Chapter 12

China Sea Coastal and Marine Nonfuel Minerals: Investigation and Development

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Abstract *In this chapter, we survey the economic potential of coastal and marine nonfuel minerals in the East and South China seas. We describe briefly the mineral economies for eight China Sea countries and review historic and current efforts in exploration, development, and production of coastal and marine nonfuel minerals. The benefits of CCOP, an international joint prospecting organization, are described. Using 1984 data based upon production of marine sand and gravel in Kyushu, Japan, marine tin production in Indonesia, and marine salt production in China, the countries surrounding the two China Seas produce about one-third of a billion dollars worth of marine nonfuel minerals annually. This figure is small in comparison, for example, with offshore crude oil production, estimated at $11 billion in that year. From a global perspective, output of marine nonfuel minerals from the East and South China seas is proportionately much more important to world marine nonfuel production than the output of marine hydrocarbons from the same region is to world marine hydrocarbon production. Taking only sand and gravel and tin production, the marine mines in these two seas produce almost one-quarter of Broadus' (1987) estimated $600 million annual revenues from all sea-bed nonfuel materials world wide. Nearshore minerals have the best prospects, and the prospects for deepsea minerals, although they occur in the region, are remote and should not influence maritime boundary settlements.*

Sunshine over Chengzhou clears up river fog,
gold diggers—girl partners over the riverside crowd;
all beauty decorations and lords' signets
come from the depths of waves and sands.

Liu Yuxi
Tang Dynasty poet
Guizhou, Guangdong Province

The recovery of native gold from alluvial placer deposits, illustrated by Liu during China's renaissance period (618-907), has gone on for centuries. Indeed, in China's Yuan dai, the practice of "washing grains of gold out of sands" was well known before the thirteenth century. All of the countries surrounding the two China seas have had a long history and much experience in the investigation and development of coastal and marine nonfuel minerals.

Because economic entities in the China seas—national governments and private firms—devote scarce labor and capital resources toward the search for and assessment, development, and production of marine nonfuels, an understanding of the potential of these mineral resources is important for marine policy. In this chapter, we describe the marine nonfuel resource potential of the East and South China seas, with attention to the nonfuel mineral economies of eight of the countries that frame this regional sea. Because of its 14,500-km long coastline—the longest of all national coasts along the two China seas—a hypothetical exclusive economic zone of approximately 281,000 square kilometers (km^2), and with a population of about 400 million (40% of the total) living near the coast, we concentrate upon activities related to marine nonfuel mineral resources in the People's Republic of China (China). Activities occurring in the Republic of Korea (Korea). Japan, Taiwan, the Philippines, Malaysia, Indonesia, Thailand, and Vietnam are important for the two China seas and have been included as well.

We begin with a sketch of the region and summarize briefly the mineral economies of each of eight China Sea countries. Next, we present the history of development and production activities of coastal and marine nonfuel minerals in the two China seas. Apart from current offshore production, there is a substantial amount of ongoing marine prospecting and exploration activity in this region, and we survey the most recent efforts and present some of the results of national and international investigations. Finally, we discuss some of the salient issues and concerns for public policy, and we indicate some potentially fruitful areas for future research.

Any discussion of the potential for marine nonfuel minerals as contributors to the economy of a region or the world should begin with words of caution. There is a tendency for students of marine minerals to be caught in the throes of imagination, besieged by claims of boundless potential and glittery images of gold placers, precious coral, and cobalt crusts. A much more sober realization of this potential requires an understanding of how mineral resources are found and brought into production, of the costly nature of this process, and of the factors such as depletion, technological advance, substitution, recycling, and conservation that may work for or against their development. Yet, with this caveat in mind, we can assert that the concentration of economic activity on nonfuel coastal and marine minerals in the two China seas is more diverse and more valuable than that in any other of the earth's marginal seas. This chapter represents a start at understanding the conditions that exist to make this statement true.

THE REGION

As depicted in Figure 12.1, the East China Sea (also known as *Tung Hai*) covers about 770,000km^2 and, averaging 370 m in depth, is a relatively shallow coastal sea. Seventy-one percent (71%) of the East China Sea is less than 200 m in depth, but the Okinawa Trough on its southeastern margin is generally more than 1000m deep, with a maximum depth of 2717m. The South China Sea (also known as *Nan Hai*) is five times as large as its eastern namesake and averages about 1212m in depth. The South China Sea has a deep basin in its northeast portion, and its shelf is dotted with islands, reefs, and "dangerous grounds" including the Paracel and Spratly Island groups.

Table 12.1 compares the geographic and demographic characteristics of these countries (note that, in many cases, these statistics include coastal or marine areas outside of the two China seas). (Statistics from the United States have been included in most tables for general comparison purposes). It is interesting to note that the land area of China is far greater than its hypothetical marine jurisdiction; this situation is just the reverse for Japan, the Philippines, and Korea. In fact, Japan's marine area is three times the size of its land area. The ratios of coastline to land area and marine area to land area are comparatively small in China compared to the Philippines and Japan, for example. Indonesia and Japan have the largest marine jurisdictions, but much of these two areas lies outside the South China Sea, whereas China's marine jurisdiction and coastline lies entirely within the confines of the two seas.

Table 12.2 compares general economic indicators for these countries. From 1970 through 1981, the growth rates for these countries, as measured by average annual gross domestic product (GDP), have been very high, averaging 8% for the China Sea countries, with China's estimated GDP growing at 14% during this period. Japan's GDP is the highest, more than three times that of China in 1981 at $884 billion. In per capita terms, GDP in Japan (outside of Taiwan, Brunei, and the entrepots, the only "developed country" in the region, according to World Bank standards) again is quite high, at almost $7500 in 1981. China, with its one billion people, was at a level with Vietnam in 1981, with under $300 of GDP per capita.

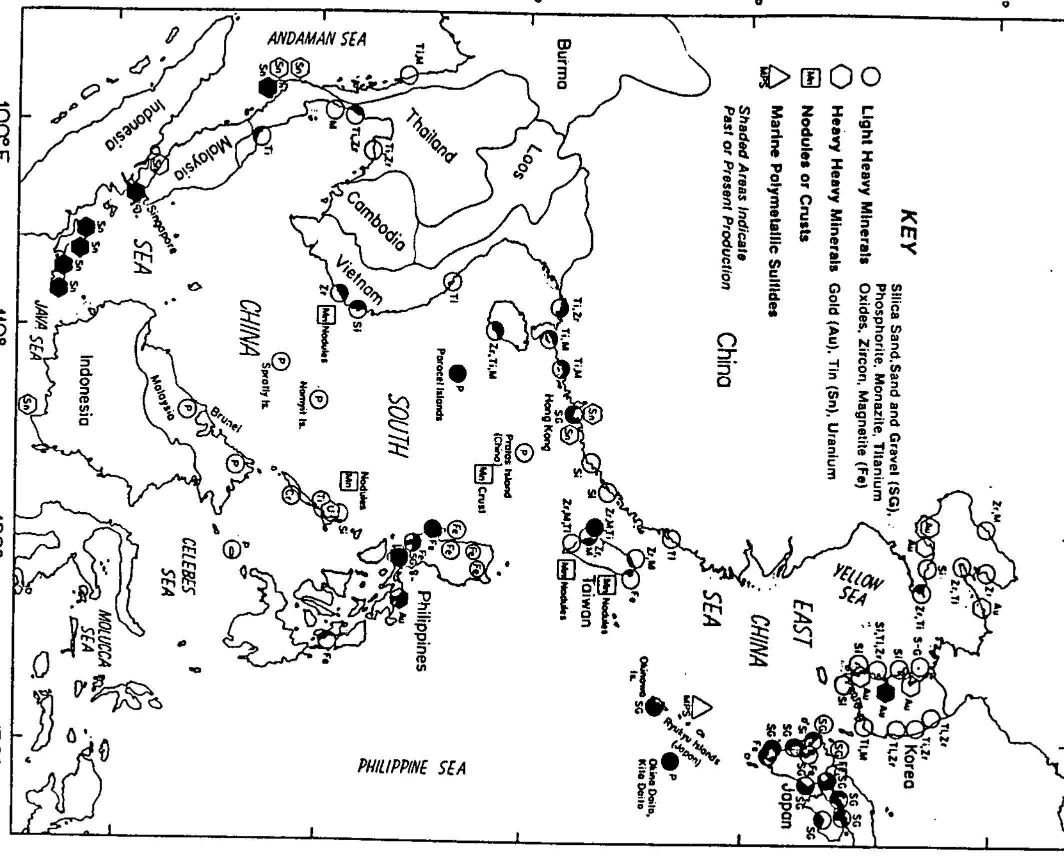

Figure 12.1 Marine nonfuel minerals: production and prospects in the East and South China seas region.

Table 12.1
Comparative Marine Geography and Demography for the China Sea Countries

Country	Land area ($km^2 \times 10^3$)	Length of coastline (km)	Ratio of coastline to land area ($km^{-1} \times 10^{-3}$)	Hypothetical area of marine jurisdiction ($km^2 \times 10^3$)	Ratio of hypothetical marine jurisdiction to land area ($\times 10^{-2}$)	Population density (persons/km^2): Land area	Population density (persons/km^2): Land and marine area
China	9600	14,500	2	281	3	103	100
Korea	98	2413	25	102	103	398	131
Japan	370	12,075	33	1126	304	319	79
Philippines	300	22,540	75	551	184	167	59
Malaysia	333	4675	14	139	42	42	30
Indonesia	1906	54,716	29	1577	83	78	43
Thailand	513	3219	6	95	19	94	79
Vietnam	330	3444	10	211	64	182	111
Total (average)	13,450	117,582	(24)	4082	(100)	(173)	(79)
U.S.	9363	19,924	2	2220	24	25	20

Note. Population statistics reported in Table 2.
Sources: Borgese and Ginsburg (1980, 1982).

Table 12.2
General Economic Indicators for the China Sea Countries

Country	1981 GDP ($US × 10^9)	1970–1981 GDP average annual growth (%)	1981 population (× 10^6)	1981 GDP per capita ($US)
China	265	14[a]	991	267
Korea	65	9	39	1667
Japan	884	5	118	7492
Taiwan[b]	60	8	19	3146
Philippines	39	6	50	780
Malaysia	25	8	14	1786
Indonesia	85	8	149	570
Thailand	37	7	48	771
Vietnam	15	—	60	247
Total (average)	1415	(8)	1488	(951)
U.S.	2893	3	230	12,578

[a]Annual average increase in gross agricultural and industrial output value from 1965 to 1979 as reported in Xue (1982).
[b]1985 data; GDP growth rate from 1970–1982 (Morrison 1987).
Source: World Bank (1983).

Regional Significance of Marine Nonfuel Minerals

In the China seas, actual marine nonfuel reserves are known for tin and sand and gravel; and coastal reserves are known for sea salt, sand and gravel, tin, titanium oxides, and associated light heavy minerals such as zircon and monazite. Other resources of coastal and marine minerals in this area include all of the above as well as gold placers, industrial silica sand, and magnetite sands. Mineral occurrences include all of the above as well as manganese nodules, cobalt crusts, and marine polymetallic sulfides. In addition, precious coral has been produced by submersible off the coast of Taiwan (CCOP 1972); deposits of guano phosphate exist on small isolated islands in the Paracel and Spratly groups in the South China Sea (BSC 1980); the subterranean workings of onshore coal mines have been extended offshore in Japan; and the potential may exist for the development of geothermal resources in some areas (Emery 1987).

Figure 12.1 shows the location of coastal and marine mineral deposits. Those that are currently producing or have produced at some point in the past are represented by solid shapes (or partially solid shapes if only coastal or marine production has occurred). Those that are prospects are represented by open shapes. Using the classification developed by Emery and Noakes (1968) with some modifications, light-heavy minerals (specific gravity less than 6.8) are shown by circles (we include sand and gravel, silica sand, and phosphate); heavy-heavy minerals (specific gravity greater than 6.8) are shown by hexagonals; ferromanganese deposits (nodules or crusts) are represented by squares; and marine polymetallic sulfides are represented by triangles.

Using 1984 data based upon production of marine sand and gravel in Kyushu, Japan, marine tin production in Indonesia, and marine salt production in China, the countries surrounding the two China seas produce about one-third of a billion dollars worth of marine nonfuel minerals annually. Of course, the exploration for and production of marine nonfuel minerals pales in comparison to offshore hydrocarbon activity. In 1984, the countries surrounding the two China seas produced an estimated $11 billion in crude oil alone from marine wells. Yet this was only about 7% of the world's offshore crude production in that year. The East and South China seas are proportionately much more important in comparison to worldwide marine nonfuel activity. Taking only sand and gravel and tin production, the marine mines in these two seas produce almost one-fourth of Broadus' (1987) estimated $600 million annual revenues from all seabed nonfuel materials worldwide. (We note that the prices and outputs of these minerals may have changed substantially since 1984 and these comparisons should be used only as a general guide.)

Influence of the Monsoon

The climate of the two China seas ranges from tropical in the South China Sea to temperate in the East China Sea. The weather patterns for the entire region are dominated by a seasonal monsoon system. On a regional scale, the prevailing weather moves from the Asian landmass toward the warmer marine environment during the winter and from the China seas toward the warmer landmass in the summer, although there are certainly spatial and temporal variations as well as variable effects that depend upon local geographic and oceanographic conditions (Cheang 1987). Marine mining activities are affected by the sometimes high-energy weather conditions, particularly storm events, or "typhoons," associated with the monsoon. Marine tin dredges off the coast of Bangka Island, Indonesia (see Figure 12.8) are known to move from one side of the island to the other depending upon the prevailing seasonal monsoon (Wu 1987). As depicted in Figure 12.2, MacDonald (1971a) has indicated the hazards of offshore mining of heavy minerals in bars in the Formosa Strait on the western side of Taiwan, based upon the historical relative frequency of typhoons in the China seas.

Although high-energy weather conditions are usually thought to impose additional costs on marine mineral development, there may be beneficial effects from these conditions as well. Interestingly, it has been hypothesized that the China seas monsoon is an important environmental factor in the concentration of mineral sands. For example, there are reports that heavy mineral occurrences in the northern Gulf of Thailand are replenished with the annual monsoon (World Mining 1982), and some believe that one source of material may be from the gulf itself (UNDP 1987). Although investigations of ocean-climate

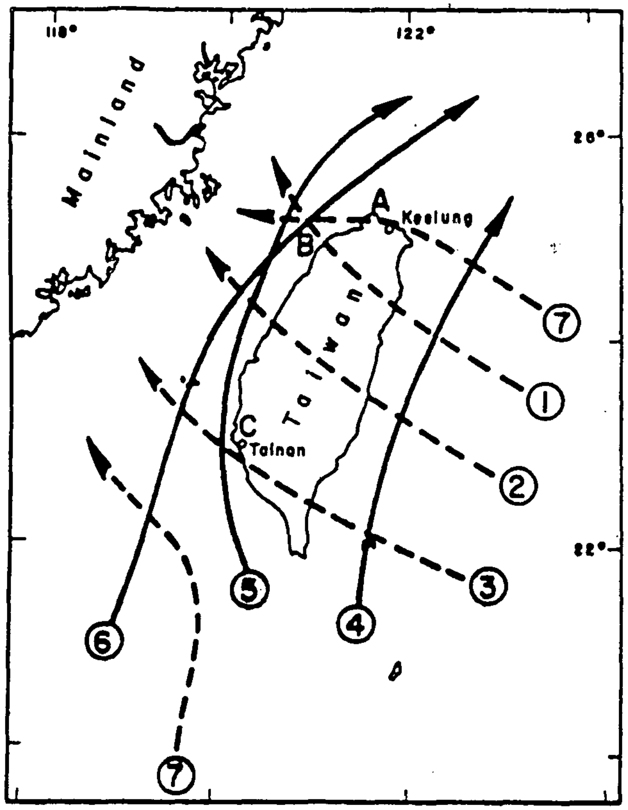

Figure 12.2 Probable typhoon paths across Taiwan. A and B are beach placers; C represents offshore heavy mineral sand bars. The historical relative frequencies of storm events associated with the storm paths are as follows: 1, 27%; 2, 11.4%; 3, 35.2%; 4, 11.9%; 5, 6.4%; 6, 5.0%; 7, 2.7%. *Source:* MacDonald 1971a.

systems in this region are receiving attention (Mao 1984; Kang 1984), we have no knowledge of whether their role as a driving force in the concentration of mineral sands has been examined closely.

