended to become concentrated over the past twenty years. The only new factor will be the entry of other than traditional mining firms into the production of primary metals.[15]

If the nationality and structure of producers is not likely to change radically with the advent of deep sea mining, the nationality of production may change sharply. With the exception of those in the Soviet Union, all of the major manganese deposits of the world occur in the developing nations. From India to Brazil to Morocco to Gabon, manganese ore provides up to 5 per cent of the

15. As Thomas A. Wilson, among others, has pointed out, the lead into deep sea mining is being taken by petroleum and chemical firms. *See*: *Undersea Mining: Where Do We Stand Today?*, 166 Engineering and Mining Journal 83 (1965).

export earnings of developing nations. This may or may not create a problem. Deep sea mining could develop so slowly that no country would lose its export markets. Even with rapid expansion into the oceans, the deposits in certain nations, Gabon for example, are so rich and so large that they probably would not suffer from the competition. On the other hand, the deposits in Ghana, Morocco, and India are more vulnerable; manganese export earnings for these countries could be cut to zero if sea floor manganese proves commercially attractive.

Obviously, the exact distribution of gains from deep sea mining among the nations of the world will depend upon the international regime finally adopted. Several groups with divergent interests can be readily identified. Unfortunately, we cannot go further into these matters without straying beyond my self-imposed limits, though it is clear that they will have much to do with the political feasibility of any proposed regime.

However, one other aspect of the economics of deep sea mining deserves consideration at this time: valuation of the resource. This becomes a problem only to the extent that the resource is limited. If a resource is essentially limitless in size, its in-place value drops to zero because there is no need to compete for it. This is the case for ocean water used as an industrial input in most locations. It is not likely to be the case for deep sea manganese nodules. The often repeated statement that nodules are forming on the ocean floor at a rate faster than that at which the world is consuming manganese is not really of much practical importance. We don't mine the ocean bottom; we mine some small portion of it. Sea floor manganese deposits vary greatly in grade, pounds of nodules per square meter, depth of overlying water, and bottom conditions.[16] They also vary in distance from markets and from supply ports, as well as in the number of days of good weather that can be expected at the surface. In this respect manganese nodules are not so different from fish. Despite the enormous mass of fish in the ocean, the demand is for certain species, and they are sought in areas where the cost of hunting them is relatively low. For manganese, certain nodules in certain localities will offer the best commercial opportunities, and competition will develop for these deposits.

16. J. Mero, *supra* note 8, at 127-241. Also: *Strategic Location is Key Factor in Marine Mineral Recovery* (an interview with Walter H. Hibbard) in Under Sea Technology at 47 (January 1967).

Therefore, as deep sea mining is shown to be first technologically and then economically feasible, the deposits themselves will come to have value, or, to be more specific, the rights to mine the deposits will come to have value. The valuation process will take note of all the factors suggested above involving quantity, quality, and location. In fact, if a market for deep sea mining rights were established with enough buyers and sellers, the value determined for each section of the ocean bottom would approximate the capitalized value of the net returns obtainable from exploiting the deposit. The higher the expected returns and the lower the expected costs of production, the higher would be the value of the deposit.

Of course, with a new resource the valuation process will be highly approximate. But the difficulties of estimation should not be overstated. In contrast with most mineral deposits, manganese nodules occur as a surficial layer (so far as the ocean bottom is concerned). They are visible to a TV camera, and it may prove simpler than we now imagine to make the necessary estimates. The uncertainties about mining and processing are likely to be greater than those about the resource itself.

The valuation process is of critical concern because it has to be operating correctly for production to be efficient. It is the very lack of a market for fishing rights that has led to the inefficient use of inputs by the fishing industry, and the inefficient delivery of outputs to the consumers. But how can a market be developed for manganese deposits on the ocean bottom, or alternatively, what mechanism can we find that will substitute for a market? These are matters to which we must now turn.

