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Woods Hole Oceanographic Institution

Seabed Material Commodity and Resource Summaries

by

Porter Hoagland III and James M. Broadus

October 1987

Technical Report

Prepared by the Marine Policy Center, Woods Hole Oceanographic Institution
with funds from the Department of Commerce, NOAA, National Sea Grant
College Program under grant Number NA86-AA-D-SG090
(Woods Hole Oceanographic Institution project Number R/S-9)
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Approved for Distribution:

James M. Broadus, Director
Marine Policy Center

ABSTRACT

Over the past five years, research on marine minerals conducted by the Marine Policy Center at the Woods Hole Oceanographic Institution has attempted to gain a better understanding of the process by which these minerals are brought into productive use in society. This technical report results from concentrated research conducted by a research team under the primary sponsorship of the National Sea Grant College Program. This report provides background documentation for the recent publication: J.M. Broadus, 1987, "Seabed Materials," Science 235(4791): 853-860. It is organized to lead the user directly to sources that may provide further information on particular seabed materials. Several presentations of data in the report are of use in understanding the fundamentals of marine mineral markets including: descriptions of the size of the marine mineral resource base and the size of the markets for onshore and offshore sources of marine minerals; price series for minerals with prospective seabed sources; composite prices for four marine mineral types; consumption and price "elasticities" of mineral reserves; trends in mineral exploration inputs and U.S. federal government expenditures for marine nonfuel resources; maps of existing, proposed, or past entitlements for marine hard minerals; a list of known marine polymetallic sulfide (MPS) deposits and reported grades; world trade flows in zinc and copper; the value of apparent consumption in the United States in relation to imports and recycling; and a bibliography.

ACKNOWLEDGEMENTS

The authors are greatly indebted to the following individuals for their contributions, comments, and suggestions: Andy Solow for the plots and curve fits in section III; Mike Mottl, Tim McConachy, Sarah Little, Cindy Van Dover, and Geoff Thompson for their feedback on the MPS locations and Rick Chandler for the *Alvin* dive data in section VII; Frank Manheim, Peter Bartlett, and Mike Cruickshank for their input on the material summaries in section II; the commodity specialists from the U.S Bureau of Mines (only some of whom are mentioned in the text) who were always willing to field questions; Frank Gable for a portion of the cartography in section VI; Bob Bowen for general comments and suggestions; and to Ellen Gately and Ethel LeFave for typing and proofreading. Ellen Gately receives extra thanks for her help in pulling the bibliography in section X together.

This project was influenced to a measurable extent by several other concurrent studies on marine minerals including work by Jim Curlin, Bill Westermeyer, Jim Mielke, and Rosina Bierbaum at the U.S. Office of Technology Assessment; Dave Ross and Thérèse Landry in their work with the National Research Council; and the participants at the 16th and 17th Underwater Mining Institute meetings. Special thanks go to Dave Duane and Bill Stubblefield for their guidance and encouragements from the National Sea Grant College Program at NOAA.

The authors accept all responsibility for errors or omissions. Comments, criticisms, and suggestions are heartily encouraged from all readers.

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Section I: Introduction

This technical report results from several years of concentrated research on seabed materials conducted by a research team led by principal investigator J.M. Broadus under the primary sponsorship of the National Sea Grant College Program.[1] The title of this report has been borrowed from the title of the annual publication of the U.S. Bureau of Mines: Mineral Commodity Summaries (BOM/MCS). Since 1954, BOM/MCS and other Bureau of Mines' publications and reports have been the most current and comprehensive authorities avaliable to describe the world markets for the most important mineral commodities. This technical report attempts to supplement the efforts of the Bureau of Mines by focusing on seabed materials, some of which are not yet commodities in the strict sense of the term.

We have organized this report as a reference book. Examination of the figures and tables in the report will reveal the presentation of information that is unavailable from any other single source. The report does not attempt an evenhanded treatment of each seabed material (as in BOM/MCS) but instead

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[1] Research projects sponsored by the National Sea Grant College Program include:

J.M. Broadus, 1982, "An Economic Analysis of Industrial Structure and Behavior in the Emerging Seabed Mining Industry," R/S-7.

J.M. Broadus, R.E. Bowen, and K.M. Shusterich, 1982, "Economic and Legal Aspects of Deepsea Polymetallic Sulfides," R/G-6.

J.M. Broadus, R.E. Bowen, and I. Pires, 1983, "Economic and Legal/Political Aspects of Polymetallic Sulfides," R/G-7.

D.A. Ross and J.M. Broadus, 1984, "The Relationship Between Natural Resource Characteristics, the Character of the Client Industry, and Optimal Resource Access Provisions: The Case of Marine Polymetallic Sulfides," R/G-9.

J.M. Broadus, 1986, "Economic and Legal-Political Implications of Mineral Resource Potential in the U.S. Exclusive Economic Zone: An Application of Lessons Learned in the Case of Polymetallic Sulfides," R/S-9.

Publications resulting from these research projects are referenced in the text of this report and listed in the bibliography.

works to provide the most interesting and potentially useful information on selected seabed materials. The report is organized to lead the user directly to sources that may provide further information on a particular seabed material.

Generalizations and conclusions drawn from the data in this report can be found in the recent publication: J.M. Broadus, 1987, "Seabed Materials," *Science* 235(4791): 853-860. The report can be used as a background reference for that article. In particular, the tables presented in Section II of this report serve as compilations of data that were incorporated into Figure 1 of Broadus (1987). Sources for this data as well as for the price series presented in Section III are included in this report.

The research conducted by the Marine Policy Center over the past five years on marine minerals has attempted to gain a better understanding of the process by which these minerals are brought into productive use in society. This has involved an examination of the economic aspects of mineral discovery, exploration, development, and production including the identification and distribution of resources and reserves, technological capabilities and changes, and other factors that condition the supply of resources, namely conservation, substitution, recycling.

Of course, no one reference material such as this report can hope to be fully comprehensive. We expect that the sources referred to in each section, as well as the bibliography of marine policy publications concerning marine minerals found in Section X, will direct the reader to areas of interest that may not be covered fully in this report.

As an accumulation of information from a diverse set of primary sources, this technical report does not break new ground in the sense of gathering directly previously-unknown physical data on marine minerals. Nevertheless there are several presentations of data that we believe are unique and of significant value toward understanding the fundamentals of marine mineral markets and supply. These include:

Section II: The most up-to-date information available describing the size of the marine mineral resource base and the size of the markets for onshore and offshore sources of marine minerals. Except for *diamond*, this information is tabulated in Broadus (1987).

Section III: The Potter and Christy (1962) and Manthy (1978) price series are updated for minerals with prospective seabed sources using the same sources of primary price data originally selected by Potter and Christy. Composite prices, which appear in Broadus (1987), are compiled here for four marine mineral types.

Section IV: As a different type of analysis of scarcity, consumption and price "elasticities" of mineral reserves over the period 1970 through 1985 are examined here.

Section V: Using a variety of sources, North American mineral exploration expenditures over the period 1961 through 1985 are estimated. Other trends in mineral exploration inputs are plotted using real 1983 prices in all cases. U.S. federal government expenditures for marine nonfuel resources during 1966 through 1986 are estimated.

Section VI: The world mineral resource map found in Broadus (1987) is referenced here. This map is an update using several sources that have appeared since the seminal effort of McKelvey and Wang (1970). This section also collects, in one place, maps of existing, proposed, or past entitlements for marine hard minerals.

Section VII: This section includes the most comprehensive list known of marine polymetallic sulfide (MPS) deposits with references, their legal jurisdictions, reported grades and a comparison to existing massive sulfide mines, and an estimate of discovery effort based upon submersible dives.

Section VIII: This section elucidates world trade flows in zinc and copper over a seventy-five year period from 1908 through 1983.

Section IX: This section examines the value of apparent consumption in the United States in relation to imports and recycling and compares this to the traditional "percentage measure" employed by the U.S. Department of the Interior.

Section X: Over 1300 marine policy publications relating to marine minerals are listed in a bibliography.

More detailed descriptions of the data presented in each section are included at the beginning of each section. We welcome any comments, suggestions, additions, updates, or criticisms of this technical report.

Section II: Seabed Material Summaries

Figure II-1 (Broadus, 1987) lists selected descriptive statistics for material commodities that have seabed deposit sources. The statistics have been collected from a number of reference works and published articles, which have been explained in detail in Summary Tables that follow the figure. The statistics have been standardized for ease of comparison. It should be noted the production of material commodities from seabed deposits has occurred for only a limited number of the listed commodities. Seabed production histories are mentioned in the Summary Tables.

The following key corresponds to the column headings in Figure II-2 and to the row headings in the Summary Tables:

(A) Seabed production: This statistic is recent information on current production of material commodities from seabed deposits. This does not include past production, e.g., barite from the Castle Island, Alaska mine.

(B) World mine production: This statistic is recent information on current worldwide production of material commodities from all deposits. The U.S. Bureau of Mines' Mineral Commodity Summaries (1986) was the primary reference. This reference reports estimated 1985 world production. For hydrocarbons, figures reported by the U.S. Energy Information Administration (1986) were employed.

(C) Estimated average price: This statistic is recent information on average prices of material commodities. The U.S. Bureau of Mines' Mineral Commodity Summaries (1986) was the primary reference. The prices have been standardized in dollars per metric ton ($/mt). It should be noted that most commodities are traded in units that differ from metric tons (e.g., troy ounces or pounds), and therefore this standardization may give a misleading impression of price. Furthermore, average prices for some of the commodities with local markets (e.g., sand and gravel, shell, others) vary considerably depending upon the location of the market. Finally, to the extent possible, these are "minehead" prices, however, some reported average prices may contain varying amounts of transportation and processing costs.

(D) Seabed revenues: This statistic is the product of seabed production (column A) and estimated average price (column C).

(E) World revenues: This statistic is the product of world mine production (column B) and estimated average price (column C). It should be interpreted only as a general indicator of the size of the markets for these commodities, considering the caveats mentioned already about estimated average price. Moreover, although mine production in many cases approximates consumption, no account has been taken here of stockpiling behavior, recycling, and other secondary sources.

(F) Seabed share of world revenues: This statistic is seabed revenues (column D) expressed as a percentage of world revenues (column E).

(G) Seabed reported potential resources: Seabed resource estimates are taken from a number of references. Many of the estimates are limited only to the United States. The methods of estimating resources vary depending upon the resource, but most of the estimates reported here should be considered "speculative" or "hypothetical resources" (following the classification used by the U.S. Bureau of Mines and the U.S. Geological Survey). As noted by Broadus (1987), many of these estimates could expand through increased resource assessment efforts or even through a more comprehensive search of the literature.

(H) World onshore resources: This statistic is, in almost every case, an "identified resource." The U.S. Bureau of Mines' Mineral Facts and Problems (1980) and Mineral Commodity Summaries (1986) were the primary references. The 1985 edition of Mineral Facts and Problems was not used because Bureau of Mines has dropped the use of "identified resource" and now reports only "reserve base," a smaller classification.

(I) Seabed comparison to world resources: This statistic is seabed reported potential resources (column G) expressed as a percentage of world onshore resources (column H). Note that the categories of resources (speculative or hypothetical versus identified) are different. World onshore speculative and hypothetical resources should be much larger than the amounts reported in column G, and therefore in most cases a comparison of seabed to onshore would be smaller.

(J) Resource life index: This statistic is world onshore resources (column H) divided by world mine production (column B). Because world mine production is estimated over the course of one year (usually 1985), the units for this life index are in "years." Subject to several strong assumptions, the index roughly suggests a "waiting time" before seabed materials might be called into use but without considering either growth in consumption or substitution, recycling, conservation, and technological advance.

(K) Projected onshore depletion: This statistic indicates a projected depletion of onshore resources based upon the Leontief et al. (1984) input-output model of the world economy. The statistics show the percent of the 1980 world onshore resource that is depleted by the year 2030 using the pessimistic scenario of a low growth rate in the lesser developed countries (LDCs). Note that the depletion estimate is not bounded at 100%. For example, 120% depletion indicates that 1.2 times the identified resource would be consumed by 2030.

(L) Crustal abundance: For some of the material commodities, this statistic shows the crustal abundance in metric tons. This is the theoretical limit on the size of the resource in the earth's crust. (This statistic was not included in Figure 1.)