Jurisdictions

Boundary determinations and jurisdictions in the two China seas have been well-studied but remain unsettled for the most part. Existing and potential boundaries have been mapped by Prescott and Morgan (1983) for the South China Sea and by Miles et al. (1982) for the East China Sea. Boundaries have

been settled only between Malaysia and Indonesia. The Philippines claims an archipelagic baseline extending well into the south China Sea. This baseline would be realized upon entry into force of the United Nations Convention on the Law of the Sea of 1982 (LOS Convention). The number of "potential" maritime boundaries in these two seas is large, and boundary variations have been described by Lee (1987) and Prescott (1985).

An interesting management scheme, known as the joint development zone, has been employed in two locations in the East and South China Seas. The larger zone is managed by Korea and Japan in the East China Sea, the smaller, by Thailand and Malaysia just south of the Gulf of Thailand. Although Valencia (1986) asserts that nonfuel mineral resources have considerable potential for influencing the establishment of these zones (citing the case of the Saudi-Sudanese Red Sea Commission), the China Sea zones have been established primarily for the joint development of hydrocarbon resources.

An important consideration here is that the countries that border the two China seas do not stand to gain much in terms of additional nonfuel mineral resource potential through expanded marine jurisdictional claims. This is because of the proximity to national coastlines of known nonfuel mineral resources (see Figure 12.1). One of the most important marine metal resources, the tin placers, exists in areas where maritime boundaries already have been decided between Indonesia and Malaysia. This is in contrast to the situation for hydrocarbon resources, which may extend considerably further offshore in both China seas (Masters 1985; Masters, Root, and Dietzman 1983).

An exception to this rule may be the guano phosphate deposits of isolated islands in the Paracel group, claimed by both Vietnam and China. Although these deposits clearly are not "subsea" deposits (CCOP 1968), we consider them here because of their remoteness and relative inaccessibility (traits that they share with subsea deposits). The production history and resource potential of some of these islands have been described by the British Sulphur Corporation (1980). McKelvey and Wang (1970) have identified similar deposits on some of the islands of the Spratly group, although resource information is sparse. Some or all of the Spratly islands are claimed by the Philippines, Malaysia, China (which has claimed all islands in the South China Sea), Taiwan, and Vietnam. Because of the limited resource base and production potential of phosphate rock in some of these countries and the need for phosphate in the manufacture of fertilizer, these insular guano deposits could become important in boundary delimitations, although their relative importance is unknown at this stage.

MINERAL ECONOMIES

Table 12.3 compares several general indicators that describe the mining sectors of the economies of the eight China Sea countries. These figures include fossil fuel minerals such as oil, natural gas, and coal as well as the nonfuels. In 1981,

Table 12.3
Importance of the Mining Sector for the China Sea Countries

Country	1981 GDP due to ining sector ($US × 10^6)	1970–1980 mining sector share of GDP (%)	Mining sector annual average growth rate 1960–1970 (%)	Mining sector annual average growth rate 1970–1981 (%)	1981 number of industrial workers (× 10^3)	Percent of industrial workers employed in mining sector[a]
China	26,395[b]	9[c]	10[d]	8[d]	61,890[e]	—
Korea	917	1	8	6	2015	9
Japan	6082[f]	1[f]	4	2	10,252	10
Philippines	867	2	8	6	1561	4
Malaysia	1904[f]	7[f]	—	4	415	8
Indonesia	20,532	21	8	7	963	6
Thailand	550	2	13	6	195[g]	10[g]
Vietnam	—	—	—	—	—	—
Total (average)	57,247	(6)	(9)	(6)	77,291	(8)
U.S.	128,000	3	4	2	19,210	9

[a]Defined as nonmetallic minerals (includes hydrocarbons) and basic metals.
[b]Gross industrial output value for the metallurgical industry in 1979 as reported in Xue (1982, 972).
[c]Using a total gross industrial output value of $295 × 10^9 in 1979 as reported in Xue (1982, 972).
[d]Annual average increase in value of gross industrial output index from 1965 to 1975 (in column for 1960–1970) and for 1975 to 1979 (in column for 1970–1981) as reported in Xue (1982, 972).
[e]Employment in state- and collectively owned nonservice sectors of the national economy and cities and towns for 1979 as reported in Xue (1982, 963–964).
[f]1980 data.
[g]1970 data.
Source: World Bank (1983).

China had the largest estimated gross domestic product (GDP) due to the mining sector at $26 billion. Indonesia followed closely with $20 billion, even though only 6% of its less than one million industrial workers are employed in the mining sector. In 1981, the mining sector GDP in Japan was approximately $6 billion, but the annual average growth rate of this sector in Japan was only 4% in 1960–1970 and 2% in 1970–1980. The average growth rate for the mining sector in all of these countries was 9% during 1960–1970 and 6% during 1970–1980. Both China and Thailand experienced the most rapid mining sector growth in the first period, while China and Indonesia experienced the most growth in the second period. In Indonesia, the mining sector contributed over one-fifth of GDP in 1981, but this was predominantly due to the production of hydrocarbons. In China and Malaysia, the mining sectors also were important, accounting for 9% and 7% of GDP, respectively. Compare these proportions to the other countries, where the mining sector is only 1% to 2% of GDP.

China. Although China is classified by the world bank as a "low income economy" country, its economic growth since 1980 has been spectacular. From 1981 to 1985, the growth of total industrial output averaged 11% annually. From 1980 to 1985, the total output of heavy industry, light industry, and the total value of trade had increased 56%, 76%, and 72% respectively. Chin (1986a,1) reports that China's output of minerals and metals is "diverse and large by world standards." Wang and Chin (1978) combine output for all minerals and place China among the world's top five producers of crude minerals in terms of value and in the top ten in terms of value-added for processed minerals. But China consumes most of its mineral production; and, based upon several general assumptions including a presumed limit to the "economic potential of its current mineral reserve base," Radetzki (1986) concludes that China's net import dependence in minerals is increasing. China's gold reserves rank fourth in the world; it is thought to contain about one-fifth of the world's titanium resources and is a major tin producer. Because of huge consumption for use in agriculture, China is a major importer of fertilizer materials.

Korea. Despite a surprising level of diversity in mineral products, Korea is a mineral resource-poor country, and most of its mineral deposits are small and difficult to work. Chin (1986b) reports that Korea is deficient in most mineral resources required for its manufacturing sector. The value-added from mineral processing in Korea is significantly greater than the value of mining output (Wang and Chin 1978). Except for tungsten, the mining of metals in Korea is "insignificant by world standards" (Chin 1985, 534). Limestone is the only major industrial mineral produced by Korea, with output at a level of about 30 million mt. annually, and the largest industrial mineral processing industry is for cement.

Japan. In 1985 in Japan, because of high production costs, depleting resources, and worldwide price slumps in most nonfuel minerals, as well as the relatively high value of the yen, most Japanese nonferrous mining companies were operating at a loss. Moreover, production had dropped off in the Japanese mineral-processing sector. Mine production increased, however, perhaps in anticipation of proposed low-interest emergency loans planned by MITI. Japan is the world's second largest steel producer but imports almost all (about 124 million mt. in 1985) of its iron ore. Japan is the world's largest producer of iodine and a major producer of fertilizer materials. Wu (1986a) states that a slowed growth in the Japanese economy from 1984 to 1985 was directly attributable to a slowed increase in the output of mining and manufacturing.

The Philippines. The Philippines is renowned for its geological diversity, and some of the most important production for its mining economy comes from chromium, cobalt, copper (ranking in the top 10 of world producers), nickel, and gold. Increased production costs, negative economic growth, and sluggish domestic consumption have led to recent production decreases in most minerals, with the exception of gold and nickel. According to the Chamber of Mines (an industry association), in 1984, 70% of the copper producers encountered negative investment returns, and the mining industry sought government tax relief. Stone, sand, and cement production declined due to cutbacks in industrial projects. The Bureau of Mines and Geosciences has begun to implement a five-year plan to promote small-scale mining, to expand data collection, and to improve the climate for investment (Wu 1986b).

Malaysia. The most important nonfuel mineral produced in Malaysia is tin, where, as the world's largest producer, output is almost one-fifth of total world production. Output of other nonfuel minerals produced in Malaysia, including bauxite, iron ore (once a significant world producer), and tungsten, recently have declined, but gold production has increased. Malaysia is also a major supplier of nitrogen fertilizers to the southeast Asian region. Malaysia played a leading role in the activities of the International Tin Council (a producer and consumer association) to support and control the price of tin through the use of a buffer stock. When this effort failed in October 1985, Malaysian production of tin dropped almost 10% from 1984 to 1986 because of a collapse in price. In Malaysia alone, 300 small "gravel-pumpers" were shut down, 29 of 58 dredges were idled, and labor was cut by 30% in the wake of the tin crisis (Wu 1986c). More recently, however, production has leveled off, and the tin price has begun to firm.

Indonesia. In Indonesia, the production of mineral fuels, particularly oil and natural gas, dominate the mining sector and account for almost 20% of the country's GDP. Indonesia is the world's third largest tin producer, with more than half of its output produced offshore, and the fifth largest nickel producer (Wu 1986d). Substantial interest in the exploration and development of gold deposits has been shown by Australian mining companies, and at least five new joint ventures have been formed to explore for gold. In 1985, Indonesia produced about 131,000 mt. of ironsands.

Thailand. The most important nonfuel mineral produced in Thailand as in Malaysia, is tin, and 60% of Thai tin output is from marine sources. Thailand is among the top 10 world producers of tin (fifth), tantalum (first), and fluorite, barite, and tungsten. However, Kinney (1986a) notes that Thailand's economy in general has diversified and that tin exports are not as important now as they were a decade ago. Thailand has the only known resources of potash in Southeast Asia, but their development is potentially costly.

Vietnam. The mineral economy of Vietnam is very underdeveloped. One of the most important minerals for its predominately agricultural economy is an apatite deposit (phosphate) at Lao Cai. Although this deposit is producing, it suffered a major setback when the infrastructure was destroyed during a border dispute in 1979. Clays, limestone, and gypsum are important for the domestic economy; and tin and coal are exported. The major trading partner is the Soviet Union, although Japan also trades with Vietnam. In 1985, the Ministry of Construction recommended the building of a commercial zircon extraction plant (Kinney 1986b). In 1985, crude oil was first produced from the White Tiger oilfield in the South China Sea, and although the potential of this offshore deposit has been highly touted, its production has been slowed by technical problems (Redden 1987).

HISTORY OF COASTAL AND MARINE NONFUEL MINERAL DEVELOPMENT

China is the oldest of the ancient nations in this region, and it has had a long history of marine resource development. Over 4000 years ago, China extracted salt from sea water and exploited heavy mineral placers from river and ocean beaches. The production of lime from "shell mounds" was another ancient use of minerals from a marine source. In the period between 7000 and 3000 years ago, China's coastal populations consumed shellfish as a food source, and leftover shell was piled mountain-high on the coast (the Chinese term for these mounds means "tomb of shell"). Subsequently, local people, particularly those along the coasts of Guangdong and Thejiang, excavated these shells to make lime. Glasby (1986) reports that calcium carbonate is still being recovered from shell beds found in relict beaches on the coast of China.

We examine the following coastal or nearshore minerals here: sea salt, tin placers, sand and gravel, ironsands, subsea coal extensions, titanium oxides and associated mineral placers, and gold placers. Deepsea minerals, such as manganese nodules, cobalt crusts, and marine polymetallic sulfide (MPS) deposits, have been located in the China seas as well. But these deepsea occurrences suffer from size, grade, and mineralogical deficiencies in addition to their relative inaccessibility due to depth (nodules) or lack of technological methods for detailed exploration (MPS) or recovery (cobalt crusts). We discuss deepsea minerals in a later section on prospecting activities.

Sea Salt

Almost 2500 years ago, during China's warring state (475–221 B.C.), sea-salt production along the coasts of the provinces of Shandong and Liaoning grew in scale. Sea-salt products supplied not only the local population but were transported to and sold in areas where the current provinces of Hebei and Henan are located. During the Tang Dynasty (618–907), China's coastal sea salt production was well developed. The coasts of Jianjxi and Shandong were the main areas of sea-salt production and contributed more than half of the national production of salt products. At that time, the main centers of demand for sea salt as a food additive and preservative were located in the inland provinces of Hunan, Henan, Jianjxi, and Guizhou. Before World War II, many centers of sea-salt production existed in the provinces of Guangdong, Fujian, Chejiang, Jianjxi, Shandong, Hebei, and Liaoning. Sea salt from these areas was produced, transported, and sold throughout 70% of China; and a small portion of sea-salt products was exported. A tax on sea salt during this period was the government's main income, and revenues from the collection of this tax were used to repay foreign debts.

During World War II, when much of the Chinese coast was occupied by the Japanese army, the sea-salt fields were destroyed. In order to recover the sea salt from China, the Japanese constructed their own salt fields and transported the salt product to Japan. After 1949, the government of China paid great attention to the production of sea salt. In the period 1949–1985, China set up new sea-salt fields totalling about 1.8 million mu (120,000 hectares) in area, thus increasing production to 8 million mt. per year. According to 1983 statistics, China's sea-salt fields now total 5.11 million mu (340,000 hectares). China is endowed with advantageous natural conditions for evaporating brine in the sun for salt, and solar evaporation is the process generally practiced in China's sea-salt production. The northern coasts of China are the most suitable, with low precipitation and large-volume evaporation. There are now 578 large- and medium-sized enterprises and more than 1000 small sea-salt enterprises. The Chinese sea-salt industry employs about 230,000 workers.

China produces salt from four types of sources: well salt, mineral salt, lake salt, and sea salt. The production of sea salt now accounts for over 75% of the nation's total output of raw salt. As one of the earliest countries to begin production of sea salt, China now ranks first in the world in output. Annual worldwide production of sea salt amounts to approximately 50 million mt., and China produces about 12 million mt. annually (almost full capacity and about 24% of world production). As Table 12.4 reveals, China is clearly the major producer of salt in the region. Most of Chinese salt is consumed in China; and, although China is a net exporter, only a small portion of salt is exported, primarily to Japan. Japan is heavily (84%) dependent upon imports of salt and is the second largest consumer of salt in the region. Australia and Mexico are the leading suppliers of salt to Japan. In fact, Australia is the leading exporter of salt to Korea, Japan, and the Philippines. The China Sea region accounts for 11% of the world production of salt, even though most of the China Sea countries produce under 1 million mt. of salt annually and the regional average net import reliance is 25%.