III
INSTITUTIONAL ARRANGEMENTS AND THE EFFICIENCY OF DEEP SEA MINING

Production of manganese from the ocean bottom will involve a series of operations beginning with exploration and ending with transportation to processing and consuming plants located onshore. Whatever regime is designed must accommodate all of these steps, and must do so in a way that will permit production to be efficient, distribution of returns to be equitable, and conflicts to be avoided. It goes without saying that the regime must also be politically acceptable to enough nations to insure wide acceptance. A number of authors have discussed possible regimes in just these terms.[17] The suggestions range from a sort of laissez-faire flag nation or rule-of-capture approach through nationalization of the ocean bottom (perhaps by extension of the continental shelf doctrine) to internationalization under the aegis of the United Nations or some other international agency.

While it is tempting to slide off into discussion of the enormous issues posed by the alternative regimes, these comments are restricted to institutional means for achieving economic efficiency. (By efficiency I mean the relationship between the value of all inputs and the value of useful outputs, and the attempt to increase the latter relative to the former.[18]) In any event, I have already expressed my personal preference for an international approach, though largely on grounds other than those of economic efficiency.[19]

Any regime for deep sea mining must incorporate two fundamental principles. Northcutt Ely has stated the first as follows: "The petroleum and mining industries, whether operating on dry land or beneath the sea, require . . . above all . . . the discoverer's exclusive right to exploit the minerals discovered and security of tenure while he does so."[20] Second, the mineral industries require assurance that no special advantage or disadvantage will be granted to those mining in any particular environment.

The principle of exclusive rights is so fundamental to efficient mining that the industry often neglects to elaborate upon it. Apart from exclusive rights there is no way to insure that the returns from exploration accrue to the discoverer, hence no way to attract capital

17. Numerous discussions have been held during the past few years on alternative regimes for the high and for the bed of the sea beyond the continental shelf. Notable were those at the First Annual Law of the Sea Institute in 1966 and at the American Bar Assn. National Institute on Marine Resources in 1967. The proceedings of the former will be published shortly by The Ohio State Univ. Press as The Law of the Sea. Proceedings of the latter are scheduled for publication later this year. See also F. Christy and A. Scott, The Common Wealth in Ocean Fisheries (1966); and W. Burke, Ocean Sciences, Technology, and the Future International Law of the Sea (1966).

18. F. Knight, The Economic Organization 8 (1933). Knight's formulation of efficiency was the ratio of useful output to total input.

19. F. Christy and D. Brooks, *Shared Resources of the World Community*, New Dimensions for the United Nations 153-65 (1966). Christy has put forward arguments to the effect that internationalization would also tend to be more efficient than alternative regimes, *supra* note 14.

20. N. Ely, *The Laws Governing Exploitation of the Minerals Beneath the Sea*, Exploiting the Ocean 337, Transactions of the 2nd Annual Marine Technology Society Conference, Washington, D.C. 1966.

to the exploration effort nor any way to prevent the common property dilemma that bedevils fishing. If exclusive rights were not available one company could wait until another had done the needed exploration and then, having avoided these costs, move in on the deposit and operate in the same locale. Ignoring the obvious problem of conflict, it is easy to visualize problems of congestion with equipment forced to operate at less than optimum levels of productivity or safety. Moreover, the tendency to mine as fast as possible or to "high grade" would be aggravated by the need to reap the benefits of mining before another firm obtained them. But for materials like manganese deposits that are fixed in position and cannot move across arbitrary property lines, these problems cannot arise once exclusive use rights are made available. (It is because they are not fixed in position that common property rather than exclusive rights apply to fisheries, and that additional forces, such an unitization, must be applied to make exclusive rights applicable to fluid minerals like petroleum and gas.)

The principle that deep sea deposits be treated equally with other sources of supply is also worthy of elaboration. The point is to avoid either subsidizing or burdening deep sea mining. Every economic system strives to conduct its affairs in such a way that its demands are met at minimum cost. Indeed, one of the advantages of having a variety of alternative resources is that society can choose that source that requires the least value of inputs per unit of output. An accurate choice is possible only if costs reflect the actual social value of inputs, and this will not be the case if one resource is subsidized by receiving underpriced inputs while another is burdened with overpriced inputs. Note that this principle implies nothing about the level of taxes or subsidies; it only says that whatever taxes or subsidies exist should be applied equally to all sources. Of course, no system attains this goal, but it is one toward which a regime should strive.

