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Marine Nonfuel Minerals in the US Exclusive Economic Zone: Managing Information as a Resource

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ABSTRACT

Substantial quantities of marine nonfuel minerals are known to exist in the US exclusive economic zone (EEZ), but most of these are not yet close to production or even to being properly classified as economic resources. Nonfuel mineral prospecting, discovery and exploration activity in the EEZ is part of a long-range process of resource development. The product of this activity in the near-term is not mineral commodities such as metals, however, but rather information about the resource potential. We examine the role of investment in information in the resource development process, briefly discuss the economics of information, characterize the problems faced and the methods employed by public agencies in managing information, and highlight several critical policy issues concerning the management of information about EEZ nonfuel minerals. These issues concern the distribution of research effort, exclusive rights, confidentiality provisions, performance requirements, and national security classification.

INTRODUCTION

Although only sparsely explored to date, the US exclusive economic zone (EEZ), an area extending 200 nautical miles seaward from the coastal baselines of the US territorial sea, is known to contain substantial quantities of marine nonfuel minerals. We define marine nonfuel minerals to include all hard rock or aggregate minerals other

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than hydrocarbon minerals. Within the EEZ, examples include manganese nodules on the Blake Plateau, cobalt crusts in areas around Hawaii and the southwestern tropical Pacific, marine polymetallic sulfides (MPS) in the Gorda Ridge area, placer deposits containing chrome, gold, platinum, titanium, and other heavy minerals, phosphorites along the southeastern US margin and the coast of southern California, and sand and gravel in the New York Bight, Beaufort Sea, and in areas offshore of Southern California and Hawaii. Elsewhere, we have surveyed the literature on location, volume, and metal grades of marine nonfuel deposits and have reported on the economic significance of these deposits.[1,2]

This article offers a somewhat different perspective on policy issues associated with the management of marine nonfuel minerals. The literature has tended to concentrate on mineral end uses and the latter stages of marine minerals development, especially the production phase. For example, a common justification for instituting federal encouragements for marine nonfuel minerals development is as a source of strategic metals in militarily-related end uses. Since most mineral end uses do not discriminate between the geological sources (land or marine) of mineral supplies, except in terms of relative cost, and because many marine nonfuel minerals are not yet close to the production phase, a change from the usual perspective is instructive.

In this article, we suggest that the sensible focus for resource management in this field is the earlier stages of development, namely prospecting, discovery and exploration. Specifically, we emphasize investment in information as an important component of the costly process by which marine nonfuel mineral resources become economically productive. We examine the role of investment in information in the resource development process, briefly discuss the economics of information, characterize the problems faced and the methods employed by public agencies in managing information, and highlight several critical policy issues concerning the management of information that warrant special attention.

THE RESOURCE DEVELOPMENT PROCESS

There are geological, legal, technological, political, and economic reasons for distinguishing marine nonfuel minerals from their onshore counterparts. In a geological context, oceanographic factors, alone and in combination with other physical factors, can contribute to the concentration or accumulation of different mineral deposits. For example, marine heavy mineral sands are concentrated by nearshore currents; marine phosphorite accumulates at sites of coastal upwelling; and marine polymetallic sulfides (MPS) are deposited at seafloor spreading centers.[3] From a legal or jurisdictional perspective, the property right regime, including the identification of the resource owner (in the United States, usually a government agency acting as trustee for the public) and the method of transferring development 'rights', differs significantly from regimes for onshore minerals.[4] There may be substantial technological hurdles peculiar to ocean minerals that relate to the recovery of minerals, such as the separation of gangue from cobalt-rich ferromanganese crusts,[5] or that relate to the subsequent metallurgical processing of minerals, such as the complete extraction of gold from marine sulfides.[6] Political problems specific to marine minerals have been observed between US executive agencies that vie for administrative responsibilities or 'turf';[7] among national governments 'staking' exploration area claims;[8] or as a result of varying interpretations of international treaties, as evinced by Ecuador's claim over the Galapagos Ridge.[9]

From an economic perspective, the distinguishing features mentioned above are important only as they affect the ease with which these minerals can be brought into productive use.[1] Regardless of the location of any mineral (Antarctica, Zaire, the US EEZ, Colorado, or New York Harbor), the 'best' resources (the easiest to find, develop, extract, and use) tend to be used first, with lower quality resources postponed until the better ones are depleted.