Apart from favorable natural conditions, there are several commercial considerations for why sea-salt production has developed in China. In comparison with the investment required for well-salt production, which averages over 250 RMB yuan per ton, an average investment in sea-salt production is roughly 150

Table 12.4
Output, Consumption, and Trade in the China Sea Countries
Salt, 1984

Country	Production (mt × 10^3)	Exports (mt × 10^3)	Imports (mt × 10^3)	Apparent consumption (mt × 10^3)	Net import reliance (%)	Change in production 1979–1984 (%)
China	14,450	777	1	13,674	netexp	8
Korea	518	2	758	1274	59	4
Japan	1200	7	6458	7657	84	10
Philippines	401	m	65	466	14	25
Malaysia	—	1	130	130	100	—
Indonesia	370	m	1	371	0	−48
Thailand	175	53	10	132	8	−1
Vietnam[a]	980	4	—	976	—	—
Regional total (average)	18,094	838	7423	24,680	(27)	
World share	11%					

Notes. The chemical industry uses almost half of the world's production of salt, primarily in the manufacture of chlorine and caustic soda.
netexp = net exporting country.
m = minor amount (less than 50 mt).
[a]1983 data from U.S. Bureau of Mines (1985).
Source: U.S. Bureau of Mines (1987).

RMB yuan. The average consumption of electricity is about 12 kW-hr. per ton in the case of Chinese sea-salt production, while that of well-salt production in the Sichuan Province is 70kw-hr. per ton. Because the coastal regions of China are densely inhabited and salt is a low-value commodity, salt production is concentrated in areas near consumers. The major industrial consumers, such as the chemical industry, are located mainly in the coastal regions as well. (Interestingly, this is in keeping with a national policy concerning the distribution of supply and demand in the Chinese economy).

Through the technological transformation of old salt fields and the addition of some new ones, the salt output of China could be doubled, reaching 27 million mt. by the year 2000. The varieties of salt produced may increase as well, particularly the varieties of refined salt and flavoring salt. Some materials, most notably "halide," are leftover after salt is recovered from seawater. The extraction of useful materials from halide as byproducts could reduce the unit costs of sea-salt production and protect the marine environment as well. From 1949 to 1982 in China, 52 sea-salt chemical plants were constructed. Output of salt chemical products from these plants is presently about 450,000 mt. per year, or an annual output value of 100 million yuan.

Sand and Gravel

Second to sea salt, the most important marine mining activity in the two China seas is the production of sand for use as a construction aggregate. Because sand and gravel is a high-volume, low-value commodity, transportation costs can be a large component of delivered cost. Thus, sand and gravel tend to be produced for local markets. Onshore sources of sand and gravel, particularly near high consumption centers such as cities, may be displaced because of higher-valued land uses. Furthermore, substitution, using crushed stone for example, or recycling may be unsuitable, technologically infeasible, or relatively costly. All of these factors contribute to the economic feasibility of marine sources of sand and gravel, especially those found in shallow, low-energy coastal environments near urban settings.

Although the production of marine aggregate probably occurs locally on a small scale in all of the countries that surround the China seas, the Japanese efforts are the most extensive and have reached the highest stage of industrial development. Balzer (1986) reports that 328 dredges are working offshore in Japan to produce marine sand, but 50% of the sites are located in the relatively low-energy environment of the Seto Inland Sea between Kyushu, Shikoku, and Honshu. However, the Geological Survey of Japan (1976) has estimated that 22% of Japanese marine-sand production is produced off Kyushu. By 1985, offshore production had risen from a level of 3-5% of the total to about 35% of the total. Tsurusaki (1986) has estimated that 54 million mt. of sand was produced from the Japanese offshore in 1983.

From 1960 through 1969, 10,000 mt. of "silica stone," a deposit of 99.5% silicon dioxide, was dredged in Omura Bay, Kyushu (Archer 1973). The deposit was approximately 8 m thick and was located under a mudcap at 150 m offshore and 20 m depth. The material was sold for use in the manufacture of ferrosilicon. Silica was produced from a beach deposit on the coast of Palawan Island in the Philippines in the mid-1970s until all coastal and marine production was banned for environmental reasons in that country. In China, coastal deposits of industrial sand exist on the coast from Longkou to Chengshan Jiao in the Shandong province and on the Xiamen coast in the Fujian province. In the late 1970s and early 1980s, high-quality seashore placers were discovered in Fujian. Among these seashore placers, the quartz-sand reserves have been estimated at about 1 billion mt. The quartz reserves of Dongshan Island rank first in Asia, with a SiO_2 content not less than 95%, but the extent to which these deposits have been exploited is unknown.

Tin Placers

Led by Malaysia, and followed closely by Indonesia and Thailand, the China sea region produces a full 50% of the world's tin each year (Table 12.5). These three countries are primarily tin exporters, with their tin output going primarily to Japan, the Netherlands, and the United States (sometimes via Singapore).

Table 12.5
Output, Consumption, and Trade in the China Sea Countries
Tin (metal), 1984

Country	Production (mt × 10^3)	Exports (mt × 10^3)	Imports (mt × 10^3)	Apparent consumption (mt × 10^3)	Net import reliance (%)	Change in production 1979–1984 (%)
China	15	4	m	11	netexp	7
Korea	m	m	2	2	100	−39
Japan	1	1	31	31	97	8
Philippines	—	—	1	1	100	—
Malaysia	47	40	1	8	netexp	−36
Indonesia	22	23	—	0	netexp	−21
Thailand	20	20	—	0	netexp	−39
Vietnam	—	—	—	—	—	—
Regional total (average)	105	88	35	53	(netexp)	
World share	50%					

Notes. The major end uses for tin are cans and containers, solder for making electrical connections or joining pipes, and in alloys. In the United States, about 20% of the apparent consumption of tin is accounted for by recycling.
netexp = net exporting country.
m = minor amount (less than 500 mt).
Source: U.S. bureau of Mines (1987).

Most notably Japan but also the Philippines and Korea are heavily dependent upon imports for their tin consumption. The Philippines imports tin from Indonesia, and Korea imports tin from Malaysia, Burma, and Indonesia. China is also a large producer of tin but is self-sufficient. Tin production during 1979 to 1984 declined in the big three producers, possibly due to production controls instituted by the International Tin Council.

About 17% of the annual world tin output is produced from marine deposits, and about 40% of this comes from deposits located off the coast of Indonesia. The first offshore tin mining in Indonesia took place in 1911 off the coast of the Island of Singkep (Sujitno 1977). Modern large-scale tin dredging is usually dated from the time when the *Bangka I* dredge initiated tin production in 1968. That same year, Billiton B.V., a Dutch company, reached agreement on a contract with the government of Indonesia to explore for tin in the South China Sea (Billiton 1980). In 1977, there were 12 large dredges operating near the islands of Bangka and Belitung. These dredges could operate down to 40 m and together had an annual capacity of 19 million cubic meters. In 1982, Indonesian marine tin production was estimated at 11,400 mt. or approximately 57% of the Indonesian tin production (Galtier 1984). Sujitno (1984) has estimated the marine resources to be 820,000 mt. and reserves to be a little less than half this amount. It should be noted that the reserve estimates were formulated prior to the substantial price drop in tin during early 1985. The effect of this price shift on the commercial viability of the marine tin operations is unknown. However, one of Billiton's major dredges operating in the Pulau Tujuh archipelago north of Bangka, the *Bima,* was sold in 1985 and is currently working a marine gold placer off the coast of Nome, Alaska (Ellis 1987). In 1986, Indonesia had planned to begin production from *Singkep I,* a new marine dredge, off Karimun and Kundar Islands.

Since its early beginnings in 1907, marine-tin production in Thailand now accounts for about 43% of the world's offshore marine-tin production. All of this production occurs on Thailand's west coast in the Andaman Sea. Resources have been estimated at 1.6 million mt. and seabed production is 12,000 mt. annually. Until 1974, the Union Carbide-owned Thailand Exploration and Mining Company (TEMCO) was the largest operator in Thailand's offshore. Its concessions were revoked in 1976 and the state-owned Offshore Mining Organization (OMO) awarded concessions to at least 11 mining concerns (including Billiton). Hirunruk and Netayaraksa (1984) report that four bucket dredges and four suction dredges are operating off Phuket, Phangnga, and Takua Pa. In addition, between 1500 and 2000 small suction boats dredge tin at depths of less than 20 m and recover about 100 mt. of tin concentrates daily (Koomsup 1983). It is unknown whether the illicit production of tin off the west coast of Thailand, which is smuggled around production controls, is included in the production figures found in Table 12.5. Although there has been some prospecting activity in the Gulf of Thailand, there is no production (Kulvanich 1984).

Although Charlier (1978) reports tin mining in the Malacca Straits off Malaysia's Selangor Estate, surveys conducted jointly by Malaysia, Indonesia, and others did not find significant tin occurrences there (CCOP 1981). However, there may be limited potential for the development of marine-tin deposits in the Malaysian portion of the Malacca Straits between Port Dickson and Muar (Yong 1979).

Ironsands

Ironsands, or magnetite deposits, have been produced onshore and offshore in both Japan and the Philippines. Tixeront (1978) of the French Bureau of Geological and Mineral Research (BRGM) has estimated that 100 million mt. of ironsands, grading 10% metal content, exist on the continental shelves of Japan and the Philippines. Because Philippine production was being sold to consumers in Japan, it is useful to examine production from both countries together. Beginning in the early 1960s, small quantities of ironsands were recovered from Ariake Bay on the south end of Kyushu Island by the Yawata Iron and Steel Corporation. The estimated reserves of the ironsand deposit were 40 million mt., grading 3–5% titaniferous magnetite. Rowland (1985) states that one deposit ranged up to 50 m in thickness and that "millions of tons" were produced, and Charlier (1978) states that, by 1963, two dredges were producing 30,000 mt. of ironsands each month. However, figures published by the Geological Survey of Japan, as shown in Table 12.6, show this to be the level of annual production (GSJ 1978). Because of the presence of strong currents, the operating costs were relatively high, and production was terminated in 1966 (Archer 1973). Other factors, including the relatively low grade, significant amounts of titanium dioxide as a gangue, and environmental considerations, also may have been involved. Two small marine deposits were worked for ironsands from 1967 to 1973 in Kagoshima Bay and Shimane (Archer 1973). It is not known whether these two deposits are still producing.

Rowland (1985) has reported on a bedded marine ironsand deposit (300–500

Table 12.6
East China Sea Marine and Coastal Ironsand Production

Year	Japanese marine or Philippines coastal production (mt × 10³)	Total production (mt × 10³)	Marine share of total production (%)	No. of marine or coastal operations
1955	—	967	—	—
1956	1	967	1	1
1957	1	1142	1	1
1958	4	955	1	1
1959	8	1357	1	1
1960	2	1751	1	2
1961	32	1712	2	4
1962	40	1443	3	4
1963[a]	33	1295	3	3
1964		1425		
1965	568			
1966				1
1967	360[b]			2
1968	450[b]			
1969	450[b]			
1970	600[b]			
1971	500			
1972	1289			4
1973	1530			4
1974	1340			3
1975	1473			2
1976	643	1329		
1977[c]		685		

[a]Japanese marine production terminated (Archer 1973).
[b]MacDonald (1971).
[c]Prohibition of Philippine coastal and marine production (CCOP 1977).
Source: Geological Survey of Japan (1968); CCOP Proceedings (1974).

m wide, 8 km long, and 6 m thick) off the northwest coast of Luzon Island at 10 m depth. Balzer (1986) has estimated the size of this deposit at 4.4 million mt. In 1975, the Filmag Mining Company was producing magnetite sands offshore near this location (CCOP 1976). During the late 1960s and early 1970s, about 500,000 mt. were produced annually and exported to Japan from a 38 million mt. coastal magnetite deposit discovered onshore by Filmag at Ilocos Sur near Santa Cruz. Smaller coastal magnetite deposits were mined for a short period of time in the early 1970s by the Long Beach Mining Company for INCO at Bataan (this output was exported to the United States) and the Anglo-Philippines Mining Company at Santo Tomas (CCOP 1975). In June of 1976, the Philippine Secretary of Natural Resources suspended beach mining operations ostensibly because of the pollution of drinking water supplies and farms, shoreline erosion, and the failure of reclamation efforts. Although some silica-sand deposits were allowed to be worked, a subsequent prohibition in October 1976 prohibited all beach mining operations (CCOP 1976). It is interesting to note that geologists from the Marine Mineral Resource Division of the Philippine Bureau of Mines were involved in resources assessment of the ironsand deposits in the years following the prohibition (CCOP 1978).

During the late 1950s and early 1960s, Taiwan was producing small amounts of magnetite from beach deposits along the coast north of Taipei to supply a local market (CCOP 1967).

Offshore Coal Extensions

In 1860, the first offshore coal field in Japan was developed near Gaodao. At present, there are 22 important coastal coal fields. At least 16 of these fields have subterranean offshore extensions. Five coastal coal fields with developed offshore extensions are located on the coast of Kyushu and the southwest tip of Honshu (Tokunaga 1969). In 1963, the annual output of coal products totalled about 10 million mt. This output increased to about 22 million mt. in the early 1980s but has since leveled off to about 20 million mt. per year. Charlier (1978) has reported that up to 38% of the total Japanese production of coal is recovered from subterranean offshore extensions.

Titanium Oxides and Associated Mineral Placers

In 1960 in Taiwan, a few retired servicemen attempted to produce heavy mineral sands from an offshore bar (known as South Tungshanchou) in the Formosa Strait; and, although some minerals were recovered with manual labor and no mechanical dredging, they were unable to find a market (CCOP 1968). Except for the ironsands described earlier, only very small amounts of light heavy minerals are produced in the China seas region. Elsewhere in this volume, Ju-chin Chen (Chapter 13) reports on the production of rare earths in 1988 off the coast of Taiwan by the Pacific Ocean Rare Earth Industry Corporation for an

end market in Japan. However, production of titanium and related minerals occurs predominantly from coastal onshore deposits. Figure 12.1 shows the location of onshore light heavy mineral placers (producing and prospective) in the two China seas and indicates those offshore areas that are likely prospects. A recent study completed by the Australian Bureau of Mineral Resources for the United Nations provides a comprehensive survey of mineral sands in the China seas (UNESCAP and BMRGG 1988).

In a recent study of 62 heavy mineral placer deposits from around the world, Attanasi and DeYoung (1987) found that those characteristics most useful for an understanding of commercial significance were deposit size and the grade of titanium oxide minerals. Neither combined grade of all heavy mineral constituents nor the grade of all titanium-bearing minerals was a useful indicator of commercial potential. Emery and Noakes (1968) have pointed out that, if significant deposits of light heavy minerals, such as the titanium oxides and other associated minerals including zircon and monazite, are to be found in a marine setting, they will occur off the high-grade onshore beach placers. However, they warn that, in general, because of the historical rate of sea-level changes and material transport factors, submerged deposits of light heavy minerals are likely to be less attractive from a commercial standpoint than either modern beach placers or raised beaches.

More than half of the world's production of titanium oxides comes from placer deposits (BGS 1985). As shown in Table 12.7, Malaysia and Japan are the leading producers of titanium oxides in the China Sea, but Japan is far and away the largest consumer, importing more than three times its own production. Malaysia is a net exporter and sends most of its titanium to Japan. Japan also imports substantially from Australia and Canada. Consumption in the other China Sea countries is not very large, except for China, where most of its consumption is accounted for by its own production. Production of coastal deposits of titanium oxides and associated minerals like zircon, monazite, or others occurs in China, Korea, Taiwan, Thailand, and Vietnam. Recently, Thailand has been investigating heavy mineral sands along the coast of the Gulf of Thailand. In 1985, SVP Associates, a Thai–West German joint venture started operations at a beach sand deposit at Prachuab Khiri Khan. In 1986, a Thai-Malaysian joint venture at Songkhla began producing ilmenite concentrates.