Figure II-1 : Seabed Materials in World Perspective

Seabed deposits	Material commodity	(A) Seabed production (10³ MT)	(B) World mine production (10³ MT)	(C) Estimated average price ($ per MT)	(D) Seabed revenues* ($ in millions)	(E) World revenues† ($ in millions)	(F) Seabed share of world revenues‡ (%)	(G) Seabed reported potential resources (10³ MT)	(H) World onshore resources (10³ MT)	(I) Seabed comparison to world resources§ (%)	(J) "Resource life" index‖ (years)	(K) Projected onshore depletion by year 2030¶ (%)
Hydrocarbons#	Crude oil	788,834	2,788,913	70	55,218	195,224	28	>61,429,000	181,857,000	34	65	185
	Natural gas	246,670	1,296,405	95	23,434	123,158	19	>60,000,000	228,214,000	26	176	45
Sand and gravel	Sand and gravel	112,300	7,620,480	3	334	22,861	1	665,778,000	Very large	Small	Long	
	Industrial sand		181,440	14		2,540		Large	Very large	Small	Long	
Shell	Calcium carbonate	16,667	1,666,667	6	100	10,000	1	90,000,000	Very large	Small	Long	
Sulfur	Sulfur	381	54,000	105	40	5,670	<1	27,125**	5,000,000	<1	93	120
Barite	Barite		5,652	31		175		2,087**	453,600	<1	80	
Phosphorite	Phosphate rock		159,000	24		3,816		7,939,000	129,500,000	6	814	12
Mineral placers	Tin	28	201	6,614	185	1,329	14	2,500	34,500	7	172	105
	Rutile		356	364		130		13,060	181,440	7	510	
	Ilmenite		4,187	49		205		230,500	907,200	25	217	
	Titanium††		90	12,236		1,101						40
	Zirconium		709	182		129		29,040	54,432	53	77	
	Hafnium		<<1	231,483		17		290	544	53	7,452	
	Yttrium		<1	35,020		14		(3,450**)	172		430	
	Thorium		2	35,850		72			5,168		2,584	
	Chromite		9,616	42		404		30,158**	32,659,200	<1	3,396	1
	Gold		1	10,600,000		10,600		<1**	72	<1	72	443
	Silver		12	206,667		2,480			743		62	295
	Platinum		<<1	9,000,000		1,980		<<1**	99	<<1	446	13
Nodules and crusts	Platinum§§							2–3		2–3		
	Cobalt		32	25,353		811		6,000–24,000	10,886	55–220	340	
	Nickel		745	5,026		3,744		35,000–131,000	129,730	27–101	174	77
	Manganese		23,406	141		3,300		706,000–2,600,000	10,886,400	6–24	465	17
	Copper		7,805	1,475		11,512		29,000–108,000	1,600,000	2–7	205	86
Massive sulfides	Copper‖‖							5,000–216,000		<1–14		
	Zinc		6,560	893		5,858		11,000–518,000	1,800,000	<1–29	274	47
	Lead		3,350	419		1,404			1,400,000		418	46

*Seabed production times estimated average price. †World mine production times estimated average price. ‡Seabed revenues times 100, divided by world revenues. §Seabed reported potential resources times 100, divided by world onshore resources. ‖World onshore resources divided by world mine production. ¶From (32), based on low growth case for developing economies. #Hydrocarbons in metric tons of oil equivalent. **Seabed estimate for the United States only; the number in braces (3,450) is for U.S. seabed monazite deposits containing yttrium and thorium. ††Titanium resources are included in rutile and ilmenite resources. §§See numbers directly above in mineral placers for platinum. ‖‖See numbers directly above in nodules and crusts for copper.

Source: Broadus (1987)

CRUDE OIL

	Data		Conversion		Source
(A)	15,128.33	BBLx10^3/D	788,834.00	MTOEx10^3	Offshore (May 1986)[a/]
(B)	53,486.00	BBLx10^3/D	2,788,913.00	MTOEx10^3	EIA, p.c. (1986)[a/]
(C)	10.00	$/BBL	70.00	$/MTOE	Broadus, p.c. (1986)
(D)	--		55,218.38	$x10^6	(A)x(C)
(E)	--		195,223.91	$x10^6	(B)x(C)
(F)	--		28.28	%	[(D)x100]/(E)
(G)	430.00	BOEx10^9	61,429,000.01	MTOEx10^3	Various[b/]
(H)	1,273.00	BBLx10^9	181,857,000.00	MTOEx10^3	Masters et al. (1983)
(I)	--		33.78	%	[(G)x100]/H
(J)	--		65.21	Years	(H)/(B)
(K) (L)	489,032.00	MTCEx10^6	185.00	%[c/]	Leontief et al. (1984)

Notes:

a/ 1985 daily average production estimate multiplied times 365, then converted to MTOE using 7 barrels of oil per metric ton of oil equivalent.

b/ Drew and Root (1982) world "discovered" resource of 200 BOEx10^9 plus Masters (1985) world "undiscovered" resource, areas "A" and "B" of 230 BOEx10^9. Note: the Drew and Root estimate does not include Masters' Area "B" (China, North America, and the Soviet Union). In addition, offshore production has not been factored out of the Drew and Root estimate. These two factors counterbalance each other to some extent; however, the resultant resource estimate is still considered conservative.

c/ Using 0.688 MTOE/MTCE.

NATURAL GAS

	Original Data	Conversion	Source
(A)	28,383.90 FT^{3}x10^6/D	246,670.00 MTOEx10^3	*Offshore* (May 1986)[a]
(B)	54,449.00 FT^{3}x10^9	1,296,405.00 MTOEx10^3	EIA, p.c. (1986)[b]
(C)	2.25 \$/FT^{3}x10^3	95.00 \$/MTOE	Broadus, p.c. (1986)
(D)	—	23,433.65 \$x10^6	(A)x(C)
(E)	—	123,158.47 \$x10^6	(B)x(C)
(F)	—	19.03 %	[(D)x100]/(E)
(G)	61,429.00 MTOEx10^6	60,000,000.00 MTOEx10^3	Various[c]
(H)	9,585.00 FT^{3}x10^{12}	228,214,000.00 MTOEx10^3	BOM/MFP (1980)
(I)	—	26.29 %	[(G)x100]/H
(J)	—	176.04 Years	(H)/(B)
(K)	150,370.00 MTCEx10^6	45.00 %	Leontief et al. (1984)[e]
(L)			

Notes:

[a] 1983 average daily production multiplied times 365, then converted to BOE using BOE/6000 FT^3 (Masters, p.c., 1986; Note: API conversion factor is BOE/5604 FT^3), then converted to MTOE using MTOE/7 BBL.

[b] Average annual production, converted as above.

[c] A good rule-of-thumb to estimate natural gas resources offshore is a 1:1 ratio, in terms of heat content (oil equivalents) with crude oil resources offshore (see: crude oil notes). The 61,429 MTOEx10^6 crude oil resource estimate is reduced slightly here to get a 60,000 MTOEx10^6 natural gas resource estimate because offshore resources tend to be slightly "oilier" than continental resources (Masters, p.c., 1986). In the past, discovered natural gas resources have been underreported because there were no markets.

[d] "Ultimate resources" defined as the Sum of cumulative production, proved reserves, and potential reserves.

[e] Using 0.688 MTOE/MTCE.

SAND AND GRAVEL

	Data		Conversion		Source
(A)	112,300.00	MTx10^3	112,300.00	MTx10^3	Various[a]
(B)	8,400.00	STx10^6	7,620,480.00	MTx10^3	BOM/MFP (1985)
(C)	3.00	$/ST	3.31	$/MT	BOM/MCS (1986)
(D)	--		336.90	x10^6$	(A)x(C)
(E)	--		22,861.44	x10^6$	(B)x(C)
(F)	—		1.47	%	[(D)x100]/(E)
(G)	665,778.00	MTx10^6	665,778,000.00	MTx10^3	Various[b]
(H)	(very large)		(very large)	MTx10^3	BOM/MCS (1986)
(I)	--		(small)	%	[(G)x100]/H
(J)	--		(long)	Years	(H)/(B)
(K)					
(L)					

Notes:

[a] Sum of the following production figures:

Country	MTx10^3	Year	Source
Japan	54,000	1983	Tsurasaki (1986)
United Kingdom	19,500	1985	Uren (1986)
Netherlands	15,000	1984	de Groot (1986)
Denmark	5,100	1983	de Groot (1986)
Canada	5,000	1983	de Groot (1986)
France	4,200	1982	Galtier (1984)
West Germany	3,800	1984	de Groot (1986)
USA	3,000	1980	de Groot (1986)
Finland	1,400	1983	de Groot (1986)
Belgium	700	1984	de Groot (1986)
Iceland	500	1984	de Groot (1986)
Sweden	100	1984	de Groot (1986)
	112,300		

The de Groot and Galtier figures have been rounded. Production figures in the United States are difficult to estimate, because offshore mining activity occurs on a local or state level and, although sanctioned by the Army Corps of Engineers, offshore production figures are not aggregated nationally (Padan,J., 1986, Personal communication, Washington: Office of Ocean Minerals and Energy, NOAA, July). Galtier estimated 4,000 MTx10^3 U.S. offshore production in 1978 and de Groot estimated 3,400 MTx10^3 in 1980. Nevertheless, these figures should be regarded as highly uncertain.

[b] Sum of the following resource estimates:

Location	Volume	MTx10^3	Source
U.S. Atlantic	444 x10^9	600,000*	Duane and Stubblefield (1986)
U.S. Pacific	29 x10^9	39,000*	Clague, Bischoff and Howell (1984)
U.S. Hawaii	19 x10^9	26,000	Clague, Bischoff and Howell (1984)
United Kingdom		190**	Uren (1986)
Japan		540**	Tsurasaki (1986)
Australia		48	Glasby (1986)
		665,778	

* Using 1.35MT/m^3 (Manheim, 1979) and then rounded.

** "Reserves."

INDUSTRIAL SAND

	Data		Conversion		Source
(A)	137,000.00	MT	137.00	$MTx10^3$	Glasby, 1986[a]
(B)	200.00	$STx10^6$	181,440.00	$MTx10^3$	BOM/MFP (1985)
(C)	12.90	$/ST	14.22	$/MT	BOM/MCS (1986)
(D)	--		1,948.14	$\$x10^3$	(A)x(C)
(E)	--		2,540.16	$\$x10^6$	(B)x(C)
(F)	--		0.08	%	[(D)x100]/(E)
(G)	(Large)		(large)	$MTx10^3$	Estimate[b]
(H)	(Very Large)		(very large)	$MTx10^3$	BOM/MFP (1985)
(I)	--		(small)	%	[(G)x100]/H
(J)	--		(long)	Years	(H)/(B)
(K)					
(L)					

Notes:

[a] Dredging from Parengaenga Harbor, Northland, New Zealand (1979 Figure).

[b] Magdalen Silica, Inc. reports 250 m^3x10^6 (roughly 338,000 $MTx10^6$) of recoverable silica sand off the Madeleine Islands, Gulf of St. Lawrence, Canada (Hale, 1984).

CALCIUM CARBONATE

	Data	Conversion	Source
(A)	--	16,666.67 MTx10^3	Estimate[a]
(B)	--	1,666,666.67 MTx10^3	Estimate[a]
(C)	--	6.00 $/MT	Broadus (1985)
(D)	--	100.00 $x10^6	Glasby (1979)
(E)	--	10,000.00 $x10^6	Glasby (1979)
(F)	--	1.00 %	[(D)x100]/(E)
(G)	70,000.00- 90,000.00 MTx10^6	70,000,000.00- 90,000,000.00 MTx10^3	Earney (1980)[b]
(H)	(very large)	(very large) MTx10^3	Estimate
(I)	--	(small) %	[(G)x100]/H
(J)	--	(long) Years	(H)/(B)
(K)			
(L)			

Notes:

[a] Glasby (1979) reports the following data supplied by the Institute of Geological Sciences, London, England:

Country	Seabed Production (MTx10^3)	Value (US$x10^6)
United States	14,000	67.00
France	900	25.00
Iceland	160	0.80
Fiji	80	0.10
Bahamas	900	1.50
Others	250	0.80
	16,290	95.20

Broadus (1985) rounds 95.2 $x10^6 to 100 $x10^6 and estimates an average price of 6.00 $/MT to derive similar seabed and world production estimates. Note: Glasby also estimates seabed production at less than one percent of world mine production.

[b] Bahamian offshore aragonite reserves. Note: Earney (1986) reports the existence of 35 years of shell sand reserves in Iceland based on current production rates (115 m^{3}x10^3/year). Using Glasby's estimate for Icelandic production of 160 MTx10^3 in 1977, Iceland has an estimated 5.6 MTx10^6 of shell sand reserves (35 x 160). Glasby (1986) reports on Summerhayes' estimates of 1 MTx10^{14} of calcium carbonate on the Campbell Plateau, New Zealand, but he mentions also that: "it is unlikely that calcium carbonate will be mined off New Zealand within the foreseeable future."

SULFUR

	Data		Conversion		Source
(A)	380.95	MTx10^3	380.95	MTx10^3	Broadus (1985)
(B)	54,000.00	MTx10^3	54,000.00	MTx10^3	BOM/MCS (1986)
(C)	104.68	$/MT	104.68	$/MT	BOM/MCS (1986)
(D)	--		40.01	x10^6$	(A)x(C)
(E)	--		5,760.00	x10^6$	(B)x(C)
(F)	--		0.69	%	[(D)x100]/(E)
(G)	27,125.00	MTx10^3	27,125.00	MTx10^3	Carpenter, p.c. (1986[a/]
(H)	5.00	MTx10^9	5,000,000.00	MTx10^3	BOM/MFP (1980)
(I)	--		0.54	%	[(G)x100]/H
(J)	--		92.60	Years	(H)/(B)
(K)	6,020.00	MTx10^6	120.40	%	Leontief et al. (1984)
(L)					

Notes:

[a/] U.S. seabed "probable reserve" estimate, 17.5% of U.S. "probable reserve" estimate of 155 MTx10^6. G. Carpenter, personal communication, Minerals Management Service, U.S. Department of the Interior, Reston, Virginia, July 28, 1986.