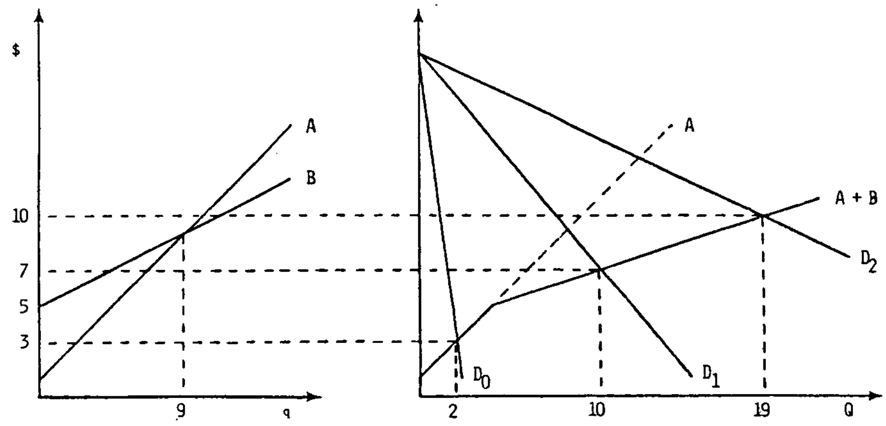
Lower quality resources sometimes are described as 'backstops'. Backstop resources may exist in large quantities but tend to be of low grade, difficult to refine metallurgically, difficult to recover without causing severe environmental degradation, or otherwise inaccessible. Economic theory predicts that, as depletion of existing higher quality resources takes place, *ceteris paribus,* price will tend to rise with increasing scarcity until development and exploitation of the backstop becomes economically feasible.[10]

An optimistic outlook for longrun mineral supply is favored by the historically proven ability to substitute among minerals, to conserve and recycle, to extend available resources through technological innovation, and thereby to exploit sources which previously were uneconomic. The presence of potential marine sources for many minerals reinforces this optimism. Some marine deposits that are now classified as only 'occurrences' or 'identified subeconomic resources' may eventually be upgraded to the status of 'reserves'.[11] Even with continued advances in knowledge about marine nonfuel minerals, however, others will remain perpetual backstops (White, G., 1987, pers. comm.) 'always the bridesmaid and never the bride'.[12]

Only a few marine minerals can now be called 'ores' in the geologist's sense, meaning 'rocks and minerals that can be recovered at a profit'.[13,p.1] Known marine nonfuel 'ores' within US jurisdiction are all nearshore and located on the submerged lands of coastal states. These include the gold placers found off Nome, Alaska, the sand and gravel deposits at the entrance to New York Harbor (a by-product of channel dredging), and the shell lags of the Chesapeake Bay and the Gulf Coast.[14] (Aggregates such as sand and gravel and shell are more properly referred to as 'economic minerals' and not 'ores', although this is only a semantic distinction.) Much recent attention has been paid to the ore potential of other types of marine deposits that occur within the US EEZ, including heavy minerals containing titanium dioxide and zirconium, phosphorites, marine polymetallic sulfides (MPS), and others.[15] For several decades (perhaps even on a cyclical basis), these marine deposits have been both studied and promoted.[1,p.857–8;2,p.77–85] However, they have yet to prove themselves competitive with existing onshore resources.

To understand the process by which marine mineral deposits become ores, a simple model of longrun supply functions is useful. By 'supply function' we mean a description of the amount of a mineral from any source, on- or offshore, that will be provided by producers at different prices consumers are willing to pay. The 'longrun' is a period of time long enough that all 'factors' of production (e.g. employees, dredges, mine sites, information from exploration) are variable. In other words, amounts of minerals supplied to the market can be varied by varying any or all of these factors. The amount of mineral supplied at each level of price will be determined by the incremental or marginal cost for factors of production. We expect that the longrun supply function has a positive slope because as the amount of minerals supplied to the market is increased, it takes more factors of production to supply each additional ton of minerals than it does to supply each preceding ton.