The development of seashore placers in China has taken place for at least several hundred years, and recently the investigation and development of some of these placers have moved from the beach into shallow water. As shown in Table 12.8, according to the results of marine geological investigations, going from north to south, there are at least 11 seashore placer zones situated on the coast of China. Preliminary investigations indicate that over 90% of China's seashore metal placer resources are concentrated along the coast of the Guangdong Province. Here 120 deposits reach the grade of industrial extraction, and there are 220 mining spots and 40 additional areas of heavy mineral anomalies. Most of China's seashore non-metal placer deposits are distributed

Table 12.7
Output, Consumption, and Trade in the China Sea Countries
Titanium Oxides, 1984

Country	Production (mt × 10^3)	Exports (mt × 10^3)	Imports (mt × 10^3)	Apparent consumption (mt × 10^3)	Net import reliance (%)	Change in production 1979–1984 (%)
China	110	2	4	112	2	—
Korea	m	2	47[a]	45	100	—
Japan	206	17	652[a]	841	76	16[b]
Philippines	—	—	2	2	100	—
Malaysia	235	224	1	12	netexp	18
Indonesia	—	—	12	12	100	—
Thailand	1	—	2	3	67	−31
Vietnam	m	—	1	1	100	—
Regional total (average)	552	245	721	1028	(46)	
World share	10%					

Notes. Ninety-five percent of titanium minerals, including rutile, anatase, ilmenite, and leucoxene, is used to make titanium dioxide pigments for paints, paper, plastics, and rubber. About 5% is used to manufacture titanium metal.
netexp = net exporting country.
m = minor amount (less than 500 mt).
[a]Oxides plus titanium ores and concentrates.
[b]Change from 1981 to 1984.
Source: U.S. Bureau of Mines (1987).

along the coast of Beihai in Guangxi Province. The beach and shallow waters of Beihai hold approximately one billion mt. of quartz sand resource. An equivalently sized resource of quartz sand exists at Jinjiang and at Putian in the Fujian Province.

It is difficult to evaluate the resource potential of seashore placer minerals in China because of the lack of data. Most placers lay exposed on beaches, but some are situated under 15 m of water, some are found at more than 30 m depth, and some lie hidden at very shallow depths, located on terraces in the coastal zone. The known placer bodies are preserved in the quartz layer of sand dikes and bars. The sizes of individual ore bodies are varied, the largest being 10 km^2, and their thickness is generally less than 10 m, but most of these placer deposits are of small or medium size.

The exploitation of China's seashore placer minerals has developed gradually, and existing production capacity is relatively small. However, total output of all minerals from seashore placers is about 230,000 mt. per year. Because the overall economy has risen rapidly in recent years, in the future, we expect demand for placer minerals in China could increase. According to the estimates of some Chinese government experts (Table 12.9), projected demand for placer

Table 12.8
Description of Seashore Placer Deposits on the Coast of China

1. *Zircon* from the Yalu River mouth around the Liaodong Bandao (peninsula) to the coast near Gaixian, in Liaoning Province.
2. *Zircon* and *monazite* on the coast of Hebei Province from Shanhaiguan to Beidaihe.
3. *Gold* on the coast from Hutoya ("Tigerhead") to Longkou, in Shandong Province.
4. *Zircon* and *magnetite* on the coast near Chengshan Jiao in Shandong Province. It has been discovered that on the Shandong Bandao (peninsula), metamorphic rock systems are extensively emerging, and both intrusive and mesozoic-cenozoic volcanic rock are developed. Exposed bedrock, which has undergone long-term weathering and denudation, has provided plentiful materials for the formation of seashore placers. Along the coast of this peninsula, four geomorphological terraces can be found at water depths of 5, 10, 15, and 25 m. From 1951 through 1965, during investigations of these terraces, more than 10 placer mineral deposits were discovered, including zircon, quartz, and building sand. There are seven placer deposits of zircon at Rongcheng and at Rizhao, an area of about 1000 km^2; reserves are about 10,000 mt at each location. Deposits of zircon, magnetite, and garnet were discovered in the south part of the Qundgas coast in 1973.
5. *Ilmenite* on the Shachen port coast, in Fujian Province.
6. *Zircon* and *monazite* in the western part of the Taiwan coast.
7. *Zircon* on the Yasping coast, Guangdong Province. Placer resources along the Guangdong coast, found in modern seashore sediments and lagoons, are composed mainly of zircon with the following other minerals: ilmenite, monazite, and magnetite, among others. In the 1950s, the Department of Geology of the Guangdong Province carried out investigations for seashore placers. It found valuable placer deposits, which subsequently were exploited.
8. *Cassiterite* on the coast between Lufeng to Yangjiang, Guangdong Province.
9. *Monazite* on the coast between Yangjiang to Wucuan, Guangdong Province. In the tidelands of the Guangdong coast, there are several placer deposits of zircon, ilmenite, and quartz, found in deposits with dimensions of about 1000 km^2 in area, with a thickness that varies from 0.01 m to 7 m. The zircon content of these deposits is more than 10 kg/m^3.
10. *Zircon, ilmenite,* and *monazite* in the eastern part of the coast of Hainan Island. From 1971 to 1978, the South China Sea Gëological Survey Command of the Ministry of Geology carried out comprehensive investigations in the areas of the Beibu Gulf, Hainan Island, the Leizhou Bandao, the western portion of Naneao Island, on 17 islands of the Xisha Archipelago, and on more than 40 islands along the Guangdong seashore. It discovered a variety of minerals, including zircon, ilmenite, monazite, phosphyttrite, rutile, and quartz, among others. In the eastern and southern parts of Hainan Island, there are a few zircon placer deposits. The dimensions of these deposits are slightly more than 0.1 km in length, 0.1 km in width, with a thickness of about several meters. Nearly 100 mineral deposits of industrial grade were discovered within the 15 m isobath, of which one first-class anomaly was as large as 300 km^2. An atlas of placer distribution in this area was compiled.
11. *Rutile, ilmenite,* and *zircon* in Quangxi Province. In the 1980s, over 20 seashore placer deposits were discovered along the Guangxi coast, including quartz, rutile, zircon, and ilmenite. Some individual minerals have met the requirements of industrial extraction, and some others have been found suitable for co-product or byproduct use. There are four placer deposits totaling about 1800 km^2, containing rutile, zircon, ilmenite, and monazite.

Table 12.9
Production and Projected Consumption of China Seashore Mineral Placers

Mineral	Output (mt × 10^3) 1983	Projection 1990	2000
Phosphyttrite	120	270	340
Ilmenite	100	110	160
Zircon	9	n.a.	n.a.
Monazite	1	2	2
Rutile	< 1	n.a.	n.a.
Quartz	n.a.	1050	2000
Moulding sand	n.a.	170	340
Total	230	1602	2842

minerals with seashore sources in China will be almost 3 million mt. Because of this projection, we expect that increasing emphasis may be placed on the exploration for and, potentially, the development of seashore placer resources.

Gold Placers

Worldwide, exploration for gold continues at a heady pace, and gold placers deposited in marine settings have been investigated in China, Korea, and the Philippines. In the Philippines, gold placers were recovered from the 1890s until 1955 in Paracale Bay in the southeastern part of the Island of Luzon (one of the earliest marine placer mining activities in the region). Before 1942, Korea had more than 30 alluvial and coastal area operations that exploited gold, annually producing 10,000 mt. of gold placer sands. Emery and Noakes (1968) explain that it is unlikely that gold and related minerals will move far out onto marine shelves from alluvial sources because of their high specific gravity (or if they do, the grain size will be so small as to be too costly to recover). But because of its great value, we expect that increasing attention will be paid to marine gold prospects.

Almost 10% of world gold production comes from the China Sea region, primarily from China, Japan, and the Philippines (Table 12.10). It should be noted, however, that substantial amounts of gold are recycled worldwide (Milling-Stanley and Green 1986). Japan is the leading consumer; and, although second only to China in gold production, Japan is still 82% reliant upon imports for its consumption. Most of Japanese gold imports come from Switzerland and the United Kingdom. China, again, is self-sufficient in gold and has increased its production 850% from 1979 to 1985. Malaysia, however, increased its production of gold nearly 1400% when it began recovering gold as a by-product of copper production at the Mamut Mine in Sabah Province in 1980. Only the Philippines is a net exporter of gold, sending most of it to Japan. Both

Thailand and Vietnam are completely dependent upon foreign sources for gold, but their consumption is believed to be quite small.

PROSPECTING

The exploration for marine minerals is conducted by individual governments or private firms from almost all of the 13 economic/political entities in this region, with the possible exception of Cambodia. Localized marine prospecting efforts have occurred in discrete areas of the two China seas since the turn of the century. The most notable of these efforts concerns the proving-out of marine cassiterite deposits off the Indonesian tin islands in the South China Sea. In 1966, four China Sea countries—Taiwan, Japan, Korea, and the Philippines—were the first to form an international body, the Coordinating Committee for Joint Prospecting of Asian Offshore Areas (CCOP), sanctioned by the United Nations, solely for the purpose of joint prospecting efforts for marine hydrocarbon and nonfuel minerals. (CCOP is an organ of the United Nations Economic Commission for Asia and the Pacific [ESCAP, formerly ECAFE].) Taiwan was

Table 12.10
Output, Consumption, and Trade in the China Sea Countries
Gold, 1984

Country	Production (× 10^3)	Exports (× 10^3)	Imports (× 10^3)	Apparent consumption (× 10^3)	Net import reliance (%)	Change in production 1979–1984 (%)
China	1900	5	8	1903	0	850
Korea	79	8	63	134	41	229
Japan	1342	204	6215	7353	82	2
Philippines	787	295	10	502	netexp	47
Malaysia	90	54	237	273	67	1400[a]
Indonesia	79	—	48	127	38	39
Thailand	—	m	76	76	100	—
Vietnam	—	—	m	m	100	—
Regioal total (average)	4277	566	6657	10,368	(59)	
World share	9					

Notes. Almost 50% of all gold produced is used in jewelry and the arts; electronic uses account for another 35%. More than one-third of all the gold that has ever been produced (1.1 billion troy ounces) is held in national government vaults as a monetary metal.

netexp = net exporting country.

m = minor amount (less than 500 mt).

Quantities in units of 10^3 troy ounces.

[a]In 1980, recovery of gold as a coproduct with copper was initiated at the Mamut Mine in Sabah. This output now accounts for about 87% of Malaysian gold production.

Source: U.S. Bureau of Mines (1987).

a member until 1971, when the United Nations formally recognized the People's Republic of China (China became active in CCOP in the late 1970s). Two of the major contributions of CCOP have been the loans of equipment and technical expertise to member countries so that they might gain an increased understanding of their marine mineral stocks and the compilation of information collected in prospecting efforts. Private firms and government agencies from developed countries such as the Netherlands, the Soviet Union, Germany, the United States, the United Kingdom, Canada, and France also contribute significantly to investigations in this area. The early efforts of Japan in offshore prospecting served as a goal for the nascent organization:

> The Committee noted with satisfaction that a decade of offshore exploration in Japan (1956–1965) had resulted in the discovery of oil and gas fields, extensions of coal fields beneath the sea, and concentrations of ironsands, all of which were being commercially exploited; it expressed the hope that in the case of the other countries participating in the first meeting of the Committee, in which relatively little attention had yet been paid to offshore mineral prospects in general, a similar result might be achieved, perhaps even in a shorter period of time (CCOP 1966).

CCOP has grown to include Cambodia, China, Indonesia, Malaysia, Papua New Guinea, Singapore, Thailand, and Vietnam as members and Australia, Germany, France, the Netherlands, the Soviet Union, the United Kingdom, and the United States as "cooperating countries." Its annual budget is now nearly $1 million. CCOP has been a success, not only because of its capacity to arrange shared prospecting efforts between member countries (and also between members and nonmembers) but also because of its annual meetings, which serve as a forum of exchange, its training efforts, and its documentation of the investigations and research that have been conducted in the area. Indeed, this latter function may be its most important role; if left unrecorded, the results of investigatory efforts and the benefits of reduced geologic uncertainty could have been lost (cf. Broadman 1985).

Specific data on the size of investments and spending on marine nonfuel minerals are sparse or unavailable for the countries that border the China seas. Even budgets for oceanographic research are difficult to obtain. UNESCO (1984) has published broad indicators of total research and development (R&D) for several countries, and these indicators are summarized in Table 12.11 for the China Sea countries. Care should be taken in examining these figures because of the variable nature and consistency of individual country reports of R&D expenditures or manpower. At $26 million in 1982, Japan is the leading R&D spender, funding more than two-and-a-half times as much as China. Of the countries with available data, the Japanese government contributes only 26% to its R&D effort, while the Chinese and Vietnamese governments contribute 100%. Japan claims to have over 37 million "potential scientists, engineers, and technicians" (PSET), or almost one in three Japanese workers falls within

Table 12.11
General Indicators of R&D in the China Sea Countries

Country	1982 R&D expenditure ($US × 10^3)	1982 R&D compared to GNP (%)	1982 R&D funded by public sources (%)	Share of 1982 R&D in earth, seas, and climate research (%)	"PSET" potential[a] scientists, engineers, technicians (× 10^3)	PSET per 1000 population
China	9902[b]	4	100	—	5296	6
Korea	627	1	41	—	2026	52
Japan	26,299	3	26	2	37,050[c]	314
Philippines	61	1	77	4	1084	29
Malaysia	—	—	—	—	35	4
Indonesia	445	1	—	—	1218	9
Thailand	1	1	—	—	68	2
Vietnam	11	1	100	—	25	1
Total (average)	37,346	(2)	(69)	(3)	46,802	417
U.S.	82,223	3	48	1	3167[c]	14

[a]UNESCO defines *potential manpower* in these fields as the number of qualified persons, regardless of whether or not they are employed in "economic activity."
[b]1980 data reported in Xue (1982).
[c]Eighty-one percent of the Japanese total are technicians. Care should be taken in examining these figures because each country may account for classes of employment or R&D budgets idiosyncratically. For example, the United States does not report "technicians." It is interesting to note that, excluding technicians, Japan reports about 7 million scientists and engineers, the United States reports about 3 million, and the Soviet Union reports about 13 million.
Source: UNESCO (1984).

this category. This contrasts sharply with the other countries in the region, such as Korea with only one in 20 workers classified as a PSET or China with only six out of every 1000 workers.

In this section we examine prospecting activity in marine nonfuel minerals. We separate the important nearshore prospects from the deepsea minerals because of the relatively greater commercial potential of the former. Broad-scale marine geophysical work in this area has been compiled by Hayes (1978) in *A Geophysical Atlas of the East and Southeast Asian Seas* as part of the Southeast Asia Study of Tectonics and Resources Program (SEATAR) of the International Decade for Ocean Exploration (IDOE). More detailed nearshore geophysical work has been conducted by individual countries, cooperative governmental efforts, or by private enterprises. The Circum Pacific Council for Mineral and Energy Resources has plans to publish their map of the nonfuel mineral resources of the Northwest Pacific quadrant (which includes the China seas) in 1988 (Stewart 1987).

China's Organization and Policy

In China, the following ministries together are responsible for mineral prospecting activities: Geology and Mineral Resources, Metallurgical Industry, Oil, Chemical Industry, and Building Materials. Historically, each ministry has been responsible for prospecting for those minerals of importance to their economic sectors. For example, the Institute of Marine Geology of the Ministry of Geology and Mineral Resources is responsible for the general survey of marine minerals, the Metallurgical Ministry is responsible for the investigation of marine metals, the Building Materials Ministry is responsible for the prospecting and assessment of seabed quartz and building sand, and the Ministry of Oil is responsible for marine hydrocarbon exploration. Each ministry determines its scale of activity and required funding levels, but the annual budgets by ministry are not publicly available.