BARITE

	Data		Conversion		Source
(A)					
(B)	6,230.00	$STx10^3$	5,651.90	$MTx10^3$	BOM/MCS (1986)
(C)	28.00	\$/ST	30.86	\$/MT	BOM/MCS (1986)
(D)					
(E)	--		175.21	$\$x10^6$	(B)x(C)
(F)					
(G)	2.30	$STx10^6$	2,086.56	$MTx10^3$	Earney (1980)[a]
(H_1)	500.00	$STx10^6$	453,600.00	$MTx10^3$	BOM/MCS (1986)[b]
(H_2)	2.00	$STx10^9$	1,800,000.00	$MTx10^3$	BOM/MCS (1986)[b]
(I_1)	--		0.46	%	$[(G)x100]/H_1$
(I_2)	--		0.12	%	$[(G)x100]/H_2$
(J_1)	--		80.30	Years	$(H_1)/(B)$
(J_2)	--		318.48	Years	$(H_2)/(B)$
(K)					
(L)	9.40	$MTx10^{15}$	9,400.00	$MTx10^{12}$	Erickson (1973)[c]

Notes:

[a] Barite deposit formerly in production at Castle Island, Alaska. This estimate includes cumulative production through 1975. The deposit occurs above and below sea level, but it was depleted first on the surface and then mined below sea level so that it is now considered a seabed deposit. Earney (1980) reports other barium sulfate concretions offshore San Clemente, California; the Kai Islands, Indonesia; and Colombo, Sri Lanka.

[b] H_1 are identified resources. H_2 are resources in all categories (including speculative and hypothetical).

[c] Barium.

PHOSPHATE ROCK

	Data		Conversion		Source
(A)	(1.50	MTx10^6)	(1,500.00	MTx10^6)	Yates et al. (1986)[a]
(B)	159,000.00	MTx10^3	159,000.00	MTx10^3	BOM/MCS (1986)
(C)	23.50	$/MT	23.50	$/MT	BOM/MCS (1986)
(D)	--		(36.00	$x10^6)	(A)x(C)[a]
(E)	--		3,816.00	$x10^6	(B)x(C)
(F)	--		(0.94	%)	[(D)x100]/(E)[a]
(G)	7,873.00	MTx10^6	7,873,000.00	MTx10^3	Various[b]
(H)	129,500.00	MTx10^6	129,500,000.00	MTx10^3	BOM/MFP (1980)
(I)	--		6.08	%	[(G)x100]/H
(J)	--		814.47	Years	(H)/(B)
(K)	16.10	MTx10^9	12.40	%	Leontief et al. (19
(L)	28.80	MTx10^{15}	28,800.00	MTx10^{12}	Erickson (1973)

* Phosphorite is technically a heavy mineral.

[a] Yates, Spagni and Keane (1986) report offshore "phosphate sand" production at San Domingo, Baja California, Mexico by Roca Fosforica Mexicana S.A.d.C.V (Rofomex), the national phosphate rock mining company. Offshore operations have since been terminated, however, due to the low grade (4-5% phosphate) a difficulties encountered in dredging the very hard, mixed phosphorite-calciu carbonate deposit (Stowasser, W.F., 1986, Personal communication, Washington Bureau of Mines, U.S. Dept. of the Interior, July).

[b] Sum of the following resource estimates:

Location	MTx10^6	Source
U.S. Atlantic	4,500	Riggs (1985)
U.S. Pacific	115	Clague et al. (1984
Chatham Rise, New Zealand	3,200	McKelvey (1986)
Baja California, Mexico*	50	Yates et al. (1986)
South Africa	8	Bartlett (1986)
	7,873	

Note: Mero (1965) estimated a resource of 300 MTx10^9 of phosphorites on the world's continental shelf. Assuming that 10 percent might be commercially recoverable, Roonwal (1986) estimates reserves of 30 MTx10^9.

TIN

	Data		Conversion		Source
(A)	28.00	MTx10^3	28.00	MTx10^3	Various[a/]
(B)	201,000.00	MT	201.00	MTx10^3	BOM/MCS (1986)
(C)	3.00	$/LB	6,613.80	$/MT	Broadus, p.c. (1986)
(D)	--		185.19	x10^6$	(A)x(C)
(E)	--		1,329.41	x10^6$	(B)x(C)
(F)	--		13.92	%	[(D)x100]/(E)
(G)	2,429.00	MTx10^3	2,500.00	MTx10^3	Various[b/]
(H)	37,000.00	MTx10^3	34,500.00	MTx10^3	BOM/MFP (1980)[c/]
(I)	--		7.25	%	[(G)x100]/H
(J)	--		171.64	Years	(H)/(B)
(K)	38,900.00	MTx10^3	105.14	%	Leontief et al. (1984)
(L)	40.80	MTx10^{12}	40.80	MTx10^{12}	Erickson (1973)

Notes:

a/ Using U.N. Economic and Social Council (1985) estimates of seabed production as a share of total production in 1982 (dervied from Galtier, 1984):

Location	(X) BOM (1985) Mine Production (MTx10^3)	(Y) Seabed Production (% of X)	(Z) Seabed Production (MTx10^3)
Thailand	20.00	60	12.00
Indonesia	20.00	57	11.40
United Kingdom (Cornwall)	4.60	100	4.60
			28.00

b/ Sum of the following seabed resource estimates:

Location	Reserves	Resources	Total	Source
Thailand	803	1606*	1606	Hirunruk and Netayaraksa (1984)
Indonesia	385	820	820	Sujitno (1984)
United Kingdom	3	--	3	White (1984)
			2429	
		(Rounded Total =	2500)	

* Our own resource estimate for Thailand calculated by using Sujitno's (1984) ratio of reserves to resources of 50% in Indonesia.

c/ Seabed resource estimate (G) subtracted from world onshore resource estimate of 37 MTx10^6.

TITANIUM METAL

	Data	Conversion	Source
(A)			
(B)	99,000.00 ST	89.81 MTx10^3	BOM/MCS (1986)
(C)	5.55 $/LB	12,235.53 $/MT	BOM/MCS (1986)
(D)			(A)x(C)
(E)	—	1,101.24 x10^6$	(B)x(C)
(F)			[(D)x100]/(E)
(G)	See:	rutile and ilmenite	
(H)	(697,483.00 MTx10^3)	(697,483.00 MTx10^3)	BOM/MFP (1980)[a]
(I)	See:	rutile and ilmenite	[(G)x100]/(H)
(J)	See:	rutile and ilmenite	(H)/(B)
(K)	280,000.00 MTx10^3	40.14 %	Leontief (1984)/(H)
(L)	153.60 MTx10^{15}	153,600.00 MTx10^{12}	Erickson (1973)

Notes:

[a] Contained titanium metal in rutile and ilmenite.

RUTILE

	Data	Conversion	Source
(A)			
(B)	392.00 STx10^3	355.62 MTx10^3	BOM/MCS (1986)
(C)	330.00 $/ST	363.76 $/MT	BOM/MCS (1986)
(D)			(A)x(C)
(E)	--	129.58 x10^6$	(B)x(C)
(F)			[(D)x100]/(E)
(G)	13.40 STx10^6	13,056.48 MTx10^3	Various[a]
(H)	200.00 STx10^6	181,440.00 MTx10^3	BOM/MCS (1986)
(I)	--	7.20 %	[(G)x100]/H
(J)	--	509.66 Years	(H)/(B)
(K)			
(L)		See: Titanium	

Notes:

[a] Sum of the following seabed resource estimates:

Atlantic & Gulf	12,156.48*	Manheim (1979)
Mozambique	900.00	Siddiquie et al. (1984)
	13,056.48**	

* "Undiscovered marginal resources" from the Atlantic and Gulf shelves (originally from McKelvey, 1968).

** Rounded to 13,060.00 MTx10^3 in Broadus (1987).

ILMENITE

	Data		Conversion		Source
(A)					
(B)	4,615.00	STx10^{3}	4,186.73	MTx10^{3}	BOM/MCS (1986)
(C)	44.00	$/LT	48.50	$/MT	BOM/MCS (1986)
(D)					(A)x(C)
(E)	--		205.16	$x10^{6}	(B)x(C)
(F)					[(D)x100]/(E)
(G)	--		230,536.78	MTx10^{3}	Various[a]
(H)	1.00	STx10^{9}	907,200.00	MTx10^{3}	BOM/MCS (1986)
(I)	--		25.41	%	[(G)x100]/H
(J)	--		217.00	Years	(H)/(B)
(K)					
(L)			See: Titanium		

Notes:

[a] Sum of the following seabed resource estimates:

Location	MTx10^{3}	Source
U.S. Atlantic and Gulf Shelves	180,536.78*	Manheim (1979)
Mozambique	50,000.00	Siddiquie, et al. (1984)
	230,536.78**	

* "Undiscovered marginal resources" from the Atlantic and Gulf Shelves (originally from McKelvey, 1968).

** Rounded to 230,500.00 MTx10^{3} in Broadus (1987).

ZIRCONIUM

	Data		Conversion		Source
(A)					
(B)	781,000.00	ST	708.52	MTx10^3	BOM/MCS (1986)
(C)	165.00	$/ST	181.88	$/MT	BOM/MCS (1986)
(D)					(A)x(C)
(E)	--		129.04	$x10^6	(B)x(C)
(F)					[(D)x100]/(E)
(G)	27.60	STx10^6	29,038.72	MT/10^3	Various[a]
(H)	60.00	STx10^6	54,432.00	MTx10^3	BOM/MCS (1986)
(I)	--		53.35	%	[(G)x100]/H
(J)	--		77.77	Years	(H)/(B)
(K)					
(L)					

Notes:

[a] Sum of the following seabed resource estimates:

Location	MTx10^3	Source
U.S. Atlantic and Gulf	25,038.72*	Manheim (1979)
Mozambique	4,000.00	Siddiquie, et al. (1984)
	29,038.72**	

* Zircon "undiscovered marginal resources" from the Atlantic and Gulf Shelves (originally from McKelvey, 1968).

** Rounded to 29,040.00 MTx10^3 in Broadus (1987).

HAFNIUM

	Data		Conversion		Source
(A)					
(B)	80.00	ST	0.07	MTx10^3	BOM/MCS (1986)
(C)	105.00	$/LB	231,483.00	$/MT	BOM/MCS (1986)[a]
(D)					(A)x(C)
(E)	--		16.89	x10^6$	(B)x(C)
(F)					[(D)x100]/(E)
(G)	250.39	MTx10^3	290.39	MTx10^3	See: Zirconium[b]
(H)	544.32	MTx10^3	544.32	MTx10^3	See: Zirconium[b]
(I)	--		53.35	%	[(G)x100]/H
(J)	--		7,452.05	Years	(H)/(B)
(K)					
(L)					

Notes:

[a] Average of reported extreme sponge price values.

[b] Hafnium resources estimated at one-hundredth the size of zirconium resources.

YTTRIUM

	Data	Conversion	Source
(A)			
(B)	400.00 MT	0.40 MTx10^{3}	Hedrick, p.c. (1986)[a]
(C)	35.02 $/KG	35,020.00 $/MT	BOM/MCS (1986)
(D)			(A)x(C)
(E)	—	14.01 $x10^{6}	(B)x(C)
(F)			[(D)x100]/(E)
(G)	3.80 MTx10^{6}	3,447.36 MTx10^{3}	Manheim (1979)[b]
(H)	190,000.00 ST	172.37 MTx10^{3}	BOM/MFP (1980)
(I)			[(G)x100]/H
(J)	—	430.00 Years	(H)/(B)
(K)			
(L)			

Notes:

[a] Contained yttrium oxide in monazite concentrates. *

[b] Monazite (a source of yttrium, thorium, and rare earths) "undiscovered marginal resources" from the Atlantic and Gulf shelves (originally from McKelvey, 1968), rounded to 3,450.00 MTx10^{3}. This same figure also is used for thorium.

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* James B. Hedrick, Mineral commodity Specialist, U.S. Bureau of Mines, Personal communication.

THORIUM

	Data	Conversion	Source
(A)			
(B)	1,544.00 MT	1.54 MTx10^3	BOM/MFP (1985)[a]
(C)	35.85 $/KG	35,850.00 $/MT	BOM/MCS (1986)
(D)			(A)x(C)
(E)	—	71.70 x10^6$	(B)x(C)
(F)			[(D)x100]/(E)
(G)	3.8 MTx10^6	3,447.36 MTx10^3	Manheim (1979)[c]
(H)	5,697.00 STx10^3	5,168.32 MTx10^3	BOM/MFP (1980)
(I)			[(G)x100]/H
(J)	—	2,584.00 Years	(H)/(B)
(K)			
(L)	140.00 MTx10^{12}	140.00 MTx10^{12}	Erickson (1973)

Notes:

[a] 1983 world production.

[b] Thorium oxide, 99% grade.

[c] Monazite (a source of yttrium, thorium, and rare earths) "undiscovered marginal resources" from the Atlantic and Gulf shelves (originally from McKelvey, 1968), rounded to 3,450.00 MTx10^3. This same figure also is used for yttrium.