Figure 1 displays this simple model graphically. First examine the left panel of the figure. Let A represent supply from an onshore deposit (or set of deposits) for any particular mineral. At relatively low levels of output (q) marginal costs are low so the mineral output can be sold at low prices. Marginal cost (and the required price) rise steeply, however, as output levels increase, perhaps as a result of competing land uses, environmental protection costs, or political taxes. Let B



D	P	Q	q_A	q_B
0	3	2	2	0
1	7	10	6	4
2	10	19	9	10

Fig. 1. Shifting resource bases with rising costs and demand growth. (A) output at various prices from onshore deposit(s), (B) output at various prices from marine deposit(s), (A + B) is the longrun supply of minerals from both onshore and marine sources.

represent supply of the same mineral from a marine deposit. Initially this source is much more costly than A and requires a much higher price to support production. Once production is underway, however, additions to output increase incremental cost less steeply than for A. The horizontal summation of A + B is equivalent to total longrun supply, as constructed on the right side of the figure. We can now show the relative contributions q from each deposit to total supply Q at hypothetical levels of demand D and visualize the movement of marine deposit B from a status of resource to one of reserve.

Following the entries in the matrix underneath Fig. 1, we see that at the relatively low demand of D_0, the price of the mineral is \$3/ton and the total quantity supplied to the market is 2 tons. All of the production comes from the onshore deposit A, because the marine deposit cannot be supplied commercially at a price below \$5/ton. If demand expands to D_1 (because of population growth, increases in the average income of consumers, or increases in the prices of substitute goods), then consumers now are willing to pay up to \$7/ton for 10 tons of mineral. This new, higher price accompanying an expanded demand draws factors of production into the industry that may have been employed in other applications. Output increases to 6 tons from deposit A, but, because this deposit is depleting, extraction at higher levels is unprofitable. At the same time, this level of production from A is insufficient to supply the total market. At the $7 price, it now has become profitable to employ some merchant mariners, engineers, geologists, and other 'ocean miners' on dredges at permitted offshore 'commercial recovery' areas to produce up to 4 tons to satisfy the remaining demand. At an even higher level of demand, such as D_2, the marine deposit is of better relative quality, and it becomes the dominant source. Thus, longrun supply represents a combination of production from both the onshore and marine deposits at all levels of total output above the marine 'trigger' price of $5/ton.

The quantities and prices we have used here are merely for illustration. In practice, reliable empirical estimates of potential mineral output at different price levels for all currently available and prospective sources are nonexistent. The work of the US Bureau of Mines on its 'minerals availability system' and studies of other researchers (e.g. Harris and Skinner[16]) have begun to provide 'material flow' estimates, an analogous method of understanding longrun mineral supply. Unfortunately, this work is only just emerging, and it does not focus specifically on marine nonfuel mineral 'flows'.

ECONOMICS OF INFORMATION

Natural occurrences of minerals become resources, in the manner we have described, only when they have been brought within reach of practical exploitation. This requires the costly application of both human effort and ingenuity. The physical parameters of any mineral deposit are never known with complete certainty until the deposit has been completely 'played out' or exhausted.

Obtaining information (prospecting, discovering, exploring, or learning) is a kind of investment. However, the 'return' on investment in mineral information can be distinguished from some other learning investments such as education.[17,p.3] Exploration is much riskier and, in many ways, resembles basic scientific research. In a study of exploration by major mining corporations, Eggert[18,p.106] found that 'potential returns from exploration are often so difficult to estimate . . . that changes in the level and distribution of exploration are in some instances determined more by habit and simple rules of thumb than by careful calculations . . .'. Although 'bonanzas' (high quality deposits) can result in huge paybacks, they tend to be quite rare. Also, one bonanza may have to cover multiple unsuccessful exploration investments.

It is helpful to think of information as itself a resource. For any particular mineral deposit, information has value because it is useful and scarce. Information is a form of capital, though 'intangible', and thus is a factor 'input' in the mineral development process along with the tangible capital inputs, and labor and mine site factors. As with these other inputs, mining firms or government agencies must 'hire' exploration services away from other productive activities to devote them to ocean mineral exploration, the product of which is the information input. For minerals not yet in production, like many of the marine nonfuel minerals, the cost of investing in the search for mineral deposits and in their systematic exploration (equivalent to the value of the exploration services in their most productive other uses) can be a significant proportion of total development costs. However, gains made in understanding their geological, technological, and even legal/political attributes could make significant reductions in future production costs, relative to onshore deposits that are more completely understood.

For commercially exploitable deposits, resource information helps resolve the size of the expected economic rent or financial return to the resource owner from development. Although information is a product of purposeful economic activity, a point may be reached where increased investments in understanding the economic and geological characteristics of a mineral deposit do not pay for themselves fully through application of the knowledge gained. Although the qualitative benefits of information as 'increased knowledge' are well-known, investment in information is costly—so there is always an optimal level of information (or alternatively, of ignorance!).