The Mineral Resources Law of China was formulated on March 19, 1986 and entered into force on December 1, 1987. The main purposes of this law are to improve prospecting, development, and conservation of minerals. Until this law came into effect, there was no unified planning for mineral prospecting, and sporadic reports of mineral prospecting activities were thought to have unintended effects on the national economy. In order to correct this, a plan for the unified management of government mineral prospecting is now being implemented, and it will include a unified registration system for mineral prospecting. Any entity that wants to prospect must register, and the registration must be approved by the Ministry of Geology and Mineral Resources before a prospecting license is granted.

The Chinese institutions most involved in research on marine minerals (Zhang 1984) are

- Ministry of Geology and Mineral Resources:
  —Institute of Marine Geology in Qingdao, Shandong Submarine Mineral Resources Division
  —Geological Survey Bureau in Shanghai, Zhejiang
  —South China Sea Geological Survey at Guangzhou, Guangdong
- Institute of Oceanology, Academic Sinica in Qingdao, Shandong:
  —Department of Marine Geology
- Tongji University in Shanghai, Zhejiang:
  —Department of Marine Geology
  —Institute of Marine Geology
- Nanjing University in Nanjing, Jiangsu:
  —Division of Marine Geomorphology and Sedimentology Research

Other research organizations with broad interests in oceanography and marine geology include the National Bureau of Oceanography in Beijing and some branches of the State Oceanic Administration.

Coastal and Nearshore Efforts

China. Other than sea salt, which will not be treated here, most prospecting efforts for marine minerals in China have focused on the heavy mineral placers, including titanium oxides, zircon, monazite, and tin. However, during 1979 and 1980, the Chinese Institute for Marine Geology worked with Columbia University's Lamont–Doherty Geological Observatory in a joint survey of the South China Sea basin. On this survey, general oceanographic measurements were taken, including bathymetry, seismics, and other geophysical sampling. Seven cores were made, and some manganese nodules were recovered by trawl (CCOP 1982).

There have been several hundred years of investigation into seashore placers in China, but there were no records kept for most of this period. After 1949, coastal provinces initiated government-sponsored investigations and several important placer deposits were found. For example, the Guangdong Geological Bureau, on the basis of numerous investigations and studies of seashore heavy minerals, discovered several economic placers. The Institute of Oceanology, Academica Sinica, has studied the geochemistry of sediments in the East China Sea (Zhao 1983) and has examined the distribution pattern of light heavy and heavy heavy minerals in the Bohai Gulf (Chen et al. 1982). Recent compilations of geological surveys have appeared in two geological maps: the "China Littoral Placer Distribution Map" and the "Minerogenetic Condition and Prospective Area Map for Littoral Placers in Shandong Peninsula" (Feng 1986).

There are now 13 seashore placer zones (including industrial sand deposits) located along the coast of China and about 120 known deposits. These placers are preserved in the quartz layer of sand dikes and bars. The sizes of individual deposits vary, the largest being 10 km^2, and their thickness is generally less than 10 m. The economic minerals are mainly zircon, ilmenite, monazite, (phosphyttrite), and rutile; and both gold and diamond placers have been discovered. The Chinese delegation to CCOP reported in 1984 that state mining companies were mining seven coastal placer deposits and that local communities were mining 15 coastal placers. In the early 1970s, coincident with the extension of seashore placer prospecting from the coast into shallow water, over 40 offshore areas of promising heavy mineral anomalies were detected. None of these deposits is yet in production.

Two more recent Chinese efforts deserve mention here. In 1984, the Institute of Marine Geology found gold indications in Liazhou Bay in northeastern Shandong. The bay is considered very promising for placer gold because about 200 gold deposits have been identified in the surrounding area. The institute has conducted shallow seismic profiling, sampled the seabed, and drilled eight boreholes. The final results of this prospecting effort have not yet been released (CCOP 1984). During the same time, and with the assistance of CCOP specialists and equipment, a survey of marine tin in the Honghai Gulf was completed. after preliminary geophysical work in 1983, cassiterite was discovered in a sand

and gravel bed about 20 m below the surface of the seabed (or 100 m below the ocean surface). Plans have been made to conduct geological and geophysical surveys of monazite and xenotime in Guangdong, and the possibility of exploring for littoral zircon and gold placers in several coastal provinces was being discussed (Feng 1986).

Korea. In Korea, much of the prospecting efforts for marine resources has been directed at placers, particularly silica sands and heavy minerals. Moreover, although there has been some sampling activity for resource assessment purposes, the Korean efforts have focused on coastal deposits. Beginning in 1957, the Geological Survey of Korea (GSK) initiated a series of investigations of Korea's major placer deposits. Thirty such deposits were investigated from 1957 through 1967, and Won (1968) reports mineral type, grade, and resource size estimates. As depicted by Figure 12.3, most of these deposits are alluvial, aeolian, or, in any case, far from a coastal or marine setting and represent only about 30% of the estimated number of placer deposits in Korea. Won stated that these deposits were of marginal grade and at that time undeveloped, although GSK (1969) describes 11 of these deposits in greater detail and documents some earlier production.

Beginning in 1969, GSK began to investigate coastal and marine placers, an effort that was continued by the Korean Institute of Geology and Mineral Resources (KIGAM) from 1974 through 1979 and by the Korean Institute of Energy and Resources (KIER) from 1982 to the present. These research efforts, as reported in the annual CCOP proceedings volumes, have been summarized in Table 12.12 and located on the map in Figure 12.3. Placer deposits located on the east coast were examined first, along with two alluvial gold prospects south of Seoul at Pyongtaek (estimated resource of 605 kg gold metal) and Yesan (1327 kg) (GSK 1971). In the early 1970s, GSK explored some heavy mineral sand deposits on the west coast, such as the Mohang and Kusapo beaches, but then switched to the examination of silica sand deposits. In 1977, a sand and gravel bar was mapped in Kyunggi Bay, where it could be used for construction purposes at Inchon (Chun and Sung 1979). From 1974 to the present, over 66 million mt. of silica sand was assessed on beaches and small islands of the southwestern and southern coasts of Korea.

Korea's center of oceanographic research is the Korean Ocean Research and Development institute (KORDI), located at Ansan, southwest of Seoul on the Yellow Sea. Since 1973, KORDI has been conducting oceanographic research, including research in marine geology. Both KORDI and KIER have been involved in broad-scale geophysical surveys of the offshore areas, most recently in the southern offshore. However, the bulk of mineral investigations have been conducted by KIER. In late 1986, the Asian Development Bank approved a $53 million loan (its entire loan program for that year) to Korea's Ministry of Education for a marine sciences education project (ADB 1986). The loan has a 20-year payback period beginning in 1990 at a variable interest rate. The loan

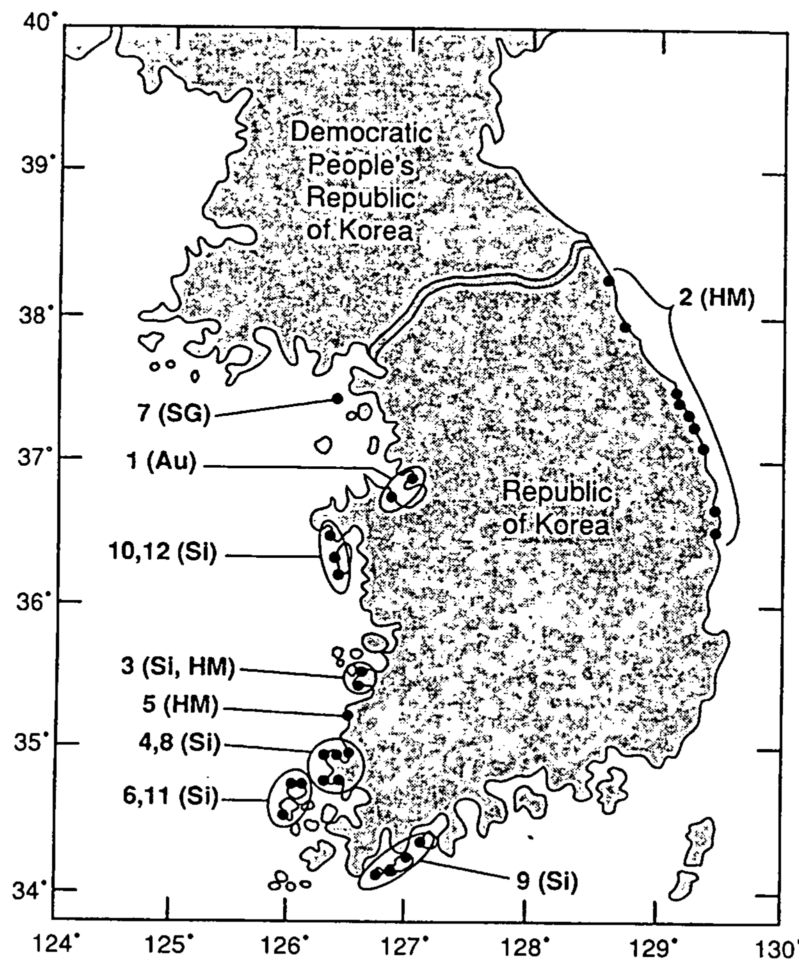

Figure 12.3 Coastal and marine placer deposits in South Korea. *Sources:* GSK 1968 and CCOP Proceedings.

covers about 58% of the project, which, among other things, is intended to fund the construction of an oceanographic research vessel and seven training vessels and establish an oceanographic research institute. The project was completed in 1990 and is expected to benefit 12,000 students annually. Although there has been little specific mention of the research areas most likely to benefit from this investment, we expect that Korea's ability to conduct oceanographic research and to investigate mineral resource potential will be enhanced by this project.

Table 12.12
Korean Coastal and Marine Nonfuel Mineral Resource Assessment

Date	Agency	Name	Location	mt × 10^3	Mineral
1969	GSK	Pyongtaek	37°N, 127°E	605 kg	Gold
		Ye San	36°40′N, 126°50′E	1327 kg	Gold
		Mukho	37°30′N, 129°10′E	149	Heavy minerals
1969	GSK	East coast beaches	36°30′–38°20′N,		
		Ogkae	128°20′–129°30′E	3990	Heavy minerals
		Kunduk		5990	Heavy minerals
		Bugu		2280	Heavy minerals
		Pyonghae		1680	Heavy minerals
		Younghae		1780	Heavy minerals
		Sonyang		3840	Heavy minerals
		Jukwang		1030	Heavy minerals
1974	KIGAM	Mohang Beach	35°40′N, 126°30′E	2	Heavy minerals
		Kosapo Beach		11,125	Silica sand
1975	KIGAM	Imjado Is.	35°5′N, 126°05′E	11,960	Silica sand
1975	KIGAM	Kusipo area	35°25′N, 126°25′E	2080	Silica sand
				45	Heavy minerals
1976–1978	KIGAM	Juan Is.	34°30′–35′N,	20,700	Silica sand
		Bigum Is.	125°45′E		
		Uei Is.			
		Docho Is.			
1977	KIGAM	Kyunggi Bay	37°20′N, 126°30′E	283,500	Sand and gravel
1979	KIGAM	Aphae Is.	35°N, 126°25′E		
		Jeung Is.		10,000	Silica sand
		Muan Coast			
1979	KIGAM	Sinji Is.	34°15′–30′N,	2000	Silica sand
		Saengil Is.	126°45′–127°15′E	7	Silica sand
		Pyeongil Is.			Silica sand
		Geogeum Is.			Silica sand
1982	KIER	Nammeyon Is.	36°20′–40′N,		Silica sand
		Anmyeon Is.	126°15′–30′E	8000	Silica sand
		Weonsan Is.			Silica sand
1984	KIER	Gwanmae Is.	34°30′N, 126°E		Silica sand
1985	KIER	Anmyeon Is.	36°25′N, 126°20′E		Silica sand

Source: CCOP Proceedings (various years).

Japan. Annual reports provided by Geological Survey of Japan (GSJ) to CCOP provide a thorough record of prospecting activity by government agencies and private firms in Japan for marine nonfuel minerals during the past 30 years (Table 12.13 and Figure 12.4). There are four sections of GSJ's Department of Marine Geology, including one that deals specifically with marine

mineral resources. Japan has bilateral cooperative agreements in the field of marine mineral resources with the United States, France, and the former West Germany. For the United States and Japan, this bilateral cooperation takes place primarily through the Marine Mining Panel of the United States/Japan Program of Natural Resources (Rogich 1986).

From 1953 through 1965, the GSJ, with encouragement from the Japanese Ministry of International Trade and Industry (MITI), conducted geophysical research (magnetometer and sonic surveys) primarily for ironsand deposits. In the mid-1970s, it became apparent that the nearshore mining of ironsands or sand and gravel deposits had an adverse environmental effect on the adjacent shoreline, and GSJ began looking in deeper offshore areas for sand and gravel deposits. From 1975 until 1979, GSJ chartered a vessel to conduct sample surveys of the Japanese offshore. Since 1981, however, GSJ has been analyzing samples collected through their Continental Margin Mapping Program (discussed below). Figure 12.4 displays the areas that have been investigated for marine sand and gravel, including the most recent work (1985) around southern Kyushu.

Beginning at a modest level in 1969, a five-year program to study and map the continental shelves and slope of Japan was initiated in 1974. Using the *RV Hakurei Maru,* GSJ extended this work during a second five-year program for 1979 through 1983. Presently, GSJ is involved in a third five-year program to prepare marine geological and sedimentological maps, and these investigations are being published in a geological map series. As seen in Figure 12.5, the areas offshore Kyushu in the East China Sea were among the first to be surveyed in 1984 and 1985, and two areas covering the west coast of Kyushu in the East China Sea already have been published (GSJ 1987).

Table 12.13
Japanese Marine Nonfuel Mineral Prospecting in the East China Sea: 1956 to 1976

Year	Mineral target	Prospecting method	Prospector	Location
1956	Ironsands	Magnetic	Mitsui K.K. Co.	Kyushu
1960	Ironsands	Magnetic	GSJ	Kyushu
1961	Ironsands	Magnetic	Kokudo K.C. Co.	Kyushu
1962	Silica sand	Sonic	GSJ	Kyushu
1963	Silica sand	Sonic	GSJ	Kyushu
1968	Quartzite	Sonic	Kyushu Resources Development Co.	Omura Bay, Kyushu
1969	Ironsands	Magnetic	Nippon Butsuri Tanko Co. Ltd.	Kakogawa, Kyushu
1975	Sand and gravel	Sonic/sampling	GSJ	Genkainda, Kyushu
1976	Sand and gravel	Sonic/sampling	GSJ	Gotonada, Kyushu

Source: CCOP Proceedings (various years).