CHROMITE

	Data		Conversion		Source
(A)					
(B)	10,600.00	STx10^3	9,616.32	MTx10^3	BOM/MCS (1986)
(C)	42.00	$/MT	42.00	$/MT	BOM/MCS (1986)[a]
(D)					(A)x(C)
(E)	--		403.87	$x10^6	(B)x(C)
(F)					[(D)x100]/(E)
(G)	34,658.00	MTx10^3	34,658.00	MTx10^3	Various[b]
(H)	36.00	STx10^9	32,659,200.00	MTx10^3	BOM/MFP (1980)
(I)	--		0.11	%	[(G)x100]/H
(J)	--		3,396.34	Years	(H)/(B)
(K)	443,000.00	MTx10^3	1.36	%	Leontief (1984)/(H)
(L)	2.60	MTx10^{15}	2,600.00	MTx10^{12}	Erickson (1973)

Notes:

[a] South African chromite ore.

[b] Sum of the following resource estimates:

Location	MTx103	Source
Oregon	27,000	USGS (1979)
Lae, Marobe Coast, Papua New Guinea	4,500	Glasby (1986)
Southwest Oregon Beach Sands	3,158	OTA (1985)
	34,658*	

* Broadus (1987) reports U.S. resource estimate only.

GOLD

	Data		Conversion		Source
(A)	30.00	TROZx10^{3}	0.90	MT	CCT (1987)[a]
(B)	47.00	TROZx10^{6}	1.41	MTx10^{3}	BOM/MCS (1986)
(C)	318.00	$/TROZ	10,600,000.00	$/MT	BOM/MCS (1986)
(D)	--		9.54	$x10^{6}	(A)x(C)
(E)	--		10,600.00	$x10^{6}	(B)x(C)
(F)	--		0.09	%	[(D)x100]/(E)
(G)	29.00	TROZx10^{6}	0.87	MTx10^{3}	USGS (1979)[b]
(H)	2.40	MTx10^{9}	72.00	MTx10^{3}	BOM/MCS (1986)
(I)	--		0.28	%	[(G)x100]/H
(J)	--		72.00	Years	(H)/(B)
(K)	319,000.00	MT	443.06	%	Leontief et al. (1984)
(L)	84.00	MTx10^{9}	0.08	MTx10^{12}	Erickson (1973)

Notes: (also see: Silver notes)

a/ "Barge Sifts 30,000 Ounces of Gold in Waters Off Nome," Cape Cod Times (September 19, 1987).

b/ U.S. estimates for:

Location	TROZx10^{6}
Gulf of Alaska, Alaska	10.00
Bering & Chukchi Seas, Alaska	13.00*
Columbia River & Coos Bay, Oregon	6.00
	29.00

* ("Between 5 and 20 TROZx10^{6})

SILVER[a]

	Data		Conversion		Source
(A)					
(B)	394.00	TROZx10^6	11.82	MTx10^3	BOM/MCS (1986)
(C)	6.20	$/TROZ	206,666.67	$/MT	BOM/MCS (1986)
(D)					
(E)	--		2,480.00	x10^6$	(B)x(C)
(F)					
(G)					
(H)	24,755.00	TROZx10^6	742.65	MTx10^3	BOM/MFP (1980)
(I)					
(J)	--		61.92	Years	(H)/(B)
(K)	2,190.00	MTx10^3	294.75	%	Leontief et al. (1984)
(L)	1.80	MTx10^{12}	1.80	MTx10^{12}	Erickson (1973)

Notes:

[a] Bolton et al. (1986) report the occurrence of silver and gold in ferromanganese crusts from a back-arc setting in the soutwest Pacific near Australia and New Zealand.

PLATINUM

	Data	Conversion	Source
(A)			
(B)	7,400.00 TROZx10^3	0.22 MTx10^3	BOM/MCS (1986)
(C)	270.00 $/TROZ	9,000,000.00 $/MT	BOM/MCS (1986)
(D)			
(E)	—	1,998.00 x10^6$	(B)x(C)
(F)			
(G)	0.35 TROZx10^6	0.01 MTx10^3	USGS (1979)[a]
(H)	3.30 TROZx10^9	99.00 MTx10^3	BOM/MCS (1986)
(I)	—	0.01 %	;(G)x100_/H
(J)	—	445.95 Years	(H)/(B)
(K)	12,400.00 MT	12.53 %	Leontief et al. (1984)
(L)	1.10 MTx10^{12}	1.10 MTx10^{12}	Erickson (1973)

Notes:

[a] U.S. estimate only of "identified resources" off Columbia River and Coos Bay, Oregon. Not included are recent estimates of platinum in "cobalt crust" deposits located in the EEZs of U.S. Trust and Affiliated Territories or of manganese nodules located between the Clarion and Clipperton fracture zones:

Mineral	TROZx10^6	MTx10^3	Source
Crusts	78.15	2.34	Clark et al. (1985)
Nodules	—	0.40-1.50	Manheim (1986)
		2.74-3.84	

Halbach (1984) reports platinum enrichment in crusts from the central Pacific region. The U.S. Bureau of Mines has been involved in a resource assessment of platinum-group-metal (PGM) placers south of Goodnews Bay, Alaska (James C. Barker, 1986, Presentation at 17th Annual Underwater Mining Institute, Biloxi, Mississippi, November 3).

DIAMOND

(note changes in measures)

	Data		Conversion		Source
(A)	100,000.00	CT	0.02	MT	Bartlett (1986)[a]
(B)	20,837.00	$CTx10^3$	4.17	MT	BOM/MFP (1985)
(C)	285.35	$/CT	1,426,800,000.00	$/MT	BOM/MFP (1985)[b]
(D)	--		28,520.00	$\$x10^3$	(A)x(C)
(E)	5,945.80	$\$x10^6$	5,945.80	$\$x10^6$	(B)x(C)
(F)	--		0.48	%	[(D)x100]/(E)
(G)					
(H)	250.00	$CTx10^6$	50.00	MT	BOM/MFP (1985)[c]
(I)					
(J)	11.99		11.99	Years	(H)/(B)
(K)					
(L)					

Notes:

a/ South African "alluvial" and marine production reported by Bartlett (1986). Hale and McLaren (1984) reported 50,700.00 CT of gem-quality diamonds recovered off Namibia in 1979-80. Lampietie (unpublished, Oceans '86 conference meeting on marine minerals) reports artisanal diamond mining occurring off Namibia at present.

b/ Diamond prices vary widely due to several factors. This price is the per carat 1983 rough natural diamond declared value for consumption in the United States.

c/ World gem diamond "reserve."

COBALT

	Data		Conversion		Source
(A)					
(B)	35,100.00	ST	31.84	MTx10^3	BOM/MCS (1986)
(C)	11.50	\$/LB	25,352.90	\$/MT	BOM/MCS (1986)
(D)					
(E)	--		811.30	\$x10^6	(B)x(C)
(F)					
(G)	6.40-24.00	MTx10^6	6-24,000.00	MTx10^3	Manheim (1986)[a]
(H)	12.00	STx10^6	10,886.00	MTx10^3	BOM/MCS (1986)
(I)	--		55.12-220.47	%	[(G)x100]/H
(J)	--		340.19	Years	(H)/(B)
(K)					
(L)	600.00	MTx10^{12}	600.00	MTx10^{12}	Erickson (1973)

Notes:

[a] Estimate for manganese nodules located between Clarion and Clipperton fracture zones. Does not include the following other estimates: 39,780.00 MTx10^3 for cobalt in "crust" deposits located in the EEZs of U.S. Trust and Affiliated Territories (Clark et al., 1985); 2,487.00 MTx10^3 for cobalt in "crust" deposits located in the EEZ of Hawaii (Hawaii and MMS, 1987); cobalt "world resources" in seabed nodules of 226,800.00 MTx10^3 (BOM/MFP, 1980); cobalt "proven reserves" in Red Sea muds at the Atlantis II Deep of 5.23 MTx10^3 (Mustafa et al., 1984).

NICKEL

	Data		Conversion		Source
(A)					
(B)	821,000.00	ST	744.81	$MTx10^3$	BOM/MCS (1986)
(C)	2.28	$/LB	5,026.49	$/MT	BOM/MCS (1986)
(D)					
(E)	--		3,744.37	$\$x10^6$	(B)x(C)
(F)					
(G)	35-131.00	$MTx10^6$	35-131,000.00	$MTx10^3$	Manheim (1986)[a]
(H)	143.00	$STx10^6$	129,730.00	$MTx10^3$	BOM/MCS (1986)
(I)	--		26.98-100.98	%	[(G)x100]/H
(J)	--		174.13	Years	(H)/(B)
(K)	99,590.00	$MTx10^3$	76.77	%	Leontief et al. (1984)
(L)	2.13	$MTx10^{12}$	2.13	$MTx10^{12}$	Erickson (1973)

Notes:

a/ Estimate for manganese nodules located between Clarion and Clipperton fracture zones. Does not include the following other estimates: 21,380.00 $MTx10^3$ for nickel in "crust" deposits located in the EEZs of U.S. Trust and Affiliated Territories (Clark et al., 1985); 1,304.00 $MTx10^3$ for nickel in "crust" deposits located in the EEZ of Hawaii (Hawaii and MMS, 1987); nickel "world resources" in seabed nodules of 689,472.00 $MTx10^3$ (BOM/MFP, 1980).

MANGANESE

	Data	Conversion	Source
(A)			
(B)	25,800.00 STx10^3	23,405.76 MTx10^3	BOM/MCS (1986)
(C)	1.43 $/LTU	140.74 $/MT	BOM/MCS (1986)[a]
(D)			
(E)	--	3,300.25 x10^6$	(B)x(C)
(F)			
(G)	706.00- 2,600.00 MTx10^6	706,000.00- 2,600,000.00 MTx10^3	Manheim (1986)[b]
(H)	12,000,000.00 STx10^3	10,886,400.00 MTx10^3	BOM/MCS (1986)
(I)	--	6.49-23.80 %	[(G)x100]/H
(J)	--	465.11 Years	(H)/(B)
(K)	1,810,000.00 MTx10^3	16.63 %	Leontief et al. (1984)
(L)	31.20 MTx10^{15}	31,200.00 MTx10^{12}	Erickson (1973)

Notes:

[a] Manganese ore (46-48% Mn) price expressed in long ton units, or one-hundredth of a long ton.

[b] Estimate for manganese nodules located between Clarion and Clipperton fracture zones. Does not include the following other estimates: 1,084,100.00 MTx10^3 for manganese in "crust" deposits located in the EEZs of U.S. Trust and Affiliated Territories (Clark et al., 1985); 44,651.00 MTx10^3 for manganese in "crust" deposits located in the EEZ of Hawaii (Hawaii and MMS, 1987); manganese "world resources" in seabed nodules of 16,329,600.00 MTx10^3 (BOM/MFP, 1980).

COPPER

	Data	Conversion	Source
(A)			
(B)	7,805.00 MTx10^3	7,805.00 MTx10^3	BOM/MCS (1986)
(C)	66.90 c/LB	1,474.88 $/MT	BOM/MCS (1986)
(D)			
(E)	—	11,512.38 $x10^6	(B)x(C)
(F)			
(G)	33-314,200.00 MTx10^3	33-314,200.00 MTx10^3	Various[a]
(H)	1.60 Mtx10^9	1,600,000.00 MTx10^3	BOM/MCS (1986)
(I)	—	2.07-19.64 %	[(G)x100]/H
(J)	—	205.00 Years	(H)/(B)
(K)	1,383.00 MTx10^6	86.44 %	Leontief et al. (1984)
(L)	1,510.00 MTx10^{12}	1,510.00 MTx10^{12}	Erickson (1973)

Notes:

[a] Seabed copper resources are estimated as follows:

Location	MTx103	Source
Clarion-Clipperton Zone Nodules	29-108,000*	Manheim (1986)
World Marine Polymetallic Sulfides	4-215,600	Broadus (1984)
Red Sea Metalliferous Muds	600	Mustafa et al. (1984)
	33-314,000	

*Copper "world resources" in seabed nodules have also been estimated at 700,000.00 MTx10^3 (BOM/MFP, 1980).

ZINC

	Data	Conversion	Source
(A)			
(B)	6,560.00 MTx10^3	6,560.00 MTx10^3	BOM/MCS (1986)
(C)	40.50 c/LB	892.86 $/MT	BOM/MCS (1986)
(D)			
(E)	—	5,858.08 x10^6$	(B)x(C)
(F)			
(G)	10.74-518.04 MTx10^6	10,740-518,040.00 MTx10^3	Various[a]
(H)	1.80 MTx10^9	1,800,000.00 MTx10^3	BOM/MCS (1986)
(I)	—	0.60-28.78 %	[(G)x100]/H
(J)	—	274.39 Years	(H)/(B)
(K)	848.00 MTx10^6	47.11 %	Leontief et al. (1984)
(L)	2,250.00 MTx10^{12}	2,250.00 MTx10^{12}	Erickson (1973)

Notes:

[a] Seabed zinc resources have been estimated as follows:

Location	MTx103	Source
World Marine Polymetallic Sulfides	8,300-515,600	Broadus (1984)
Red Sea Metalliferous Muds	2,440*	Mustafa et al. (1984)
	10,740-518,040	

*("Proven reserves" of zinc.)