Depending on the existing arrangement of property rights, there are reasons based in economic theory to believe that some investments in mineral resource information through exploration can be socially inefficient or suboptimal. Information about a mineral deposit can be a kind of public good; it may be difficult for a firm which invests in the development of information to capture enough of the resulting benefits to cover its investment costs. This can happen where one deposit spans property boundaries or where geological information is not site-specific. The possibility that information can spill over and benefit other firms at little or no cost creates a disincentive for those firms that potentially might invest in mineral information.

One recent case of information spillover concerns the leasing of outer Continental Shelf (OCS) oil and gas minerals in the Gulf of Mexico.[19]

In that case, the US government, as the resource 'owner', initially reaped the rewards of higher bonus bids on OCS leases located near discoveries made on the submerged lands within the jurisdiction of Texas. This case did not involve marine nonfuel minerals, which clearly have physical properties that distinguish them from hydrocarbon minerals. Nevertheless, we note that the US Minerals Management Service recently has decided to hold a lease sale on gold placer deposits located on the OCS adjacent to deposits currently in production on the submerged lands of Alaska. Moreover, the marine deposit currently being worked is just offshore from river placers, which have been worked for decades. This would suggest that some information may be transferable in this nonfuels example.

The tendency to underinvest in the development of mineral information has been used as an argument for government exploration programs and subsidies for private exploration efforts. Actual and proposed programs and incentives include those for proprietary information protection, such as the recently promulgated regulations for OCS minerals 'other than oil, gas and sulfur' (see below); private joint venture exploration;[20] combined public and private exploration; and public exploration efforts with a wide dissemination of resulting information.[21]

Traditionally, the development of mineral resources that are managed by government agencies has involved a combination of direct government investment in mineral resource information with the provision of incentives for private investment (such as technology patents, exploration cost write-offs, or the confidential treatment of proprietary information). These efforts are believed to compensate, at least in part, for the tendencies of the private sector to underinvest in mineral information. (Government policies to invest in mineral resource information also have been established to facilitate the achievement of other public goals, such as the development of military-strategic mineral resources.)

When exclusive rights for exploration, development, or production are allocated on the basis of first discovery, the potential exists for a socially inefficient overinvestment in information. (This situation often is described as a 'discovery rush'). It is directly analogous to the strategic nature of investments made by the international seabed mining industry, which (largely during the 1970s and 1980s) created a level of capacity for seabed mining exploration and R&D far in excess of the nearterm level of activity expected in the industry.[22] This industry has been successful in obtaining exclusive exploration claims to extensive areas of the deep seabed,[23] yet the prospects for commercial recovery remain distant.

MANAGING INVESTMENT IN INFORMATION

Resource managers in government agencies who focus on marine nonfuel minerals management are faced with problems of: (1) determining an optimal level of investment in information; (2) selecting the most effective methods for making this investment; (3) applying these methods in an environment characterized by cyclical market conditions. In this section, we describe briefly some of the existing management methods and outline some fundamental resource management problems.

The existence of external effects (positive and negative) in the 'market' for information as a factor input into the mineral development process makes it unlikely that a socially optimal level of investment in mineral exploration can occur without some form of government intervention. Government policies often include additional reasons (public 'goals') for becoming involved in the process of investing in information. For example, the Deep Seabed Hard Mineral Resources Act (DSHMRA), which governs the allocation of deep seabed exploration licenses and recovery permits to US firms, lists as one of its purposes to 'encourage the development of technology necessary to recover the hard mineral resources of the deep seabed'.[24]

The good news for marine nonfuel minerals is that inefficiencies in information investments are likely to be small. However, information as a factor input may represent a proportionally large share of total project costs at the early stages of an offshore mining project. This is because of the sequential nature of the mineral development process, with the bulk of exploration occurring prior to production, and because the costs of factor inputs for production are discounted back to their present from an extended future period, thereby reducing their relative size.[25] As a result, there may be a propensity for both private firms and government agencies to argue that marine nonfuel minerals remain largely unexploited at present mainly because there is too little investment in information (due, for example, to information spillovers) and not because of the natural status of marine nonfuels as economically inferior resources. This way of thinking could lead to the establishment of public encouragements for 'commercial' exploration activities.