Beyond the basic requirements of exclusive rights and equal treatment, there are other institutional forces that will affect the efficiency of a deep sea mining industry with the economic characteristics discussed in the preceding section. We can divide them into three groups: the direct conditions associated with exclusive exploration and exploitation rights; the method for dealing with the indirect or external effects of exploration or exploitation; and the method of charging for exclusive rights. Each of these forces will be treated as if rights to mine deep sea manganese were obtainable under some lease arangements. This is not only a matter of convenience but also because it is reasonable to think that wherever ultimate control is vested, the actual mining concern will end up securing leases from that body. Most mining and petroleum firms are familiar with leasing arrangements on the public domain in the United States and in foreign countries. They presumably expect something similar in deep ocean basins.

In addition, some sort of international agreement is assumed. There must be some set of international rules of the game that exploiters and non-exploiters alike can look to with assurance. Without rules accepted by most nations, the inevitable result would be uncertainty, whereas economic efficiency demands as much certainty as possible.

A. Direct Conditions of Leasing[21]

Assuming some form of lease system is to be set up and that it will have the respect of most of the world community, how can the leases be designed so as to promote efficiency? First, the system could be designed with just exploitation leases or with both exploration and exploitation leases. Under the former system each interested firm would undertake exploration efforts freely and then act on the basis of this proprietary information in trying to win exclusive exploitation leases. This is the arrangement currently in effect for offshore oil in the United States. Alternatively, the leasing body could offer exclusive exploration leases, presumably with the usual provision that specified fractions of the tract be returned to public ownership at set intervals, but also with the privilege of converting some fraction to an exploitation lease. This is the arrangement used by many underdeveloped nations. The choice between the

21. A number of the points in this section lean on the presentation by L. Goldie, *Geneva Convention on the Law of the Sea: The Need for Future Modifications*, The Law of the Sea (to be published). My only significant point of disagreement with Professor Goldie concerns the possibility of a mining firm operating outside of the accepted regime, which he would permit at the option—and at the risk—of the firm. But the goal of reducing uncertainty suggests that whatever international regime obtains for one firm should obtain for all. The problem might be minimal if a few small concerns elect to operate outside of the international regime. It would seem more likely that the most powerful firms would exercise this option, in which case the regime could find itself nearly powerless.

two will probably depend upon how well the resource comes to be known before exploitation is imminent.[22]

Second, any lease should be limited in area. The sea floor is a definable surface so that establishing boundary lines between leases will give rise to no serious technical difficulties. The size of any one lease should probably not be fixed but depend upon estimates of the quantity and quality of the resource available. The minimum size of the lease would be determined by the room needed for technologically efficient recovery of minerals from the bottom under ideal circumstances. Less than ideal circumstances would justify a larger area. Exploration leases, if used, should cover much more area than exploitation leases.

Third, the lease should be valid only so long as the company needs it to explore for or exploit the resource in question. On the other hand, assuming that the lessee does not violate any of its provisions, a lease should be renewable so long as work continues.

Fourth, a performance requirement should be included. This establishes some period of time within which exploitation must commence (or within which a specified expenditure must be made for exploration). Otherwise the lease is cancelled. The object of a performance requirement is to prevent firms from acquiring and indefinitely holding leases for speculative purposes. They are common to almost all lease or claim systems, and they are effective to the extent that the time or money required to satisfy them is a real barrier to "sitting on" a claim. The performance requirement takes on an added importance with a new resource such as deep sea manganese nodules. The absence of an effective performance requirement would practically invite a race to claim areas of potential value on the sea floor. Such a race would be inefficient in the extreme. It would require that capital and manpower be devoted to establishing claims on these resources before they are really needed by the world community. Total inputs would be greatly in excess of those needed for orderly development. Performance requirements do have the disadvantage that they contribute to the tendency toward excessive rates of production, but this is a problem that must be dealt with by separate techniques.