LEAD

	Data	Conversion	Source
(A)			
(B)	3,350.00 MTx10^3	3,350.00 MTx10^3	BOM/MCS (1986)
(C)	19.00 c/LB	418.87 $/MT	BOM/MCS (1986)
(D)			
(E)	—	1,403.65 x10^6$	(B)x(C)
(F)			
(G)	(Possible occurrence in marine polymetallic sulfides?)		
(H)	1.40 MTx10^9	1,400,000.00 MTx10^3	BOM/MCS (1986)
(I)			
(J)	—	417.91 Years	(H)/(B)
(K)	639.00 MTx10^6	45.64 %	Leontief et al. (1984)
(L)	290.00 MTx10^{12}	290.00 MTx10^{12}	Erickson (1973)

Notes:

Section III: Price Series

Data on the estimated average prices of several material commodities are tabulated here. The primary references are Manthy (1978), following Potter and Christy (1962), and the U.S. Bureau of Mines (1985, 1980). Other specific sources are named in the tables. Wherever possible, data used by Manthy are updated using the same reference materials that he employed. Because the data for these price series are derived from a number of different sources, it has not been possible to obtain series of identical length. The prices are deflated with the consumer price index (CPI) published by the U.S. Bureau of the Census (1985, 1976) (see Table III-1). Deflated prices are indexed to 1967 as a base year (1967=100). The figures appearing in these tables have been rounded for presentation. In several cases, following Slade (1982b), linear (solid line) and quadratic (dashed line) fits are shown. These plotted series and fits appeared in Broadus (1987). The deflating, indexing, and curve fitting for these price series was conducted by Andy Solow, Marine Policy Center, WHOI. The fits are not necessarily reliable indicators of price trends over time and have been constructed only as a general guide to inspection of the time series.

Composite price series were constructed for sand and gravel, manganese nodules, cobalt crusts, and marine polymetallic sulfides. These composites are grade-weighted prices, using an average weight percent estimated for specific material commodities found in these seabed deposits. The U.S. Bureau of Mines estimated average price for sand and gravel was used without modification. The following weight percents were used for nodules (Haynes and Law, 1982; Manheim, 1986):

Cobalt	0.24%
Nickel	1.28
Manganese	25.40
Copper	1.02

The following weight percents were used for cobalt crusts (Manheim, 1986):

Cobalt	0.73%
Nickel	0.47
Manganese	23.06

The following weight percents were used for marine polymetallic sulfides from the 21°N East Pacific Rise deposits (Bischoff et al., 1983):

Zinc	32.30%
Copper	0.81

Table III-1: CONSUMER PRICE INDEX (1967=100)

Source: BOC/Hist. Stat. (1976), pp. 210-211

Year	Index	Year	Index	Year	Index
1870	38.0	1916	32.7	1962	90.6
1871	36.0	1917	38.4	1963	91.7
1872	36.0	1918	45.1	1964	92.9
1873	36.0	1919	51.8	1965	94.5
1874	34.0	1920	60.0	1966	97.2
1875	33.0	1921	53.6	1967	100.0
1876	32.0	1922	50.2	1968	104.2
1877	32.0	1923	51.1	1969	109.8
1878	29.0	1924	51.2	1970	116.3
1879	28.0	1925	52.5	1971	121.3*
1880	29.0	1926	53.0	1972	125.3
1881	29.0	1927	52.0	1973	133.1
1882	29.0	1928	51.3	1974	147.7
1883	28.0	1929	51.3	1975	161.2
1884	27.0	1930	50.0	1976	170.5
1885	27.0	1931	45.6	1977	181.5
1886	27.0	1932	40.9	1978	195.4
1887	27.0	1933	38.8	1979	217.4
1888	27.0	1934	40.1	1980	246.8
1889	27.0	1935	41.1	1981	272.4
1890	27.0	1936	41.5	1982	289.1
1891	27.0	1937	43.0	1983	298.4
1892	27.0	1938	42.2	1984	310.7
1893	27.0	1939	41.6		
1894	26.0	1940	42.0		
1895	25.0	1941	44.1		
1896	25.0	1942	48.8		
1897	25.0	1943	51.8		
1898	25.0	1944	52.7		
1899	25.0	1945	53.9		
1900	25.0	1946	58.5		
1901	25.0	1947	66.9		
1902	26.0	1948	72.1		
1903	27.0	1949	71.4		
1904	27.0	1950	72.1		
1905	27.0	1951	77.8		
1906	27.0	1952	79.5		
1907	28.0	1953	80.1		
1908	27.0	1954	80.5		
1909	27.0	1955	80.2		
1910	28.0	1956	81.4		
1911	28.0	1957	84.3		
1912	29.0	1958	86.6		
1913	29.7	1959	87.3		
1914	30.1	1960	88.7		
1915	30.4	1961	89.6		

*BOC/Stat. Abst. (1985), p. 475.

The plots and price series are arranged as follows:

Commodity		Figure
Chromite	Plot	III-1a
	Price Series	III-1b
Tin	Plot	III-2a
	Price Series	III-2b
Titanium Metal	Plot	III-3a
	Price Series	III-3b
Rutile	Price Series	III-3c
Phosphate Rock	Plot	III-4a
	Price Series	III-4b
Composites		
Sand and Gravel	Plot	III-5a
	Price Series	III-5b
Crusts Composite	Plot	III-6a
	Price Series	III-6b
Nodule Composite	Plot	III-7a
	Price Series	III-7b
Cobalt	Price Series	III-8
Manganese	Price Series	III-9
Nickel	Price Series	III-10
Copper	Price Series	III-11
MPS Composite	Plot	III-12a
	Price Series	III-12b
Zinc	Price Series	III-13
Copper (see above)		

Figure III-1a

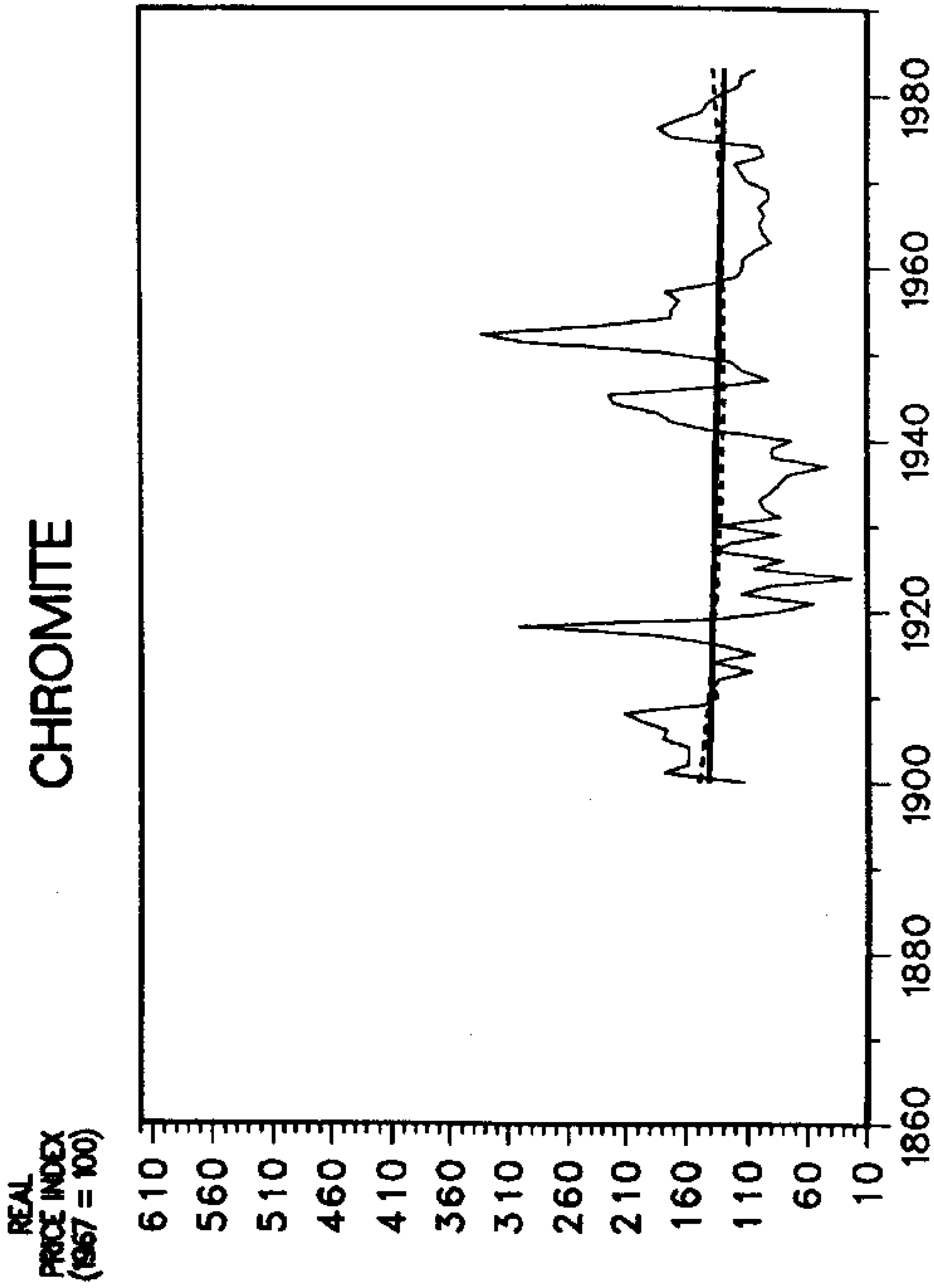


Figure III-1b

CHROMITE

Year	Price $/ST	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1900	10.0	0.40	113.32	149.34	141.49
1901	15.7	0.63	177.91	148.54	
1902	14.5	0.56	157.99	147.76	
1903	15.0	0.56	157.39	146.99	
1904	15.0	0.56	157.39	146.24	
1905	17.1	0.63	179.42	145.51	
1906	16.8	0.62	176.28	144.79	
1907	19.5	0.70	197.30	144.08	
1908	20.2	0.75	211.95	143.40	
1909	13.9	0.51	145.85	142.73	
1910	13.3	0.48	134.57	142.07	
1911	13.6	0.49	137.60	141.43	
1912	13.7	0.47	133.83	140.81	
1913	11.2	0.38	106.83	140.20	
1914	14.8	0.49	139.30	139.61	
1915	11.2	0.37	104.37	139.03	
1916	15.4	0.47	133.42	138.47	
1917	24.0	0.63	177.06	137.93	
1918	48.0	1.06	301.52	137.40	
1919	25.5	0.49	139.46	136.89	
1920	18.0	0.30	84.99	136.39	
1921	10.3	0.19	54.44	135.91	
1922	20.5	0.41	115.69	135.45	
1923	16.8	0.33	93.14	135.00	
1924	4.0	0.08	22.13	134.57	
1925	19.5	0.37	105.23	134.15	
1926	14.8	0.28	79.11	133.75	
1927	25.2	0.48	137.29	133.36	
1928	22.4	0.44	123.70	132.99	
1929	14.8	0.29	81.73	132.64	
1930	23.8	0.48	134.85	132.30	
1931	13.1	0.29	81.39	131.98	
1932	13.9	0.34	96.28	131.68	
1933	13.7	0.35	100.03	131.39	
1934	12.6	0.31	89.02	131.11	
1935	12.0	0.29	82.72	130.85	
1936	11.0	0.27	75.09	130.61	
1937	6.5	0.15	42.82	130.38	
1938	13.2	0.31	88.62	130.17	
1939	13.0	0.31	88.53	129.98	
1940	10.8	0.26	72.85	129.80	
1941	21.5	0.49	138.12	129.64	
1942	29.7	0.61	172.42	129.49	
1943	33.7	0.65	184.31	129.36	
1944	41.0	0.78	220.40	129.24	
1945	42.7	0.79	224.43	129.14	
1946	28.7	0.49	138.99	129.06	

Figure III-1b

CHROMITE (contd)

Year	Price $/ST	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1947	21.6	0.32	91.47	128.99	
1948	29.0	0.40	113.95	128.94	
1949	31.0	0.43	123.00	128.90	
1950	45.2	0.63	177.60	128.88	
1951	81.1	1.04	295.32	128.88	
1952	93.5	1.18	333.19	128.89	
1953	65.4	0.82	231.31	128.92	
1954	49.1	0.61	172.80	128.96	
1955	48.6	0.61	171.68	129.02	
1956	47.1	0.58	163.92	129.10	
1957	52.7	0.63	177.10	129.18	
1958	43.0	0.50	140.67	129.29	
1959	35.9	0.41	116.50	129.41	
1960	35.6	0.40	113.70	129.55	
1961	35.8	0.40	113.19	129.70	
1962	32.8	0.36	102.56	129.87	
1963	29.0	0.32	89.59	130.06	
1964	31.8	0.34	96.97	130.26	
1965	33.3	0.35	99.83	130.48	
1966	32.6	0.34	95.02	130.71	
1967	35.3	0.35	100.00	130.96	
1968	33.5	0.32	91.08	131.23	
1969	35.7	0.33	92.11	131.51	
1970	45.5	0.39	110.84	131.80	
1971	49.3	0.41	115.14	132.12	
1972	52.8	0.42	119.38	132.45	
1973	45.1	0.34	95.99	132.79	
1974	51.7	0.35	99.16	133.15	
1975	97.0	0.60	170.47	133.53	
1976	110.0	0.65	182.73	133.92	
1977	106.0	0.58	165.45	134.33	
1978	101.0	0.52	146.47	134.75	
1979	109.0	0.50	141.93	135.19	
1980	115.0	0.47	132.02	135.65	
1981	111.0	0.41	115.30	136.12	
1982	117.0	0.41	114.74	136.61	
1983	109.0	0.37	103.40	137.11	128.09