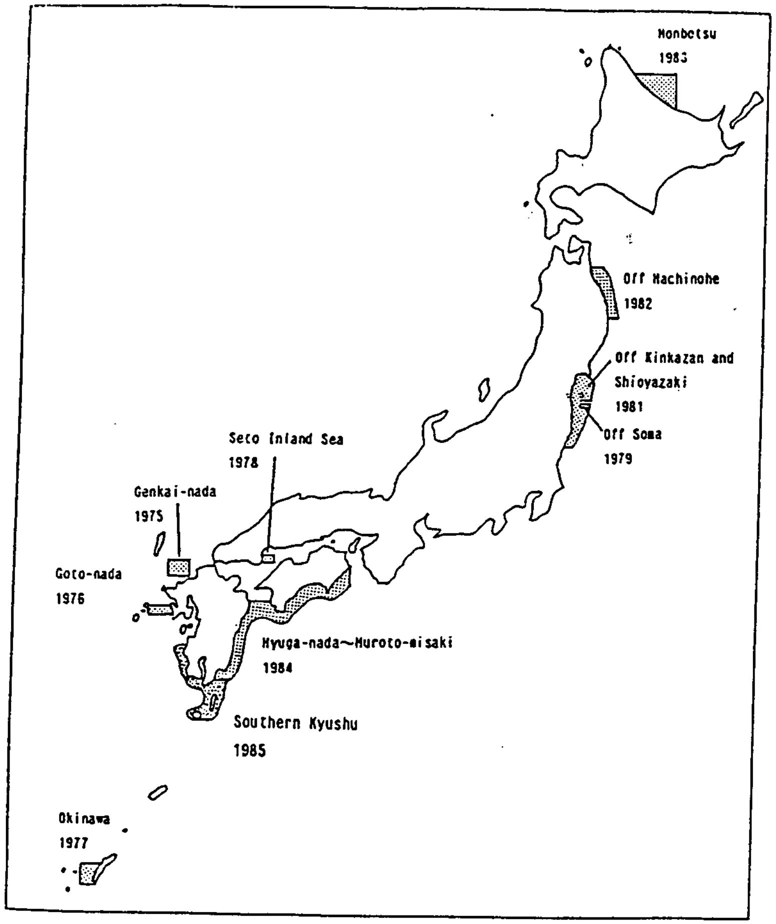

Figure 12.4 Areas surveyed for sand and gravel resources by the Geological Survey of Japan. *Source:* GSJ 1987.

The Philippines. The search for marine nonfuel minerals in the Philippines has focused on beach sand deposits, primarily ironsands but also chromite, gold, and silica. During 1969 to 1970, the Anglo-Philippine Oil and Mining Corporation studied a marine magnetite sand deposit in Damortis Bay on the eastern side of Lingayen Bay. Here they mapped and sampled a deposit estimated at more than 7 million mt., grading just over 9% magnetite (Caguiat

1972). The deposit is located offshore of the La Union Province, where Filmag had been working a beach magnetite deposit.

We have mentioned already the exploitation of magnetite sands from the beach deposits on the west coast of Luzon Island from 1967 until 1976. Beginning in 1977, the Philippine government conducted subsequent investigations on magnetite, chromite, and silica sands in the same area, on Palawan Island, and the eastern Philippines (CCOP 1979). In 1978 and 1979, the Philippine

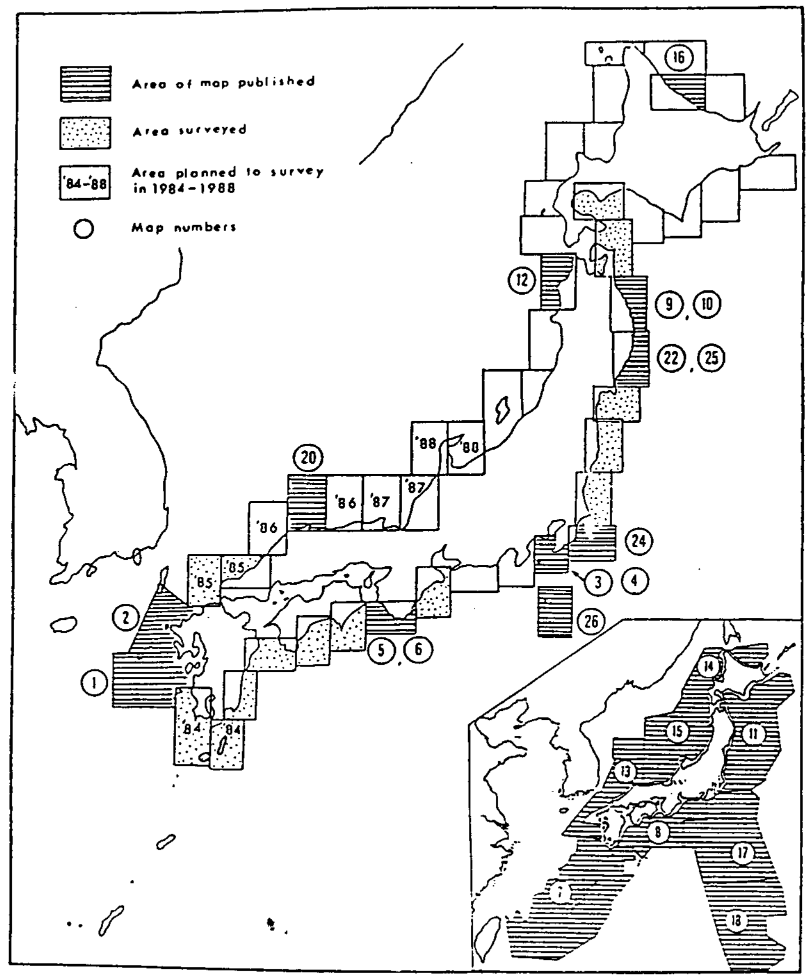

Figure 12.5 Japan's continental margin mapping program. *Source:* GSJ 1987.

Bureau of Mines and Geosciences, Marine Mineral Resources Division took additional samples (about half coastal and half marine) along the northwest coast of Luzon. Analysis of the samples revealed a deposit of 1.7 million mt. (onshore and offshore) north of the Lingayen Gulf and another deposit of 3.4 million mt. south of the gulf in the area of the old Filmag works (CCOP 1980, 1981). At the northwestern end of Palawan Island, coastal and marine heavy minerals bearing uranium, thorium, and rare earths were discovered but not in commercial grades or amounts (Dela Cruz and Tulay 1984).

In 1984, the Philippines and Japan agreed to cooperate in carrying out marine geological and geophysical surveys of the Philippine coastal waters; and, in the following year, some lines were run off the coast of Luzon. The geophysical data is processed by the Philippine National Oil Corporation.

Malaysia. In the late 1960s, McMahon and Partners, a mining consultant firm, conducted a sampling survey of the east coast of peninsular Malaysia and found poor occurrences of heavy minerals (Yong and Yap 1975). Subsequently, marine geophysical and sampling investigations conducted by the Royal Society of London (Dash et al. 1972; Dash 1971) during the early 1970s off the east coast of peninsular Malaysia found only minor amounts of cassiterite. It is not known whether the marine nonfuel mineral potential of the eastern states of Sarawac and Sabah (or of the country of Brunei) have been investigated.

In 1976, with financial assistance from West Germany and with technical assistance from CCOP, the Geological Survey of West Germany, the Geological Survey of Korea, and the Indonesian state tin enterprise (P.T. Timah), the Geological Survey Department of Malaysia initiated survey work on heavy mineral occurrences in the Malacca Straits (Yong 1977) at an estimated cost of $3 million (Balzer 1986). Some promising cassiterite samples were recovered during this survey (Figure 12.6). In 1979, Malaysia conducted a joint follow-up survey with the participation of West Germany and CCOP. Although most of the 139 grabs and 46 cores revealed tin occurrences with some high-grade samples, preliminary investigations found low tin values in most cases (CCOP 1981).

Indonesia. There has been considerable investigation into placer mineral deposits, including tin, titanium oxides, magnetite, monazite, gold, platinum, and diamond along the many coasts of Indonesia, but most of this research has concentrated in areas outside of the South China Sea (Figure 12.7). Some indications of rutile and zircon exist along the western coast of Kalimantan; however, these are believed to be of low grade (CCOP 1972). In 1982, the Canadian government lent its technical support to Indonesia for the conduct of geophysical surveys for tin, gold, and magnetite deposits (Balzer 1986). A preliminary map of metallogenic provinces showing all known mineral deposits in Indonesia was drafted in 1976 at the Bandung Institute of Technology (Asikin 1977). By far the most extensive research and prospecting has taken place in the

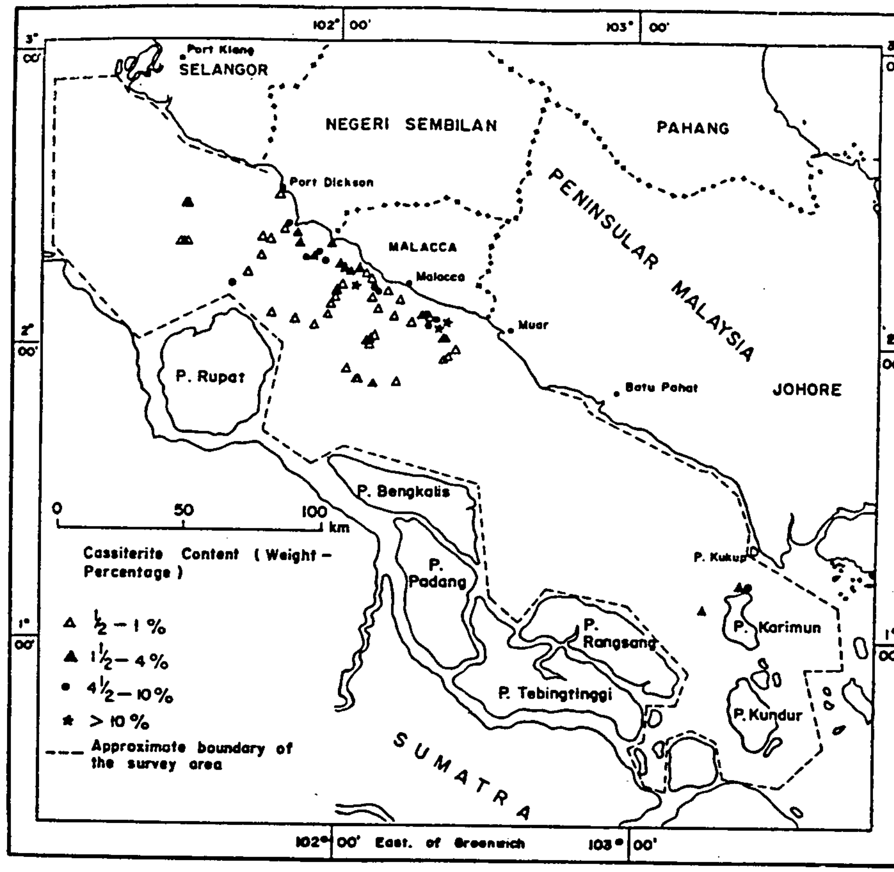

Figure 12.6 Locations of samples for marine tin (cassiterite) in the Malacca Strait between Malaysia and Indonesia. *Source:* Yong 1979.

Riau Archipelago, the Pulau Tuju Archipelago, and Belitung and Bangka Islands (also known as the Indoneisan Tin Islands) to the east of Sumatra in the southern extension of the South China Sea.

The mining of tin onshore in Indonesia has taken place since the first decade of the eighteenth century, and the first marine tin dredging occurred close to the coast of Singkep Island in 1911 (Sujitno 1977). Sporadic nearshore drilling took place around the Riau Islands at the turn of the twentieth century, but it wasn't until 1958 when early acoustical profiles of marine sediments first indicated considerable potential for offshore tin resources (Sujitno 1975). Even as the

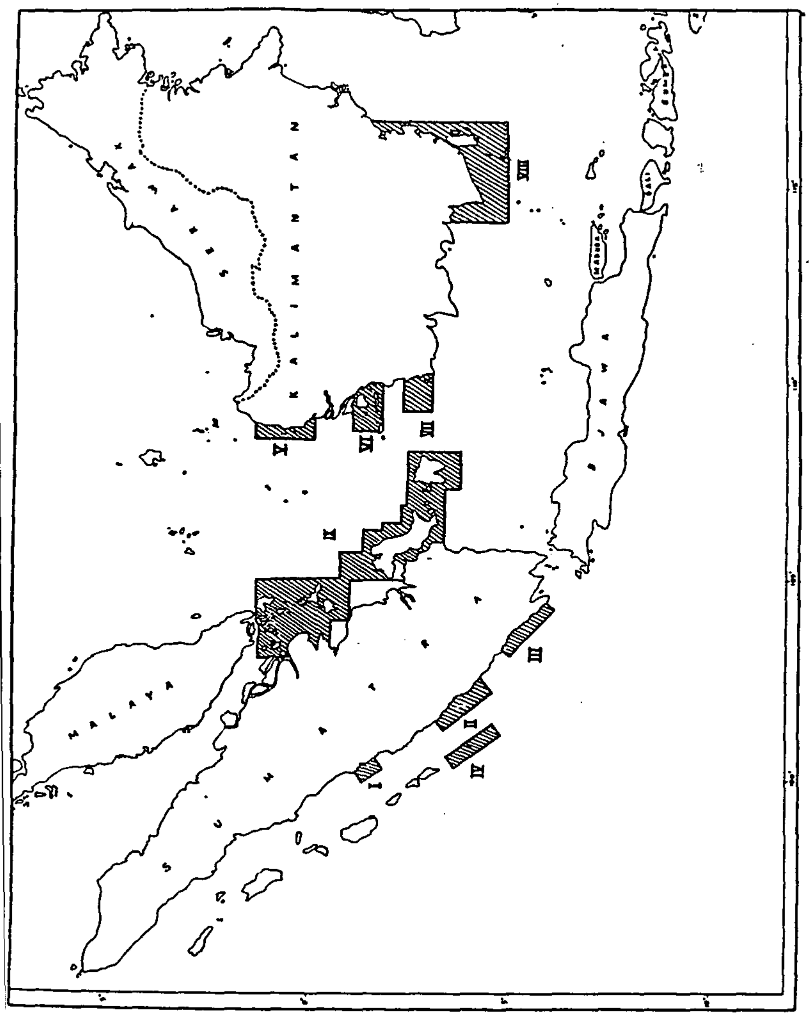

Figure 12.7 Areas of prospective offshore minerals in Indonesia. I, II, III = gold; IV = phosphate; V, VI, VII = gold, corundum, zircon, rare earths; VIII = diamond, gold, rare earths; IX = cassiterite, molybdenite, rare earths. *Source:* Untung 1969.

Bangka I began large-scale offshore production in 1966, the full potential for commercial marine tin mining off the tin islands had not yet been realized. In that year Citra, a French firm, conducted preliminary geophysical surveys with promising results (Sigit 1968). Seismic surveys and drilling in the late 1960s and early 1970s (with the financial assistance of the Dutch) helped to delineate potential ore deposits. In 1973, with assistance from a UN special fund project, a fully mechanized drilling pontoon for tin exploration was constructed and began operating off the coast of Singkep and other small islands. This drill added to the exploration capacity of P.T. Timah, the Indonesian state tin mining concern, which included 15 other pontoon mounted drills for nearshore work and a drilling ship for open sea work (P. T. Timah 1976). In 1983, P. T. Timah, along with three French government agencies (IFREMER, CEA, and BRGM), conducted high-resolution seismic surveys and magnetic surveys to find deposits of detrital tin off the coast of Bangka Island (Lericolais et al. 1987).

By the mid-1970s, intensive annual exploration for tin deposits was occurring, primarily around the islands of Bangka, Belitung, Karimun, Kundur, and Singkep. The locations of these investigations and of associated production areas are depicted in Figure 12.8. Sujitno (1977) summarizes the major technological advances and the history of tin exploration and development from the turn of the century. From 1978 through the present, Indonesian tin exploration has been documented in the annual CCOP proceedings volumes. Offshore production in 1970 by P. T. Timah was just over 5000 mt. (26% of Indonesian tin production) and increased to over 8000 mt. (35% of the total) by 1977 (CCOP 1979). From 1968 through 1975, Billiton, a Dutch dredging and tin mining concern, explored concession areas off the tin islands at an estimated cost of \$2.8 million (Archer 1973). In 1979, Billiton's large dredge, the *Bima,* began its operations under a joint-venture contract between Billiton and P. T. Riau Tin Mining and continued through 1984. In that year, total Indonesian offshore production from 18 dredges was estimated at over 11,000 mt. (57% of the total) (Sujitno 1984).