22. Under a third possible arrangement, the leasing body itself would conduct the exploration effort and then make the information available to any interested party. This arrangement would provide a significant economy in exploration expenditures, and might promote competition by reducing both risk and initial investment. However, it is unlikely to appeal to mining or petroleum firms and would place enormous burdens on the leasing agency.

Finally, some procedure—it matters little which—must be established for dealing with boundary line disputes. Again, efficiency is easily obtained for stationary resources like manganese nodules. If some adjustments are necessary, equitable divisions can be worked out much as the more complex boundary line disputes in petroleum have been settled.

B. Indirect Effects of Use

The second of the institutional forces that will influence the economic efficiency of deep sea mining involves the methods for dealing with the indirect or external effects resulting from exploration or exploitation. Efficiency is not so obvious a goal as it sometimes seems. For example, the goal of minimizing total cost for each level of output should refer not just to the cost of the mining firm itself but also to any costs that the mining activity may impose on other economic units. Similarly, any benefits conferred by mining (as, possibly, fish nutrients brought to the surface) should be counted as part of its output. Such external costs and benefits arise because of technologic interdependencies among inputs and outputs, so that one economic unit can force another to operate at higher or lower levels of efficiency than it would if operating alone. There are two common sorts of interdependencies that we may distinguish, though they both reflect the same economic forces. The first involves multiple demands for the same resource and the second, pollution.

Multiple demands arise when several valuable resources occur within the same vertical segment from ocean floor to ocean surface. For example, manganese deposits and preferred routings for submarine cables could lie in the same area, and a busy shipping lane could lie directly above both. On efficiency grounds we should allow for that use or combination of uses which will generate the highest net returns (or, in economic terms, that will maximize rent). A useful way to conceptualize the problem of selecting among multiple possible uses so as to maximize net economic returns is to ask what one operating unit would do if it owned all the resources in question. If multiple use would be inefficient or dangerous, the regime should be prepared to reallocate use rights on this basis or to permit use rights to be "bid" from one application to another. It may, for example, be preferable to prohibit mining in certain areas if surface traffic is very heavy and cannot use an alternative route without major cost increases; in other areas manganese deposits may be so valuable that it will be worth moving submarine cables to get at them. In many, perhaps most, cases it will be possible to work out some form of accommodation so that both activities can co-exist. Of course, there is nothing to force a regime to allocate by returns; "first-come, first-served" is another rule that could be followed. All that can be said is that any system other than one based on net returns will reduce economic efficiency below what it could be.

The other common external effect is pollution. This is also a matter of multiple use, the added demand for use of the sea for waste disposal. However, in contrast to the cases just presented where the benefits of resource use are shared, pollution is the process by which costs are shifted from one resource user to another. The technologic interdependencies associated with pollution are obvious. Waste disposal by one economic unit transmits physical substances to other units. Pollution may, for example, destroy a fishery or a beach, in which case the returns to the miner are higher than they should be and those to the fisherman or the beach user lower than they should be.

Certainly, exploration and exploitation leases should include clauses to deal with pollution. Since the shifting of costs resulting from transmission of pollutants takes place outside the market system, the solution is to re-distribute costs so that the effects of waste disposal come to bear on the mining firm's account books. One method for accomplishing this involves establishment of a charge or tax related to the damages imposed on other economic units by the pollutants. In effect, this "internalizes" the cost in the same way that benefits were treated by assuming they all accrued to the same firm. Mining firms might react to a pollution charge by reducing waste disposal volume, by changing it to a less noxious form, or by paying compensation to those injured. Whatever its decision, the point is that in a strictly private framework the control of pollution is not economically attractive, but that it becomes so when all costs in the system are taken into account.

Cutting across both aspects of indirect effects is the problem of values, for market prices are not always adequate reflections of social values. We can only note the problem here, for the question of how to measure values in the ocean is worthy of separate discussion. Clearly, many approximations will be necessary, but difficulties may be mitigated by the absence of large intangible values on the high seas. Losses in recreational benefits and natural beauty, and changes in ecology do not seem likely to be widespread. However, this is just a guess. It could be that deep ocean mining will so stir up bottom conditions that it will produce quite unexpected tangible and intangible effects. Recent experience with oil spills should, if nothing else, teach us to be agnostic on such matters.