Figure III-2a

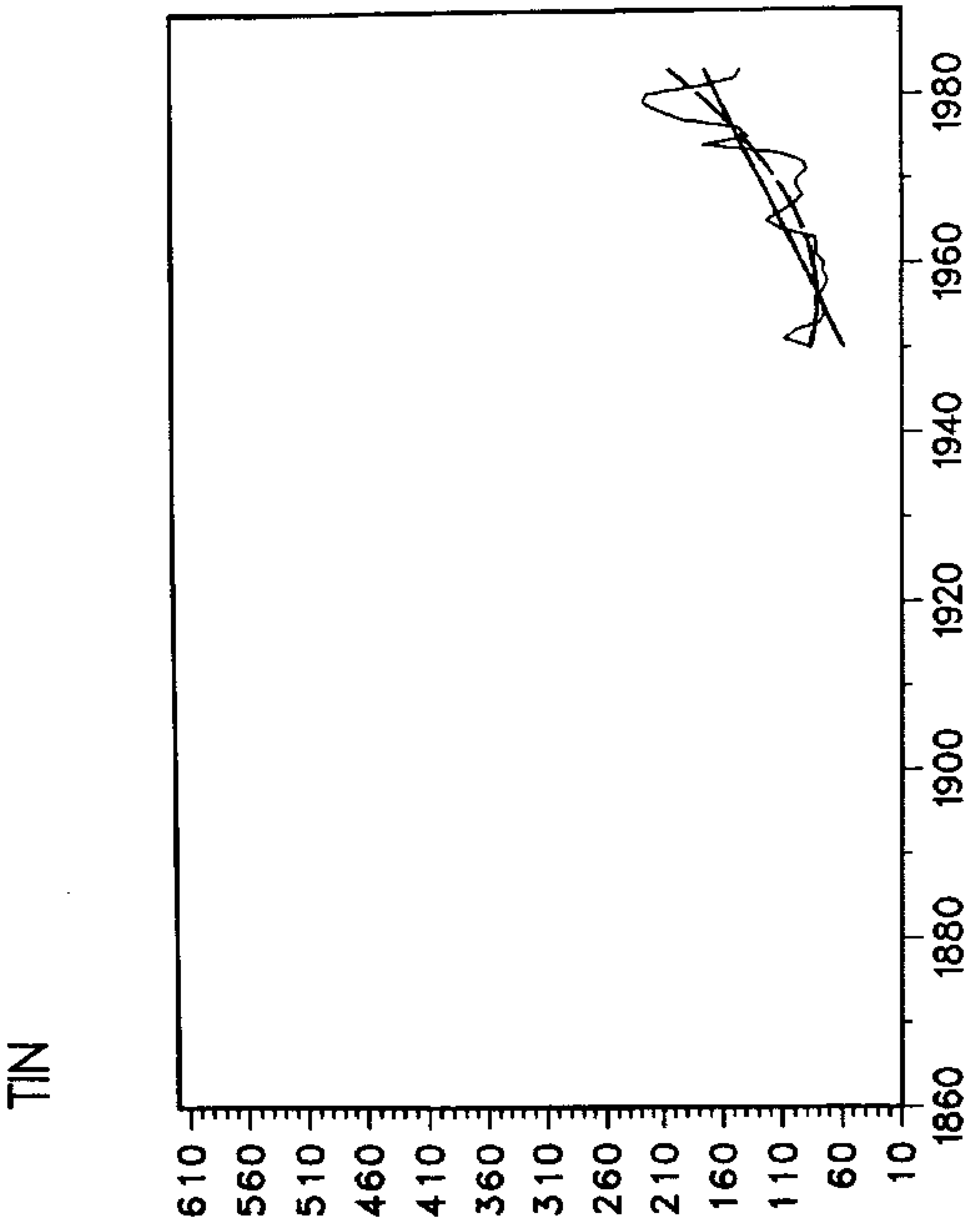


Figure III-2b

TIN

Year	Price /lb*	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1950	95.6	1.33	86.45	87.0	65
1951	128.3	1.65	107.52	85.2	
1952	120.5**	1.52	98.78	83.8	
1953	95.8	1.20	77.98	82.8	
1954	91.8	1.14	74.35	82.0	
1955	94.7	1.18	76.99	81.6	
1956	101.3	1.24	81.14	81.6	
1957	96.2	1.14	74.40	81.8	
1958	95.1	1.10	71.60	82.4	
1959	102.0	1.17	76.18	83.3	
1960	101.4	1.14	74.54	84.5	
1961	113.3	1.26	82.44	86.1	
1962	114.6	1.26	82.47	88.0	
1963	116.6	1.27	82.90	90.2	
1964	157.7	1.70	110.68	92.8	
1965	178.2	1.89	122.95	95.6	
1966	164.0	1.69	110.01	98.8	
1967	153.4	1.53	100.02	102.4	
1968	148.1	1.42	92.67	106.2	
1969	164.4	1.50	97.62	110.4	
1970	174.1	1.50	97.60	114.9	
1971	167.4	1.38	89.98	119.8	
1972	177.5	1.42	92.36	124.9	
1973	227.2	1.71	111.30	130.4	
1974	396.3	2.68	174.94	136.3	
1975	339.6	2.11	137.36	142.4	
1976	379.8	2.23	145.24	148.9	
1977	534.6	2.95	192.04	155.7	
1978	629.6	3.22	210.08	162.8	
1979	753.9	3.47	226.10	170.3	
1980	846.0	3.43	223.50	178.1	
1981	733.1	2.69	175.47	186.2	
1982	653.9	2.26	147.47	194.7	
1983	654.8	2.19	143.07	203.4	186

* Tin Price reported by American Metal Market, <u>Metal Statistics</u> (1984), p. 198.

** The price reported by American Metal Market (1984) is 12.4 cents per pound in 1952 (which is probably a typographical error). This price was included by accident in the plot found in Broadus (1987). We have since substituted the price found in Metallgesellschaft (1984) of 120.47 cents per pound (average) for the same year and replotted the series in Figure III-2a.

Figure III-3a

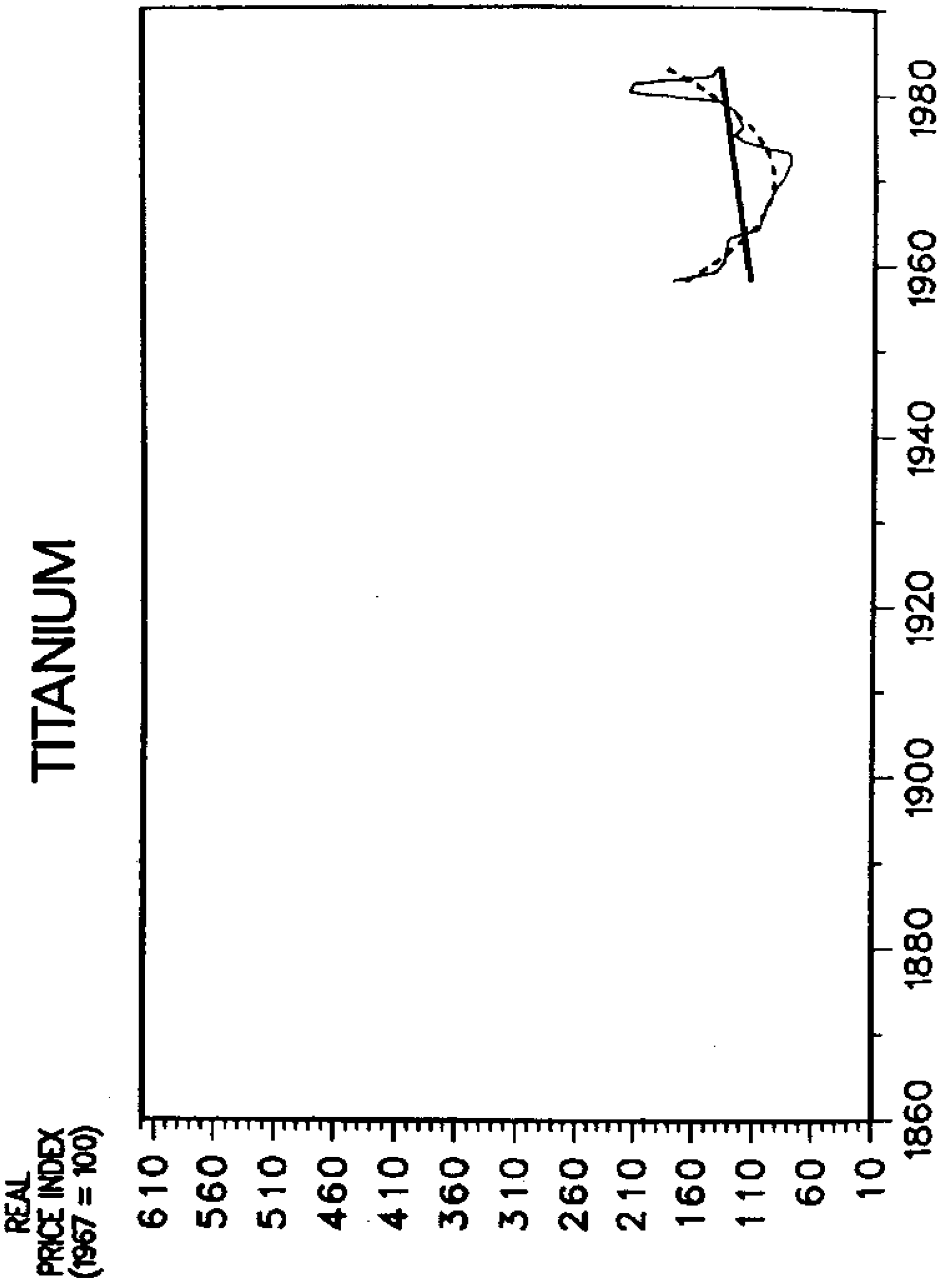


Figure III-3b

TITANIUM METAL

Year	Price $/lb	Deflated Price ($x10^{-2}$)	Index (1967=100)	Quadratic Fit	Linear Fit
1958	2.05	2.37	179.33	168.71	114.59
1959	1.66	1.90	144.05	156.67	
1960	1.60	1.80	136.65	145.68	
1961	1.60	1.79	135.28	135.76	
1962	1.60	1.77	133.79	126.89	
1963	1.60	1.74	132.18	119.09	
1964	1.32	1.42	107.64	112.35	
1965	1.32	1.40	105.82	106.67	
1966	1.32	1.36	102.88	102.05	
1967	1.32	1.32	100.00	98.49	
1968	1.32	1.27	95.97	95.96	
1969	1.32	1.20	91.08	94.55	
1970	1.32	1.13	85.99	94.17	
1971	1.32	1.09	82.44	94.85	
1972	1.32	1.05	79.81	96.59	
1973	1.42	1.07	80.82	99.39	
1974	2.25	1.52	115.41	103.26	
1975	2.70	1.67	126.89	108.18	
1976	2.70	1.58	119.97	114.17	
1977	2.98	1.64	124.39	121.21	
1978	3.28	1.68	127.17	129.32	
1979	3.98	1.83	138.69	138.49	
1980	7.02	2.84	215.47	148.71	
1981	7.65	2.81	212.76	160.00	
1982	5.55	1.92	145.44	172.35	
1983	5.55	1.86	140.90	185.76	138.46

Figure III-3c

RUTILE

Year	Price $/lb	Deflated Price ($x10^{-3}$)	Index (1967=100)	Quadratic Fit	Linear Fit
1958	0.46	5.31	115.47	118.57	110.02
1959	0.46	5.27	114.55	115.59	
1960	0.46	5.19	112.74	112.80	
1961	0.46	5.13	111.61	110.19	
1962	0.46	5.08	110.38	107.77	
1963	0.46	5.02	109.05	105.54	
1964	0.46	4.95	107.64	103.49	
1965	0.46	4.87	105.82	101.63	
1966	0.46	4.73	102.88	99.96	
1967	0.46	4.60	100.00	98.48	
1968	0.48	4.61	100.14	97.18	
1969	0.48	4.37	95.03	96.07	
1970	0.45	3.87	84.12	95.15	
1971	0.45	3.71	80.65	94.41	
1972	0.45	3.59	78.07	93.86	
1973	0.50	3.76	81.66	93.50	
1974	0.72	4.87	105.97	93.32	
1975	0.73	4.53	98.45	93.33	
1976	0.78	4.57	99.45	93.53	
1977	0.81	4.46	97.02	93.91	
1978	0.85	4.35	94.57	94.48	
1979	0.98	4.51	98.00	95.24	
1980	1.05	4.25	92.49	96.19	
1981	1.25	4.59	99.76	97.32	
1982	1.25	4.32	93.99	98.64	
1983	1.25	4.19	91.07	100.15	88.83