Thailand. Much of the research and prospecting efforts for marine nonfuel minerals in Thailand have focused on the cassiterite deposits on the west coast in the Andaman Sea near Phuket, Phangnga, and Takuopa. Of course, tin has been dredged off Phuket since 1907, and tin has been recovered in this area by artisanal methods since the early part of the nineteenth century (Kulvanich 1984). In 1974, with financial and technical assistance from the Netherlands and CCOP, the government of Thailand conducted geophysical surveys and vibracore and grab samples along the entire west coast of Thailand (CCOP 1976). Subsequent analysis of heavy mineral contents identified the area off Phuket as having the best potential for marine mineral occurrences (CCOP 1979). A follow-up geophysical survey off the west coast from Phuket to Phangnga conducted by the Thai Department of Mineral Resources and with assistance from the United Nations Development Program (UNDP) recom-

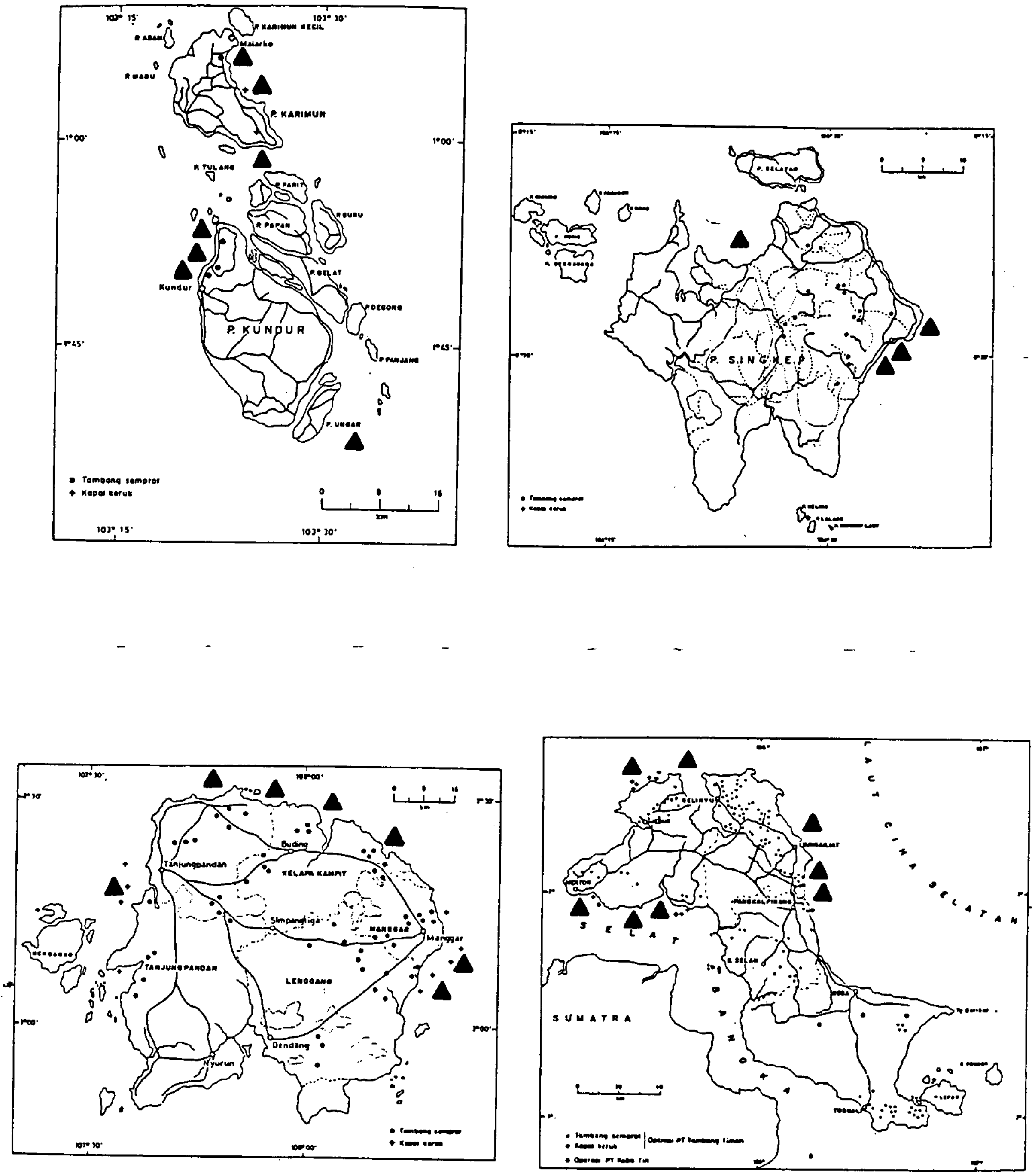

Figure 12.8 Marine and onshore mining and exploration for tin in the Indonesian tin islands. Solid triangles indicate areas of recent exploration interest (1984–1986). Clockwise from upper left (starting on facing page): Karimun and Kundur Islands, Singkep Island, Bangka Island, and Belitung Island. *Source:* Indonesia Department of Mining and Energy, 1985.

mended a drilling program based upon the discovery of several zones where economic concentrations of cassiterite potentially existed (CCOP 1980). Beginning in 1980, another UNDP-sponsored effort called the "Offshore Exploration for Tin and Heavy Minerals in Thailand" proceeded with drilling and sampling efforts that identified a resource of 90 million m^3 above a cutoff grade of 120g/m^3 and an additional resource of 828 million m^3 above a cutoff grade of 50g/m^3 (Guy-Bray 1987).

By contrast, the Gulf of Thailand has not received as much attention for nonfuel minerals, as it is located in the fringe of the tin belt that sweeps down through Thailand into Malaysia and the Indonesian portion of the South China Sea. However, there has been considerable exploration for hydrocarbon minerals by Unocal Thailand Inc., Thai Shell Exploration & Production Co., and the Petroleum Authority of Thailand (OGJ 1987). In 1974, the Thai Department of Mineral Resources planned to conduct geophysical surveys, heat-flow measurements, drilling, and grab samples in the Gulf of Thailand to help determine its tectonic structure and to investigate an hypothesized relationship between the age of granites in the gulf and occurrences of tin mineralization (Supalak et al. 1975). It was not until the early 1980s that the Offshore Exploration Unit of the Thai Department of Mineral Resources (DMR) initiated nearshore geophysical surveys in three areas to the east of Bangkok near Rayong and Chanthaburi and one area to the southwest of Bangkok near Prachuap Khiri Khan. DMR also sampled heavy mineral sands off the beach at Maptaphut near Rayong (Rasrikriengkrai et al. 1987). Even before this offshore work, DMR geologists had examined Landsat imagery to determine the potential for mineral resources onshore in this area and to give some indication of the likelihood of offshore potential (Jantaranipa et al. 1981). Based upon this preliminary work, in August of 1987, UNDP initiated a five-year project entitled "Offshore Mineral Exploration in the Gulf of Thailand" to target heavy minerals and some gemstone minerals in the nearshore areas described above. The project is projected to cost approximately $2 million, with UNDP contributing about 45% of the funding.

Vietnam. The Soviet Union and Vietnam have conducted joint-venture exploration efforts for marine hydrocarbons. The possibility of significant beach placers in Vietnam appears remote (CCOP 1968, 1970). Silica sands have been produced from the beaches at Cam Ranh (Noakes 1972). Early work by CCOP located a titanium oxide deposit (primarily ilmenite) near Cam Ranh Bay, but its size was estimated at only 5,000–10,000 mt. (CCOP 1968). Some limited analysis of heavy mineral sands from coastal deposits was conducted by the Malaysian Geological Survey and indicated promise for the beach deposit at Thuan An (CCOP 1970). Reconnaissance work in the early 1970s by Noakes (1972) and MacDonald (1971b) suggested further work should be done on deposits at Vinh My near Hue and Hai Long, near Phan Thiet, northeast of Ho Chi Minh City. Noakes presents some mineralogical results for Vinh My and summarizes analyses of sands from other beaches south from Hue to the Mekong Delta; but deposit sizes were not estimated, and it is not known whether these deposits were examined further. It has been reported that Vietnamese scientists are extracting zirconium silicate between Mon Cay and Phan Thiet as a byproduct in the production of "scarce and valuable components" from "sea sands," but the exact location of the deposits that are being exploited for this purpose and the amounts produced are unknown (Kinney 1987).

Phosphate

Phosphate is used in the manufacture of fertilizer, and fertilizer is important for the agricultural sectors in many of the China Sea countries. As seen in Table 12.14, China greatly outstrips all other countries in the region in the production of phosphate rock. China consumes most of its own production, and its consumption is five times greater than the next largest consumer, Japan. Japan, Korea, Malaysia, and Indonesia are the next largest consumers and are completely reliant upon imports for sources of phosphate. The United States is the leading exporter of phosphates to Japan, Malaysia, and Indonesia. Indonesia also imports substantial amounts from Jordan. Malaysia imports most of its phosphate from Christmas Island. With China's huge production, the China Sea region produced about 8% of the world's phosphate rock in 1984.

There are only small or low-grade occurrences of marine phosphorites in the two China seas. There are some indications of phosphorite occurrences off the

Table 12.14
Output, Consumption, and Trade in the China Sea Countries
Phosphate Rock, 1984

Country	Production (mt × 10^3)	Exports (mt × 10^3)	Imports (mt × 10^3)	Apparent consumption (mt × 10^3)	Net import reliance (%)	Change in production 1979–1984 (%)
China	11,800	1	6	11,805	0	−22
Korea	—	—	1652	1652	100	—
Japan	—	—	2323	2323	100	—
Philippines	7	—	14	21	67	27
Malaysia	—	2	285	283	100	—
Indonesia	2	1	637	638	99	−64
Thailand	3	—	—	3	0	−32
Vietnam	25	—	20	45	44	—
Regional total (average)	11,837	4	4937	16,770	(29)	
World share	8%					

Notes. About 90% of the production of phosphate rock is used in the manufacture of fertilizer for agriculture and as an additive to animal feeds. There is no substitute for phosphate in agricultural end uses.
Source: U.S. Bureau of Mines (1987).

west coast of Thailand (Stauffer 1977) and in the Indonesian archipelago (Hehuwat 1976), but, as depicted in Figure 12.9, apparently only limited potential in the South China Sea. When they were under the jurisdiction of Vietnam, guano phosphate deposits were produced in the Paracel Islands until the mid-1960s (BSC 1964), but it is unknown whether these deposits contain sufficient resources to be reopened; and there is now an outstanding jurisdictional dispute. McKelvey and Wang (1970) have indicated that there are guano islands in the Spratly group (probably Spratly and Namyit), but they do not report indications of resource potential.

Deepsea Efforts

The prospects for deepsea minerals in the East and South China Seas are remote, even more remote than the prospects for deepsea minerals in the central Pacific. Although manganese nodules and cobalt crusts have been dredged from isolated areas in the South China Sea (Academica Sinica 1983), geochemical analysis shows these deposits to be only average in the metals of most interest, namely nickel, cobalt, and copper (Manheim 1987). At least one marine polymetallic sulfide deposit has been located in the Okinawa Trough, west of the Ryukyu Island Chain in Japanese waters, but the mineralogy has not been published (Uyeda 1987; Hotta 1987).

Because of several factors that affect the costs of exploration, development, and production, it is unlikely that deepsea deposits in the China seas will be considered to have much commercial significance. Among these factors are depth (most of these deposits are at least 1000 m deep, if not much deeper); exposure (the deposits normally are located in unprotected areas where monsoonal weather patterns could have a significant adverse impact on fixed operations); the nonexistence of systematic exploration tools (although this is not so much a problem for the nodules and crusts, there has been little success with the operation of hard-rock drills for the delineation of seabed massive sulfides); the nonexistence of commercial recovery technology (this is most pronounced in the cases of the crusts, where separation from the subsurface gangue material is difficult—contrary to purported technological breakthroughs, and the sulfides). All of these factors contribute to higher costs of exploration and development in comparison with land-based sources of the materials that are most likely to be found in the deepsea deposits (Broadus 1987). Given the state of technological development for exploration and recovery (Hoagland 1986), manganese nodules located in the Clarion-Clipperton zone of the east Pacific (excluding those located in the China Seas) might be considered as resources for the future. The cobalt crusts and MPS deposits, especially those existing within the confines of the China seas, should be regarded as either speculative resources or merely as mineral occurrences.

Nevertheless, at least three countries in the China seas region—Japan, China, and Korea—have expressed interest in conducting scientific research,

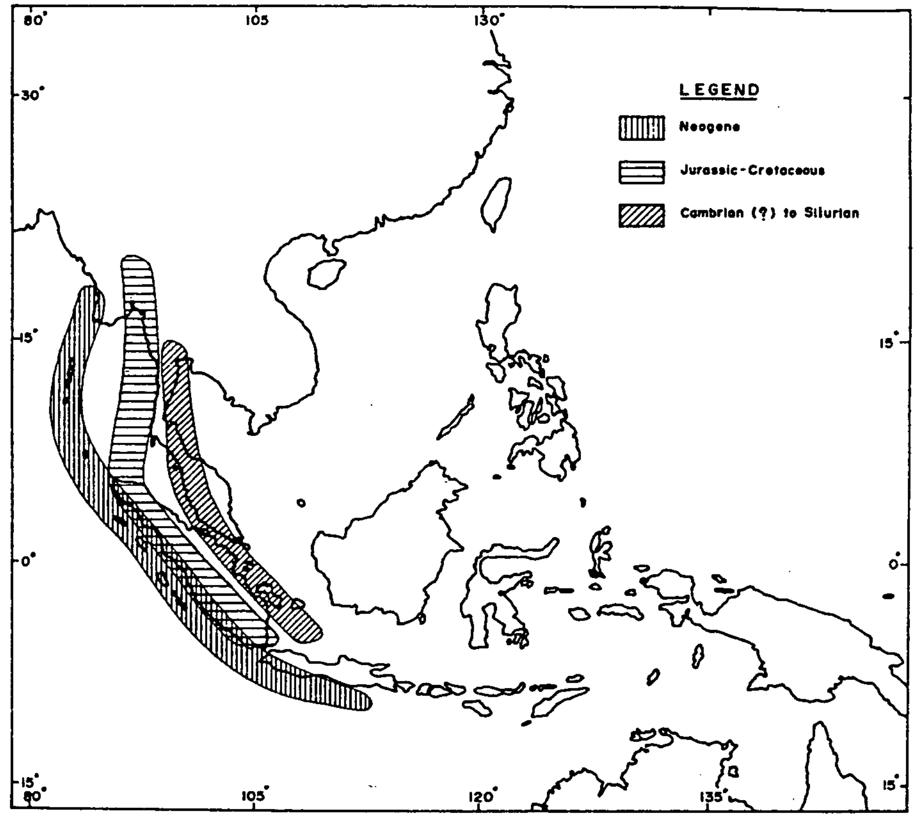

Figure 12.9 Potential for phosphorite deposits in the South China Sea. *Source:* Stauffer 1977.

and, in the case of Japan, R&D on technology to be used to explore for and exploit deepsea deposits. Japan has done the most work of these three. Broadus (1986) documents the efforts of the Japanese government and private firms in prospecting and technological development on manganese nodules, and this will not be repeated here, except to say that the Japanese efforts are continuing, although at a slower pace than in the past. Japan is reputed to have staked a claim to a manganese nodule exploration area to the west of the area between the Clarion and Clipperton fracture zones, and this may be in the general location of work done by GSJ in the late 1970s and early 1980s (Figure 12.10).