C. *Charges for Exclusive Rights*

The final area we must take up is the matter of charges for exploration and exploitation rights. As before, emphasis will remain with the impact of such charges on the efficiency of production rather than with the matter of who receives the payment. Actually, it may not make much difference to the potential miner whether he makes payments to his own country, to some other country, or to an international agency. He is almost sure to pay something, even if it is no more than a nominal fee for protection.

However, the principle of equal treatment of all resources suggests that the leasing authority, whatever it is, charge more than a nominal sum for exclusive rights. If it does not attempt to extract fair market value (which admittedly may be very low or even nil at first), an unfair advantage would accrue to ocean mining firms compared with firms that must pay for rights to mine similar onshore resources. As a result, capital and labor inputs would tend to be inefficiently allocated between onshore and offshore areas, as well as *among* various offshore areas. If exclusive rights to deep sea resources are too highly priced, exploration and exploitation will be deterred and other deposits will be used though they are higher cost sources. If exclusive rights are priced too low, there will be a tendency for excess inputs of capital and labor to move into deep sea mining in order to reap the returns, thus aggravating the problem of high rates of production that may result just from the economic characteristics of the mining operation.

How can the value of exclusive rights to this resource be determined, and how can a mechanism to charge for these rights be set up? These two questions are inseparable. If we can find an appropriate mechanism for capture revenues, we will at the same time have found a way for determining their value. There is no one best solution, but some suggestions seem in order.

First, it would be useful to distinguish between charges to cover the cost of administering a deep sea regime and charges related to the market value of exclusive rights. The former is a cost of operation that ought to be borne by those who benefit from it. That is, there will be certain public costs associated with recording leases, protecting them, and dealing with boundary disputes. These costs could be expressed in terms of an annual rental per square mile of ocean bottom, such rental to be fixed for all parties so as to just cover the public costs. Alternatively, public costs could be covered by a license fee, a system that would be more appropriate if the largest share of the costs occur upon establishment of the lease rather than being distributed over its working life.

Second, the possibility of external effects suggests that a bonding system be developed. Such a system would require that firms desiring exploration or exploitation leases establish a fund large enough to pay for external damages. In the event that prescribed pollution-control procedures were violated or that unexpected damages occurred, the fund could be used to reduce the pollution or compensate those who had suffered from it. If no damage occurred, the bond would be returned to the firm upon termination of the lease. Bonding arrangements are commonly a part of mining regulation, particularly with surface mining for coal in the eastern part of the United States. The needed pollution-control measures, the appropriate size of the bond, and the conditions under which it would be forfeited could only be determined from experience.

Third, and most difficult, a system is needed to establish and collect the market value for exclusive rights.[23] A number of techniques are possible including various kinds of bidding, appraisal prices, royalties based on flat or sliding scales, tax systems, etc. Each technique requires that somebody have authority to dispose of exclusive rights and that it either offer specified portions of the bottom or permit firms to suggest the areas to be put up for auction. Each also requires that the criterion for awarding leases be unambiguous so that no question can arise as to which firm made the best offer. My suggestion is for a sealed bid auction in which bids are made in the form of a gross production tax or royalty.

Sealed bidding is strongly recommended because under the competitive conditions to be expected with deep sea mining, it is more likely than open (oral) bidding to yield true market values. The number of bidders is apt to be small, but based on his studies of sealed bids by oil and gas firms operating on the continental shelf of

23. Many of the suggestions in the following paragraphs are based on a fine article by W. Mead, *Natural Resource Disposal Policy—Oral Auction vs. Sealed Bids*, 7 Natural Resources Journal 194-224 (1967).

the United States, Walter Mead reports that "even where . . . a lack of bidder interest, rather than collusion, results in one-bidder sales under sealed bid procedures, such sales may yield a price close to a competitive price, . . ."[24]

Mead also suggested that the structure of the industry should be considered when selecting a bidding practice. Sealed bids are generally more appropriate for conditions where large capital investments are necessary and consequently where bidding is apt to be oligopsonistic. This conclusion is reinforced for industries that have alternative sources of raw material, that operate on the basis of long-lived leases, and that expend relatively large sums in exploration efforts.[25] These characteristics practically describe deep sea mining. Thus, there is every reason to think that the sealed bid auction is appropriate.