Figure III-4a

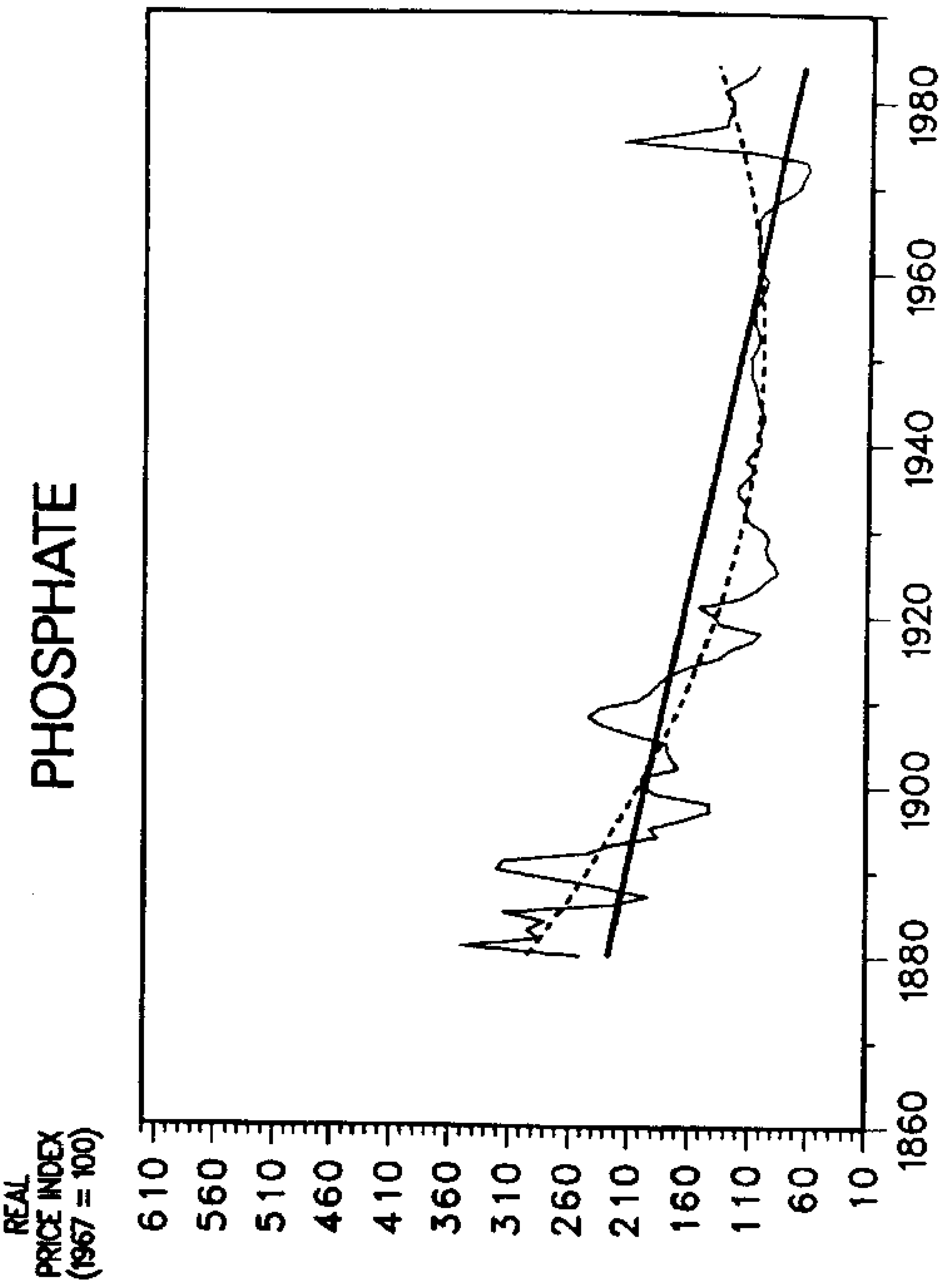


Figure III-4b

PHOSPHATE ROCK

Year	Price $/MT	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1880	5.3	0.18	250.36	293.20	225.86
1881	7.4	0.26	349.56	287.83	
1882	6.0	0.21	283.43	282.54	
1883	6.0	0.21	293.55	277.32	
1884	5.5	0.20	279.05	272.18	
1885	6.2	0.23	314.57	267.12	
1886	4.3	0.16	218.17	262.13	
1887	3.8	0.14	192.80	257.21	
1888	4.5	0.17	228.32	252.37	
1889	5.4	0.20	273.98	247.61	
1890	6.3	0.23	319.64	242.92	
1891	6.2	0.23	314.57	238.31	
1892	4.8	0.18	243.54	233.77	
1893	4.4	0.16	223.24	229.31	
1894	3.5	0.13	184.41	224.92	
1895	3.5	0.14	191.79	220.61	
1896	3.0	0.12	164.39	216.37	
1897	2.6	0.10	142.47	212.21	
1898	2.6	0.10	142.47	208.13	
1899	3.4	0.14	186.31	204.12	
1900	3.6	0.14	197.27	200.18	
1901	3.6	0.14	197.27	196.32	
1902	3.2	0.12	168.60	192.54	
1903	3.4	0.13	172.51	188.83	
1904	3.5	0.13	177.58	185.19	
1905	3.5	0.13	177.58	181.64	
1906	4.1	0.15	208.02	178.15	
1907	4.7	0.17	229.95	174.74	
1908	4.8	0.18	243.54	171.41	
1909	4.6	0.17	233.39	168.16	
1910	4.1	0.15	200.59	164.97	
1911	3.9	0.14	190.81	161.87	
1912	3.9	0.13	184.23	158.84	
1913	3.8	0.13	175.27	155.88	
1914	3.5	0.12	159.29	153.00	
1915	3.0	0.10	135.19	150.20	
1916	3.0	0.10	125.68	147.47	
1917	3.0	0.08	107.02	144.81	
1918	3.3	0.07	100.24	142.23	
1919	5.1	0.10	134.87	139.73	
1920	6.1	0.10	139.27	137.30	
1921	5.9	0.11	150.79	134.95	
1922	4.3	0.09	117.34	132.67	
1923	3.9	0.08	104.55	130.47	
1924	3.6	0.07	96.32	128.34	
1925	3.3	0.06	86.11	126.29	
1926	3.4	0.06	87.88	124.32	
1927	3.6	0.07	94.84	122.41	

Figure III-4b

PHOSPHATE ROCK (continued)

Year	Price $/MT	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1928	3.6	0.07	96.13	120.59	
1929	3.5	0.07	93.46	118.84	
1930	3.6	0.07	98.63	117.16	
1931	3.7	0.08	111.15	115.56	
1932	3.4	0.08	113.88	114.04	
1933	3.2	0.08	112.98	112.59	
1934	3.5	0.09	119.57	111.22	
1935	3.6	0.09	119.99	109.92	
1936	3.4	0.08	112.23	108.70	
1937	3.3	0.08	105.13	107.55	
1938	3.5	0.08	113.62	106.48	
1939	3.3	0.08	108.67	105.48	
1940	3.1	0.07	101.11	104.56	
1941	3.3	0.07	102.51	103.72	
1942	3.6	0.07	101.06	102.94	
1943	3.7	0.07	97.85	102.25	
1944	3.9	0.07	101.38	101.63	
1945	4.1	0.08	104.20	101.08	
1946	4.5	0.08	105.38	100.62	
1947	5.2	0.08	106.48	100.22	
1948	5.8	0.08	110.20	99.90	
1949	5.7	0.08	109.36	99.66	
1950	5.8	0.08	110.20	99.49	
1951	6.0	0.08	105.65	99.40	
1952	6.0	0.08	103.39	99.38	
1953	6.1	0.08	104.32	99.44	
1954	6.3	0.08	107.21	99.57	
1955	6.3	0.08	107.61	99.78	
1956	6.3	0.08	106.02	100.07	
1957	6.3	0.07	102.38	100.43	
1958	6.2	0.07	98.08	100.86	
1959	6.1	0.07	95.72	101.37	
1960	6.6	0.07	101.93	101.96	
1961	6.9	0.08	105.49	102.62	
1962	6.9	0.08	104.33	103.36	
1963	7.0	0.08	104.57	104.17	
1964	7.0	0.08	103.22	105.05	
1965	7.2	0.08	104.37	106.02	
1966	7.4	0.08	104.29	107.05	
1967	7.3	0.07	100.00	108.17	
1968	6.8	0.07	89.40	109.36	
1969	6.1	0.06	76.11	110.62	
1970	5.8	0.05	68.32	111.96	
1971	5.8	0.05	65.50	113.37	
1972	5.6	0.05	61.22	114.86	
1973	6.2	0.05	63.81	116.43	
1974	12.1	0.08	112.22	118.07	
1975	25.4	0.16	215.85	119.78	
1976	21.3	0.12	171.14	121.58	
1977	17.4	0.10	131.33	123.44	
1978	18.6	0.10	130.40	125.38	
1979	20.0	0.09	126.03	127.40	

Figure III-4b

PHOSPHATE ROCK (continued)

Year	Price $/MT	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1980	22.8	0.09	126.55	129.49	
1981	26.6	0.10	133.77	131.66	
1982	25.5	0.09	120.83	133.90	
1983	24.0	0.08	110.18	136.22	
1984	24.0	0.08	105.82	138.62	65.58

Figure III-5a

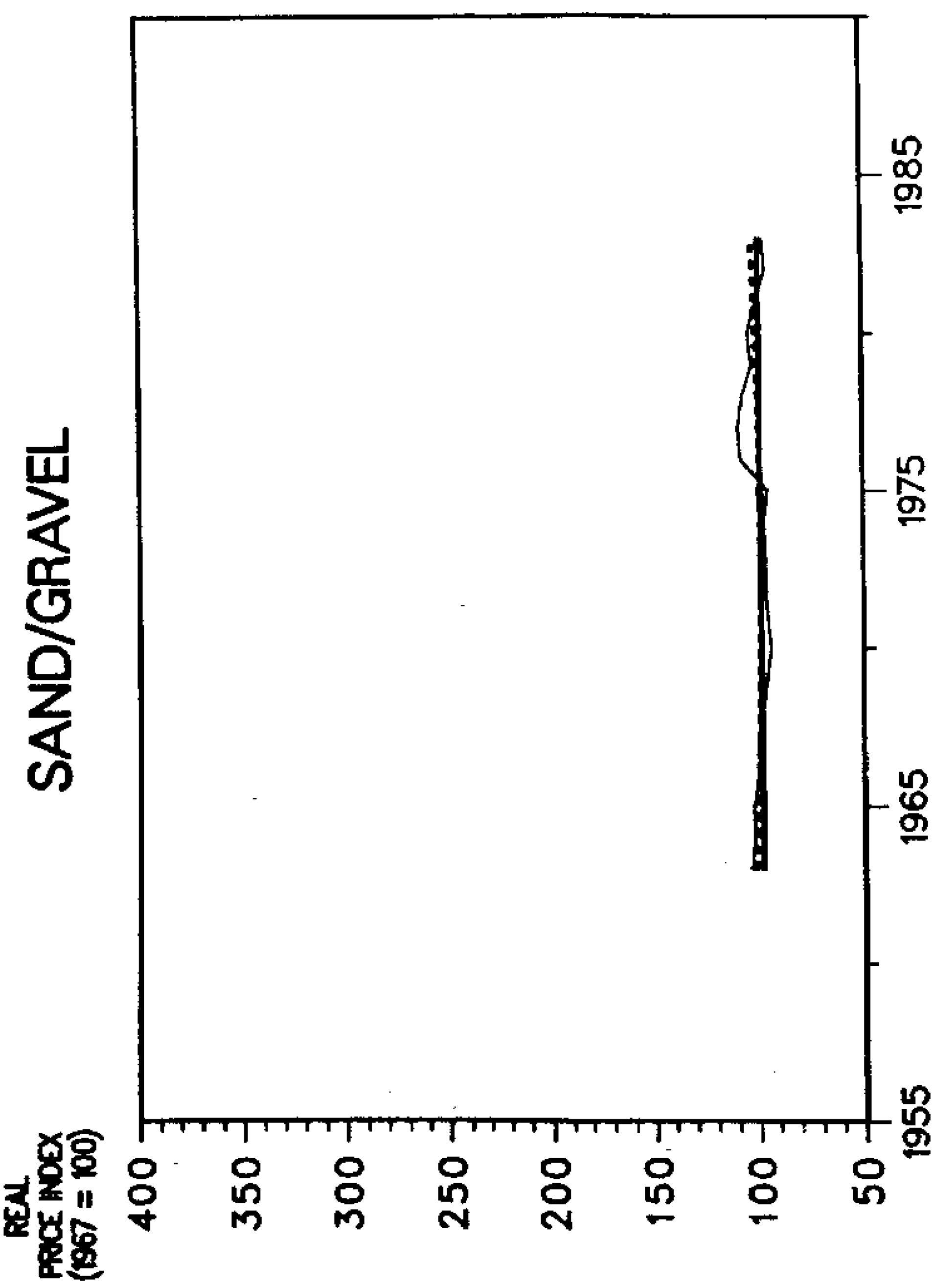


Figure III-5b

CONSTRUCTION SAND & GRAVEL COMPOSITE

Year	Price $/ST	Deflated Price ($x10^{-2}$)	Index (1967=100)	Quadratic Fit	Linear Fit
1963	0.97	1.06	103.71	101.47	98.09
1964	0.97	1.04	102.37	101.03	
1965	0.99	1.05	102.71	100.65	
1966	0.99	1.02	99.85	100.31	
1967	1.02	1.02	100.00	100.02	
1968	1.04	1.00	97.85	99.79	
1969	1.07	0.97	95.54	99.61	
1970	1.11	0.95	93.57	99.47	
1971	1.18	0.97	95.37	99.39	
1972	1.23	0.98	96.24	99.36	
1973	1.31	0.98	96.49	99.38	
1974	1.46	0.99	96.91	99.45	
1975	1.56	0.97	94.88	99.58	
1976	1.88	1.10	108.10	99.75	
1977	2.02	1.11	109.11	99.98	
1978	2.13	1.09	106.87	100.25	
1979	2.27	1.04	102.37	100.58	
1980	2.62	1.06	104.08	100.95	
1981	2.79	1.02	100.41	101.38	
1982	2.82	0.98	95.63	101.86	
1983	2.95	0.99	96.92	102.39	99.12