A good example of this argument can be found in the National Seabed Hard Minerals Act (HR 2440), a bill that would establish a new regime in the US EEZ for the development of marine nonfuel minerals. The bill was originally drafted and has been supported by a coalition of industry, environmental groups, and coastal states. It has been proposed in various forms since 1986, when it was first introduced. In the current version of the bill, one of the congressional 'findings' is that 'the acquisition of data and the development of technology required for the commercial recovery of certain hard mineral resources of the seabed will require substantial investment for many years.[26] The bill calls for NOAA, in cooperation with other federal agencies, to:

> 'Conduct a comprehensive and systematic program of research to support activities with respect to environmental assessment, general mapping and charting of areas subject to potential exploration and commercial recovery under this Act, and *assessment of the extent and nature of hard mineral resources in such areas.* The program shall include the development, acceleration, and expansion, as appropriate, of governmentally sponsored studies of the biological, ecological, *geological,* chemical, and physical aspects of the seabed and waters above it, and the *encouragement of private studies of the resource potential* in general areas of the seabed where exploration and commercial recovery under the authority of this Act may occur . . .' (emphasis added).[27]

The bill would authorize roughly $75 million over an initial 3 year period for government activities in 'mapping, charting, and geophysical assessment of hard mineral resources of the seabed.[28] (Although this appears to be a major new government investment in information for EEZ nonfuel minerals, in fact the bill continues current government programs at slightly elevated levels of funding.)

In addition to the direct sponsorship of marine geological research by government agencies, other passive and active management methods exist through which government agencies can encourage investment in information on marine nonfuel minerals. The 'passive' methods of encouragement, which are applied uniformly across mineral industries (and, in some cases, across all industries) include the following:

- *Patents.* These are government grants of property rights to exclude others from the manufacture, use, or sale of a technological invention, such as for deep seabed mining exploration and recovery technologies (e.g. See Ref. 29).

- *Tax allowances*. These include credits against income for basic research and experimentation on technology and deductions for exploration costs and for depletion of mineral deposits.

Other, more 'active' methods of encouragement, specific to marine minerals, include the following:

- *Confidential treatment* of proprietary prelease geological and geophysical data and information. Regulations promulgated recently by the US Minerals Management Service (MMS) to carry out OCSLA provisions relating to marine nonfuel minerals allow geophysical data obtained under permit to be held confidential for up to 50 years and for geological data, information, and samples and geophysical information obtained under permit to be held confidential for a period of up to 25 years.[30] ('Information' is defined as 'data'—facts, statistics, or samples—that has been subject to analysis, processing, or interpretation. The definition of information found in the MMS rules is more narrow than the one we employ here.)
- *Exclusive entitlements*. These are exploration or commercial recovery areas that have been allocated on either a 'first come, first serve' basis (as under DSHMRA or the proposed NSHMA) or by competitive bid (as under OSCLA).[4,3] The former method of allocation is thought to provide a higher level of encouragement because no financial payments are required until the license is obtained (when rental payments may become due).
- *Performance requirements*. These are embodied in 'due diligence' clauses, financial rentals, minimum or advance royalties, exploration area relinquishments, or other policies. These requirements act to encourage the pace of exploration and development, sometimes at a socially inefficient rate.[32]
- *Exploration offsets*. This is the crediting of documented exploration expenditures against bonus bids. The use of offsets would permit firms bidding in a competitive auction to bid their estimated exploration costs. Successful bidders then would be required to incur those costs, thereby 'encouraging' exploration, although there is no guarantee that this exploration will be socially efficient.[4,p.484] The MMS has studied the potential for the use of exploration offsets in its competitive allocation process.[33] Recently promulgated leasing regulations for marine nonfuel minerals on the US OCS do not include specific provisions for the use of exploration offsets. However, neither is their use precluded, as the rules are open-ended in this regard.[34]

- *Clearinghouses.* These institutions provide bibliographic, data retrieval, and other data management services to facilitate access to a growing stock of marine mineral information. In the United States, the primary marine nonfuel minerals clearinghouse is the National Geophysical Data Center (NGDC). NGDC contains the results of both public and private studies and research efforts on marine minerals.[35] For a minor fee, NGDC will provide clearinghouse services to those who submit requests. As shown in Fig. 2, there are large and growing numbers of articles that describe and analyze marine nonfuels. The logarithm of numbers of articles pertaining specifically to manganese nodules are plotted over time in the figure to demonstrate the growth in efforts to study these minerals. (It would be interesting to speculate on the reasons why numbers of articles pertaining to manganese nodules have not declined significantly, even in the wake of reduced industrial interest. We leave that task to another article.) Another important clearinghouse is MMS, although its primary focus has been on hydrocarbon minerals, and the availability of mineral information is subject to confidentiality rules.