During the period 1976–1978, China initiated investigations of deep seabed minerals. Since that time, China has conducted four oceanic investigations that have been devoted, at least in part, to deepsea mineral investigations. On those

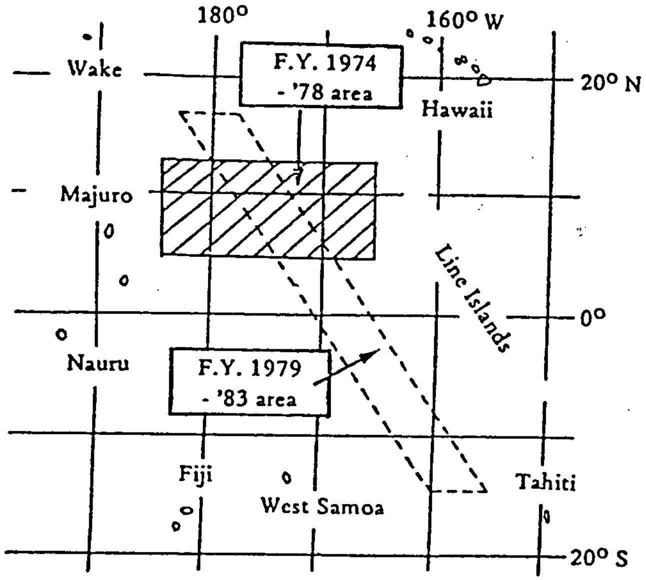

Figure 12.10 Location of Japanese investigations for manganese nodules in the west Pacific. *Source:* GSJ 1981.

cruises, gravity and magnetic surveys were conducted and manganese nodules were collected. In 1983 and 1985, the *RV Xiang Yang Hong 16* conducted surveys of deep seabed manganese nodules in the 167–178 °W and 7–11 °N area of the Pacific Ocean. In 1983, 302 kg of manganese nodules were collected. Chen and Xu (1986) recently have reported results of their geochemical analysis of the nodules collected during the first cruise. From November 30, 1986 to July 18, 1987, the *RV Ocean 4* conducted a 48,000 km geological survey of the nodule-rich Clarion–Clipperton area in the Pacific to gather data on geological structures, paleoceanography, sediments, and the condition of mineral resources.

There have been investigations in Japan on cobalt crusts, and at least one Japanese firm, Nippon Kokan, has shown some interest, albeit skeptical, in these deposits (Hikai 1985). Commander Yoshio Masuda, one of the early pioneers in the development of the continuous-line bucket system for nodules, has achieved some limited success with the use of this technology in the recovery of crusts and is continuing work in this direction (Masuda 1987). Japanese scientists have participated in cruises conducted by the U.S. Geological Survey and the West German marine exploration firm Preussag A. G. in the investigation of cobalt crusts on Pacific seamounts near Hawaii and Johnston Island.

In 1986, Chinese geological research vessels discovered cobalt crusts in the South China Sea. These were located in the northern portion of the South China Sea's central basin. The crusts averaged about 0.1–0.3 cm thick, but on some seamounts the crust was up to 8–12 cm thick.

Marine geologists from the GSJ are currently conducting a five-year project to study hydrothermal activity in the Izu-Ogasawara Arc area, to the southeast of Japan (CCOP 1987). Already they have discovered active vents and massive sulfide deposits (Figure 12.11) in at least three locations (Urabe et al. 1987; Usui et al. 1986). The University of Ryukyu, the University of Tokyo, and the Japanese Marine Science and Technology Center (JAMSTEC) have collaborated in a study of hydrothermal activity in the Okinawa trough using the *Shinkai 2000,* a deepsea submersible. There they have located at least one hydrothermal vent site.

DISCUSSION

The countries of the China seas region have a long history in the search for and development of coastal and marine prospects. Some areas, such as the northeastern coast of China for sea salt, the Indonesian portion of the South China Sea for tin, and the bays and protected seas of Japan, have natural conditions that, in combination with market structures, make marine minerals competitive or even rent-yielding deposits. In terms of marine nonfuel production, the region clearly has a large share of the world's output of these minerals and, we surmise, a proportionate share of the world's exploration effort for marine nonfuels.

Even though current production of marine nonfuel minerals is important and, in some cases, has shown recent growth, additional units of effort at the margin are devoted to the search for and systematic assessment of new marine sources, rather than the expansion of existing sources. The nonfuel minerals with the most near-term promise are located nearshore, and experience gained through the exploitation of coastal mineral deposits is a positive factor influencing the potential for associated marine deposits. More exotic minerals such as ferromanganese nodules and crusts are found in the South China Sea, but these occurrences have only remote economic potential, certainly even more remote than the same minerals found in higher grades and concentrations in the central Pacific. Although only one marine sulfide has been located in the East China Sea, given the technological strength of the Japanese in deepsea prospecting, we expect that more of these deposits will be located and that their nearshore location may make them at least as significant as the deepsea sulfides, if still remote as an economic resource.

The potential for marine nonfuel mineral development in the China seas is an important issue for marine policy because economic entities in the region de-

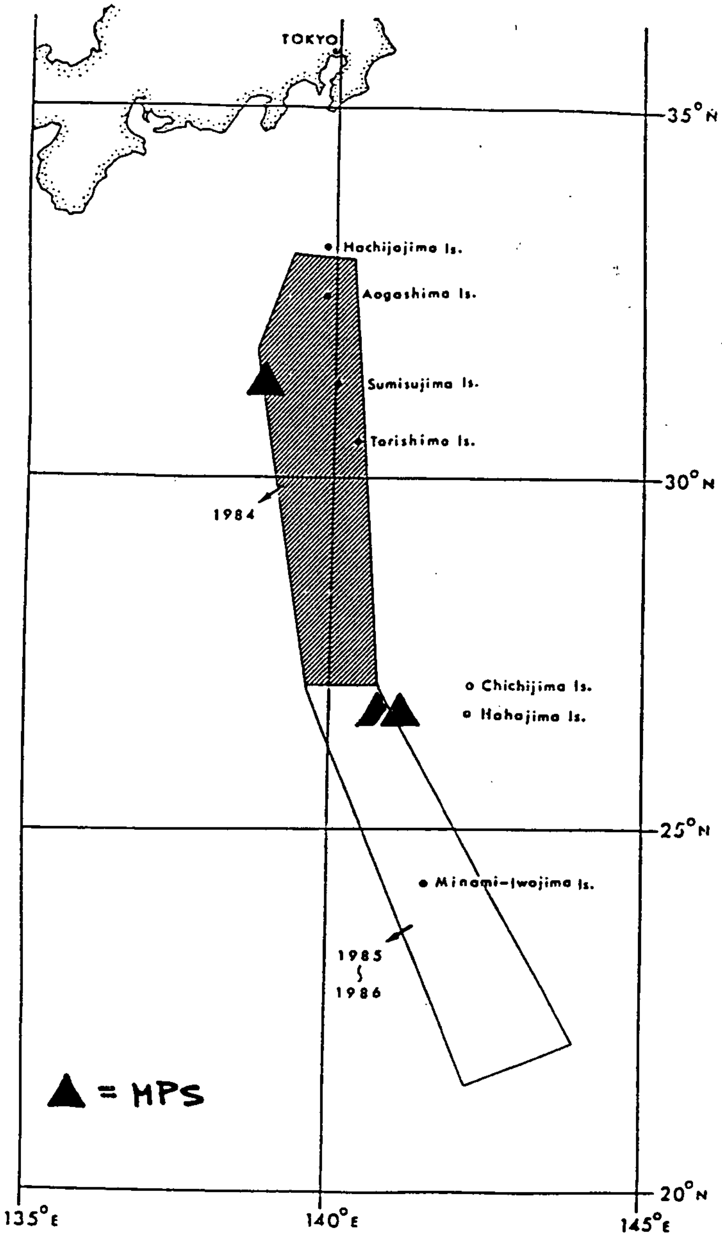

Figure 12.11 Location of Japanese investigations of marine polymetallic sulfide (MPS) deposits in the Izu-Ogasarawa Arc region. *Sources:* Toyoda 1987; GSJ 1985.

vote scarce labor and capital resources toward the search for, and assessment, development, and production of these mineral deposits. It is common for economic entities, such as nations or private firms, to assess mineral stocks as prospective assets or as future inputs into production processes, even when the recovery of these stocks may not yet be commercially feasible. However, especially where jurisdictions are incompletely determined, as they are in the two China seas, it can be possible for these entities to spend their efforts at an inefficient rate in discovery and exploration.

An organization for joint prospecting, like CCOP, performs several important functions. First, CCOP provides a forum for member countries to share risks and other costs in the exploration for nonfuels. This is beneficial because, with the potential for information spillovers or leaks, we expect that there could be underinvestment in exploration activity in some areas of the China seas. Thus, we see the influence of CCOP in the joint exploration by Malaysia, Indonesia, Korea, and Germany for tin deposits on the Malaysian side of the Malacca Strait, one of the only settled maritime boundaries in the region. Second, the information that is collected in joint exploration efforts is publicized by CCOP in its annual proceedings volumes, technical bulletins, and other formats. Treated in this manner as a public good, the benefits of new knowledge about China Sea marine nonfuel mineral prospects can be realized by a large number of interested parties. Even if the individual benefits are small, the number of beneficiaries is potentially large, and the total benefits may outweigh the costs of exploration.

Of course, the potential for discovery rushes, or overinvestment in marine exploration, could take place in areas of the two China seas where boundaries are ill-defined. For example, a recent scholarly publication out of Academica Sinica (1983) is entitled "The First Discovery of Manganese Nodules at the Northeastern Continental Slope of the South China Sea." While we note that there could be other reasons for excessive discovery effort, such as national policies of commitments to demonstrate scientific or technological competence or strategic behavior among marine mineral firms (Broadus 1987, 1986), we believe that the economic potential for deepsea nonfuel minerals in the China seas should not be used as a justification for the expansion of maritime jurisdictions. Those marine nonfuel minerals with the brightest potentials are located close to shore and well within recognized jurisdictions. Possibly the only exception are the guano phosphate deposits in isolated island settings. We have uncovered little information on the resource potential of these deposits, although apparently there are military installations on some of the islands of the Spratly Group (Prescott 1985). We believe that, even though the need for phosphate in the region is large, the degree to which these islands should fuel jurisdictional disputes could be overblown. This issue is a promising one for further research.

In recent years, the countries that surround the East and South China seas have experienced extraordinary growth, as measured by gross domestic production. However, with the notable exception of Japan, these countries have relatively low per capita GDP and are classified by the World Bank as either low- or middle-income developing countries. It is unlikely that high rates of economic growth are positive indicators for the expansion of marine nonfuel minerals potential in this region. This is because most of the products for offshore minerals trade in world markets, and offshore sources will have to compete with existing onshore sources in terms of size, grade, accessibility, and, of course, price. An important exception is sand and gravel, for which the markets are local. Here Japan, with its large marine-to-land-area ratio has developed its offshore aggregate sources the most extensively. (And it is interesting to note that the estimated average price of aggregate in Japan is about twice the world average, thus making the offshore resource a competitive mineral commodity.)

It is easy to overplay the potential and presumed importance of marine nonfuel minerals as economic resources. The actual production of offshore minerals in the East and South China seas and the diversity of experience shown by the countries of the region in investigating and developing coastal and marine nonfuel resources is impressive, even on a world scale. Yet most of the countries are merely dabbling for nonfuels offshore. Much of the marine sand and gravel and tin reserves are exploited in shallow, low-energy environments, using technology that has been adapted from onshore locations. Sea salt, a major component of our estimated "marine" production, is really an onshore operation. In China and many of the other China Sea countries, the mineral economies are diverse, and there is a significant amount of interdependence in mineral trade among the countries of this region. Two salient exceptions in international trade are China, where its mineral economy is largely independent, despite recent steps to open trade doors, and Vietnam, which is slowly reconstructing. Of course, we have neglected the important role of the entrepots, Singapore and Hong Kong, which facilitate greatly the mineral trade both regionally and globally.

The exploration for and development of offshore hydrocarbon resources is big business in the East and South China seas, and the output of marine nonfuels is almost incomparable to the oil and gas minerals. Offshore hydrocarbon development in the China seas region is most developed in the South China Sea, where Indonesia, Malaysia, and Brunei are major producers. In 1986, the countries in the China seas region accounted for 4% of world marine crude production (down to $2 billion from the $11 billion in 1984 mentioned earlier) and 7% of world marine natural gas production (Offshore 1989).

Over the years, the China Sea countries have gained valuable experience in nearshore production technologies, in the institutional aspects of contracting with foreign corporations and creating joint ventures, and in international trading of mineral commodities. These experiences are applicable to marine hydrocarbons as well as the nonfuels. A good recent example concerns China's offshore oil and gas. In China, this industry is still in its exploration and trial-production stage. China's offshore crude production is small, averaging

1000 barrels per day in 1986 and representing only a fraction of the China seas' production. Beginning from late 1950s and early 1960s, China embarked independently on a reconnaissance survey of oil and gas resources in the Bohai Gulf, followed by similar surveys in the Yellow Sea, the East China Sea, and the South China Sea. By the end of the 1970s, major oil-gas-bearing basins, such as the Bohai, southern Yellow Sea, and East China sea basins, as well as the Zhumiang River Estuary, Beibu Gulf, and Yingge Sea basins, had been discovered. Since that period, China's strategy has been to engage in joint ventures with other countries and thus to master new technologies and gain experience that otherwise would have been difficult to acquire.

A related side-effect of the marine hydrocarbon development activity is the application of technological developments on those resources to benefit the search for and recovery of marine nonfuel minerals. The degree to which this has occurred in the China seas deserves closer scrutiny than we have attempted here. To a substantial extent, the activities of CCOP have been driven by national interests in the search for oil and natural gas; and, without this impetus, it is not clear that CCOP could continue to exist in its present form solely for nonfuel mineral investigations. General oceanographic measurements, including bathymetry, seismics, and drilling, certainly are important precursors to a basic understanding of the potential for both hydrocarbon and nonfuel minerals in this region. Geophysical technologies used expressly for oil and gas exploration can be of some limited use in general reconnaissance for nonfuel minerals, and navigation equipment and techniques that can identify precise locations on the seabed are of great importance to marine-mining operations of any sort. Probably the most likely technological spinoff could be the hands-on experience gained through the operation of exploration and production platforms in a high-energy environment, but this remains to be seen for the nonfuels. We expect that the knowledge gained in the future through the use of side-scan sonar systems, in combination with bathymetric measurements and other remote sensors, could contribute significantly to a greater understanding of the occurrence, distribution, and economic potential of marine nonfuels.

In this chapter, we have attempted to take some initial steps toward understanding the activities that indicate the economic potential of marine nonfuel minerals in the East and South China seas. Other areas of public policy concern that we have not examined closely include estimating the size of onshore and offshore resources for nonfuel minerals, analyzing the environmental effects of nonfuel mineral exploration and development, examining country strategies in the conduct of oceanography and marine economic geology, approximating the size of expenditures by countries and private firms in the search for marine nonfuels, determining the extent to which ocean-atmosphere phenomena such as the monsoon contribute to the replenishment and concentration of beach placers; and characterizing the markets for fertilizer materials with an emphasis on phosphate, among others. With this initial work, we hope to direct and focus future research efforts in this promising and interesting region.

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