Mead also suggests that a refusal price that "realistically reflects competitive prices becomes more important as the structure of the buyer industry becomes more concentrated (oligopsonistic)."[26] However, as he also points out, for some resources it is very difficult to establish realistic refusal prices. This is certainly going to be the case for deep sea mining, at least for some time to come. If at some point it becomes possible to rapidly survey deep sea manganese deposits and estimate production costs, minimum acceptable prices may become appropriate. For the time being, the minimum acceptable price should simply be the rental charge noted above to cover direct public costs.

The uncertainty surrounding the value of the resource also leads to the suggestion that a yield tax or royalty system rather than a bonus payment system be utilized. A bonus must be paid upon securing the lease and regardless of whether the venture turns out to be profitable or even possible. With a new resource of uncertain value, there is reason to avoid introducing added initial costs. It is preferable to wait until production has actually begun and at that point tax output. The absence of a bonus may also induce a larger number of bids because the investment, hence the risk, is not increased by an initial payment.

Yield taxes can be designed either as a profit sharing (net income) tax or as a royalty (gross production) tax. Economic theory lends support to the former because it does not affect the costs or the

24. *Id.* at 213.
25. *Id.* at 219-23.
26. *Id.* at 223.

rate of production. If there are no profits, no tax need be paid. However, there are also some disadvantages. Net income is often difficult to determine, particularly for a single operation of a complex organization, and the problems of international policing appear unmanageable. In contrast, unless production can be hidden, which is not likely to be the case for ocean mining, gross production is so apparent and the tax so easy to estimate that there could be little question of whether the correct amount was being paid. The royalty bid would vary from firm to firm because of different situations and expectations. At least initially, when lack of competition would keep the bid low, the effect on cost of production should prove minimal. Whatever economic losses occur might well be counterbalanced by the gain in convenience and economy for both operating firms and collecting agency.

CONCLUSION

The initial section of this paper developed the idea that manganese is a resource in the sense that it is beginning to have an impact on both public and private decisions about future sources of supply. While it may not be economic to mine the nodules at present, analysis of alternative manganese resources indicates that they are close enough to the margin to place a ceiling on the long-run prices of manganese, nickel, and cobalt. In the second section, it was concluded that deep sea mining will be a highly intensive capital venture, that large capacity and high rates of production will be the rule, and that only a relatively few firms and nations will be able to participate directly in it. It was also concluded that competition for the best deposits of manganese nodules is almost certain to develop once deep sea mining proves feasible so that the rights to mine these deposits will acquire value.

The final section of the paper began with the premise that any institutional regime would have to take account of these economic characteristics. Hence, it focused on the ways in which institutional forces could be designed so as to promote economic efficiency in deep sea mining. The usefulness of a market to establish the value of exclusive mining rights was emphasized as a technique that could go far towards this goal. Among other things, it was suggested that such a market might best be organized around a lease system with closed bids offered in terms of royalty payment.

However, except perhaps for some form of exclusive rights during mining, none of the forces discussed in the third section is absolute in the sense that it must be present for mining to take place. On the one hand, leases could be given away at no charge; pollution could be ignored; performance requirements need not be enforced. A nation might decide, for example, that national security requires better knowledge of the oceans and that subsidizing deep sea mining is one way to obtain it. The point is not that such a decision would be invalid, but that economic efficiency would thereby be reduced below what it otherwise could be. On the other hand, my suggestions have been made on the basis of certain assumptions and projections. If these turn out to be wrong, the suggestions may be inappropriate. Even if they turn out to be correct, alternative institutional forces might be designed that would be preferable in terms of economic efficiency. Additional suggestions are all to the good; each of these matters requires further attention. The purpose of this paper is not to establish definitive criteria, but rather to extend discussion.