A fundamental problem for resource managers in government and

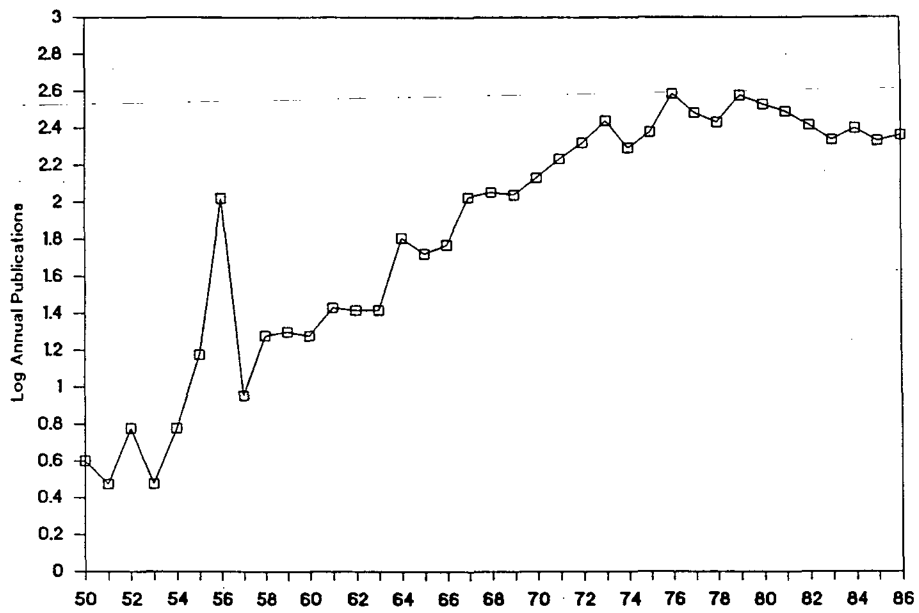


Fig. 2. Annual manganese nodule publication records in the bibliographic database of the National Geophysical Data Center. Data show increase in publications over time with a 'leveling-off' beginning in the mid-1970s.

industry is to determine an optimal level of investment in information. It is probable that, given substantial uncertainty, a nonzero exploration level on marine nonfuels is warranted. Even with only distant commercial prospects for many of the marine nonfuel mineral resources, it is not unreasonable for mining firms and, especially, government agencies to be concerned about sources of supply for minerals in the longrun.[36] The potential for inefficiency exists, however, when such investment decisions are based upon a simple linear extrapolation of recent market trends or other rules of thumb in the face of substantial uncertainty.

A second fundamental problem is the selection of the most useful management methods to achieve that level of investment. The management methods described here represent a broad range. Although it is possible to analyze in a qualitative way the benefits and costs associated with these methods, it is difficult to state with certainty that any one method is superior. There may be benefits associated with the use of multiple (and sometimes 'competing') methods of investment in information (see ref. 7). For example, the reduction of investment risk may be possible through careful management of a 'portfolio' of investment methods. In a still emerging policy area like marine nonfuel minerals management, diverse sources of information can be of great use to policymakers.

The markets for metals are notoriously volatile, due fundamentally to the high degree of responsiveness of world demand for metals to changes in aggregate economic activity. It is probable that investment in marine minerals exploration and R&D is tied to the underlying cyclical behavior of mineral commodity markets. For example, in the international seabed mining industry, several idiosyncratic factors point to cyclical behavior, including the time profile of investment activity as shown in Fig. 3;[22,29] the schedule of major seabed mining R&D programs in Japan and the USSR;[1,22] performance requirements associated with minesite licensing provisions;[32] predictions of the timing of Law of the Sea treaty commitments;[8] and indications of strategic behavior in seabed mining activities.[1] These factors, together with more general evidence on the temporal behavior of exploration activities and mineral commodity markets, have led us to conjecture that seabed mining investments may fluctuate over time in a cyclical manner and, furthermore, if the cycle is relatively regular, that an upswing in activity may be observed around 1990–95.

This linkage between investment in mineral resource information and mineral commodity market behavior presents another fundamental set of problems for resource managers. Clearly, the optimal timing and scale of certain public actions (such as leasing and licensing, enforce-

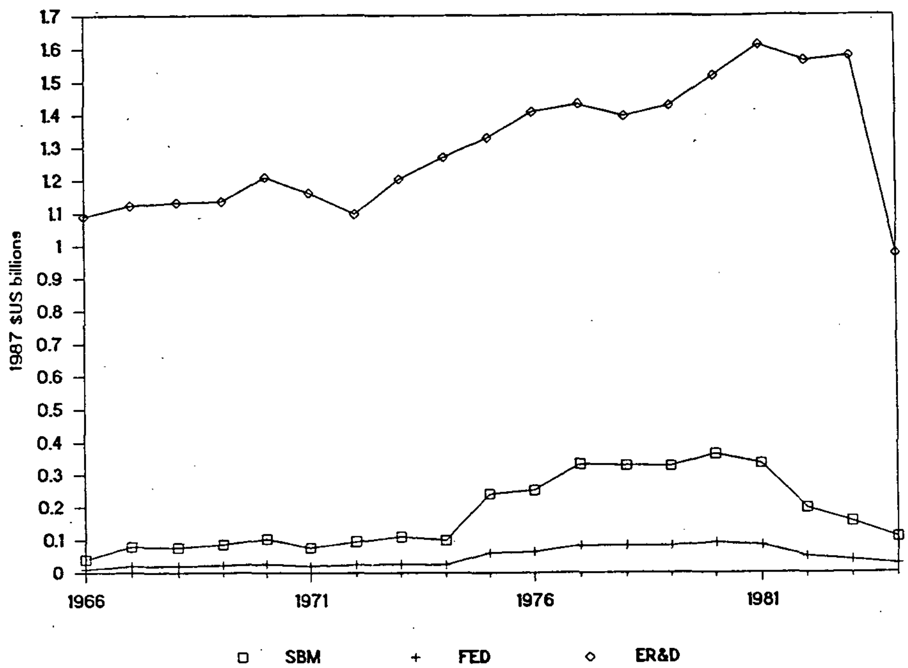


Fig. 3. Estimated US mining exploration and R&D expenditures from 1966 to 1984 compared to estimated US federal expenditures on marine nonfuel mineral management and estimated world expenditures on deep seabed mining. Note that there is some overlap in the components of each of the estimates. All values are adjusted to 1987 dollars. ER&D represents total US industrial investment in R&D and exploration for metals; Fed represents US government agency expenditures on marine nonfuel minerals exploration and management; SBM represents worldwide 'commercial' investment in exploration and R&D for manganese nodules. (From various sources.)

ment of diligence requirements, support for or intervention in scientific research, and provision of incentives or subsidies) can be affected by cyclicality. This is true especially if observed levels of exploration and R&D investment are treated as proxies for the longer-term level of activity in marine minerals. The result may be ill-timed policy measures and wasteful frictional adjustments, with the direction of error depending upon the current position in the investment cycle. The ability to anticipate 'boom–bust' phenomena in resource development activities is of great importance to managers and planners in coastal areas. Myopic government policies actually can tend to exacerbate rather than mitigate market cycles and could contribute as well to mistargeted foreign policy actions.

INSTITUTIONAL AND POLICY ISSUES

Here we identify five pressing institutional and policy issues that concern the management of marine nonfuel mineral resource information. These issues relate to research expenditures and funding sources, exclusivity of property rights, confidential treatment of information, performance requirements, and national security classification. In the next decade, resolution of these issues will be critical to achieving effective management of these resources.

Following directly from the problem of determining the optimal level of investment in information is the issue of the most appropriate distribution of research effort between public and private sources. It is important to distinguish commercial exploration directed at specific deposit characteristics (grade, size, location) from basic geological or oceanographic research directed at understanding physical processes, such as mantle convection or plate movements.[37] Although there can be substantial overlap, we expect that overinvestment in exploration might occur either when government agencies themselves explore or when they provide specific incentives for private firms to conduct commercially-oriented R&D and exploration. When commercial rents can be earned from marine hard minerals, self-interested private investors will seek to exploit them without government inducement. The use of public resources to invest in knowledge leading directly to commercial application is justified only in cases where policy goals override a goal of economic efficiency (e.g. national security, industrial development). Policy goals such as these must be examined with great care before they are implemented, because they will entail lost opportunities in other areas.

Basic scientific research is an area where government attention can compensate for an underinvestment by the private sector in information. Gains made in basic research can make downstream commercial exploration efforts more productive. A good example concerns land-based phosphate deposits with marine origins. In this example, the confluence of scientific theories about plate tectonics and coastal upwelling helped geologists to discover large phosphate deposits in Australia and the American west.[38]

One method for the US government to encourage investment in commercial exploration is to grant exclusive rights to private firms to explore and potentially to exploit marine minerals. This is the form of restricted 'access' contemplated by the current proposed legislation, HR 2440, the National Seabed Hard Mineral Resources Act. Existing law (OCSLA and its regulations) authorizes the MMS to grant nonexclusive geological and geophysical (G&G) 'prelease exploration' permits to ocean prospectors and to hold exploration information confidential for variable periods. Mineral exploration, development, and production rights subsequently may be auctioned off through a combined bonus bid, fixed royalty system.

Although the existing OCSLA system has been characterized as encouraging overinvestment in exploration in the case of oil and gas leasing[39] we expect that this is not the case for marine hard minerals. (Note that only 17 G&G permits have been issued over the past 35 years—not counting permits for sand and gravel prospecting off Alaska.) Conceding exclusive exploration rights to private firms transfers some of the risk of exploration away from the explorers (no upfront payments are required to secure property rights), but the public risks giving away a bonanza, or the rents associated with a high quality deposit, in the process.[4,p.482] While we suspect that there are few bonanzas in the EEZ, public perception may preclude the institution of such a system.

The primary public purpose of confidentiality provisions is to encourage private investment in the development of resource information, specifically geological and geophysical information and data for areas not yet under a lease. Responsible public officials are permitted access to the information, but information is not disseminated widely until after a prescribed period. The rules have been modified recently, extending the period of confidentiality for both OCS hydrocarbon and nonfuel minerals.

The problem for government managers is to strike a balance that induces investment without foreclosing timely dissemination to other users, who could gain significant benefits at little additional cost. Extending the period for information protection increases the probability that duplicative (excessive) exploration will be conducted. Reducing the length of the confidentiality period (or periodically changing its length) reduces the incentive for exploration and also may increase the likelihood that private firms keep exploration knowledge secret. Concern about this latter effect may be foremost in the minds of policymakers as they consider extending the confidentiality period for marine hard minerals.

Diligence provisions, and the broader set of performance requirements to which they belong, can be employed by resource managers to encourage both the pace of exploration and the flow of information from private explorers holding offshore mineral rights. For deep seabed mining entitlements, US exploration licensees have had the flexibility to allocate exploration effort themselves over a 10 year initial license period. While flexibility in the enforcement of diligence is a worthwhile management goal, political concerns over 'speculation at the public's expense' continually reappear in cases of backstop resources, and these concerns work to tighten enforcement of diligence rules.

Combined with the sidescan sonar images presently being collected and charted by the US Geological Survey, detailed seafloor resolution using NOAA's 'Seabeam' high-resolution bathymetry might be an invaluable tool for exploration. The US Navy's national security classification in 1985 of high resolution bathymetric data collected by NOAA was described by industry interests as a barrier to exploration of the EEZ for marine nonfuel minerals.[14] In 1989, however, the US Navy declassified the charts that NOAA had produced and removed its opposition to future high-resolution bathymetric charting, except in certain designated national security areas, such as nuclear submarine harbor egress routes.[40,p.25] Prior to the declassification, NOAA's planned program of mapping the entire EEZ had been delayed, and the agency had focused its efforts on only a few local areas. Whether a stepped-up NOAA mapping and chart production program will result in an acceleration of private marine nonfuel minerals exploration efforts remains to be seen.

SUMMARY

There are several reasons (geological, technological, other) why marine nonfuel minerals can be distinguished from their onshore counterparts, but from an economic perspective, these distinctions are important only if they affect the ease with which minerals can be gotten and used. Even if marine deposits were placed on an equal 'information' footing with onshore deposits, in many cases they still would be relegated to a 'backstop' position. (This is true especially for the deepsea deposits: manganese nodules, cobalt crusts, marine polymetallic sulfides.)

Information can be characterized as a factor input, a form of intangible capital, in the minerals development process. Investment in information often is subject to a high degree of uncertainty, making such investments risky. Since the costs of investment in information inputs form a substantial portion of the early development costs associated with these minerals, a fuller understanding in several areas can help bring marine deposits closer to their realization as productive resources. Although gains can be made through a management focus on information investments, resource managers should recognize that there is an optimal level of 'ignorance' that restrains such investments. Government has a clear role to play in correcting for the external effects of investments in mineral information, and its toughest decisions will be in determining the most appropriate levels of investment, the combination of methods to be employed in making that investment, and the distribution of effort between public and private investors in information.

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