Figure III-6a

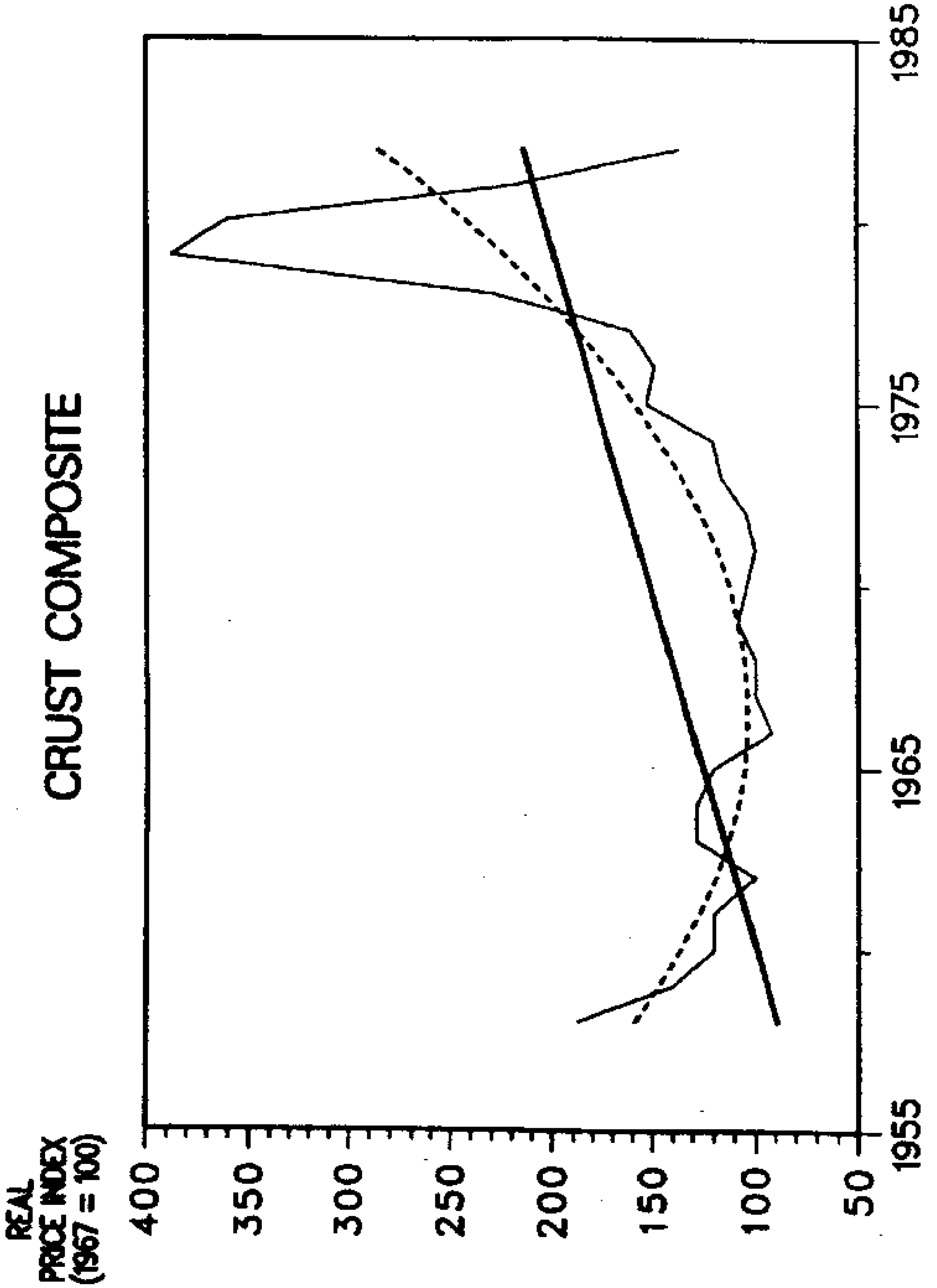


Figure III-6b

CRUST COMPOSITE

Year	Index (1967=100)	Quadratic Fit	Linear Fit
1958	188	159	89
1959	140	147	
1960	120	136	
1961	120	127	
1962	100	119	
1963	128	113	
1964	128	108	
1965	120	105	
1966	92	104	
1967	100	104	
1968	100	105	
1969	108	108	
1970	104	112	
1971	100	118	
1972	104	126	
1973	116	135	
1974	120	146	
1975	152	158	
1976	148	171	
1977	160	187	
1978	228	203	
1979	338	221	
1980	360	241	
1981	216	262	
1982	136	285	213

Figure III-7a

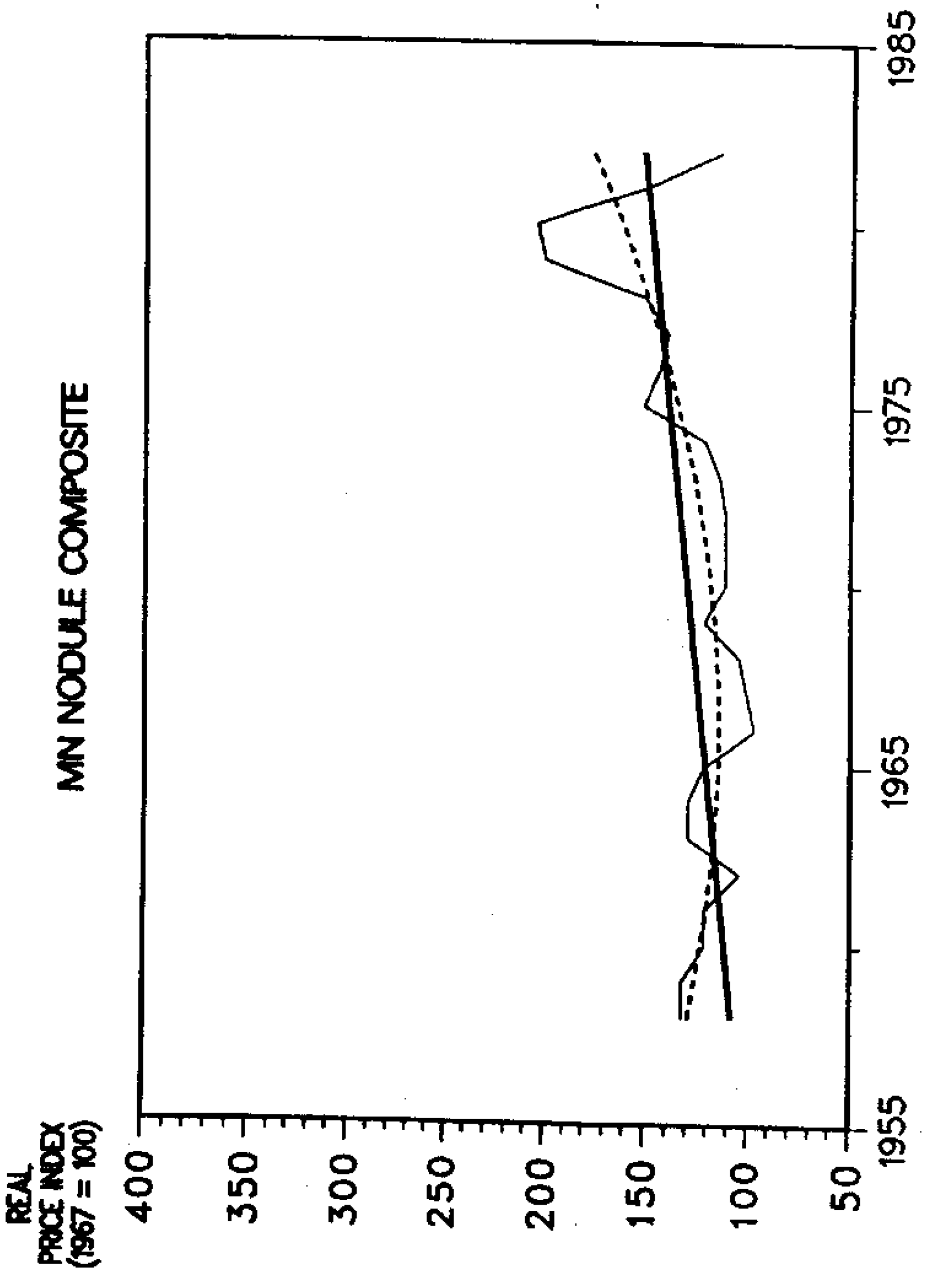


Figure III-7b

MN NODULE COMPOSITE

Year	Index (1967=100)	Quadratic Fit	Linear Fit
1958	132	129	108
1959	132	126	
1960	121	123	
1961	121	120	
1962	104	118	
1963	129	116	
1964	129	115	
1965	121	114	
1966	96	114	
1967	100	114	
1968	104	115	
1969	121	116	
1970	111	118	
1971	111	120	
1972	111	123	
1973	114	126	
1974	121	130	
1975	150	134	
1976	143	138	
1977	139	143	
1978	150	149	
1979	200	155	
1980	204	161	
1981	150	168	
1982	114	176	151

Figure III-8

COBALT

Year	Price $/lb	Deflated Price (x10^{-2})	Index	Quadratic Fit	Linear Fit
1958	2.00	2.31	124.84	81.40	48.11
1959	1.77	2.03	109.59	82.35	
1960	1.54	1.74	93.85	83.92	
1961	1.50	1.67	90.49	86.10	
1962	1.50	1.66	89.49	88.91	
1963	1.50	1.64	88.42	92.34	
1964	1.50	1.61	87.28	96.40	
1965	1.62	1.71	92.66	101.07	
1966	1.65	1.70	91.76	106.37	
1967	1.85	1.85	100.00	112.29	
1968	1.85	1.78	95.97	118.83	
1969	1.89	1.72	93.04	125.99	
1970	2.20	1.89	102.25	133.77	
1971	2.20	1.81	98.04	142.17	
1972	2.45	1.96	105.69	151.20	
1973	3.00	2.25	121.83	160.85	
1974	3.46	2.34	126.63	171.12	
1975	3.98	2.47	133.46	182.01	
1976	4.44	2.60	140.76	193.52	
1977	5.58	3.07	166.18	205.65	
1978	11.53	5.90	318.96	218.41	
1979	24.58	11.31	611.15	231.79	
1980	25.00	10.13	547.55	245.79	
1981	14.58	5.35	289.32	260.41	
1982	8.56	2.96	160.05	275.65	
1983	5.76	1.93	104.34	291.51	
1984	10.40	3.35	180.93	308.00	272.97

Figure III-9

MANGANESE

Year	Current Price*	Deflated Price (x 10^{-2})	Index (1967=100)	Quadratic Fit	Linear Fit
1958	0.06	0.07	230	244	193
1959	0.06	0.07	230		
1960	0.05	0.06	187		
1961	0.05	0.06	187		
1962	0.04	0.04	147		
1963	0.06	0.07	217		
1964	0.06	0.07	217		
1965	0.06	0.06	210		
1966	0.03	0.03	103		
1967	0.03	0.03	100		
1968	0.03	0.03	97		
1969	0.04	0.04	120		
1970	0.04	0.03	113	-14.7	
1971	0.04	0.03	110		
1972	0.04	0.03	107		
1973	0.04	0.03	100		
1974	0.04	0.03	90		
1975	0.09	0.06	187		
1976	0.09	0.05	177		
1977	0.09	0.05	167		
1978	0.08	0.04	137		
1979	0.09	0.04	137		
1980	0.10	0.04	137		
1981	0.10	0.04	123		
1982	0.10	0.04	117	0.44	-3.3

* Manganese price expressed in \$/lb and calculated using the following formula:

$\frac{\$a}{LT} \times .47 \times \frac{LT}{2240 lb}$ = current price; where a = price of ferromanganese ore reported annually (until 1982) by the Bureau of Labor Statistics; LT = long tons; 0.47 = average percent of manganese in ferromanganese ore. From 1958 through 1972, the BLS price of ferromanganese ore was calculated from the index reported in Manthy (1973) according to the following formula:

$\text{Manthy Index} \times \frac{\$94.83}{LT} \times \frac{1}{100} = a$; where \$94.83 = price of ferromanganese ore in 1926. **This method of calculating the price of manganese results in slightly higher priced manganese compared to the Bureau of Mines estimates. The preferred Bureau of Labor Statistics series has been terminated. Future series will have to rely upon the Bureau of Mines data.**

Figure III-10

NICKEL

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1913	41.2	1.39	147.60	113.57	82.25
1914	41.4	1.38	146.34	111.23	
1915	41.3	1.36	144.55	108.98	
1916	41.9	1.28	136.34	106.80	
1917	41.5	1.08	114.99	104.70	
1918	40.8	0.90	96.26	102.67	
1919	40.4	0.78	82.98	100.72	
1920	42.3	0.71	75.01	98.85	
1921	42.0	0.78	83.37	97.05	
1922	38.3	0.76	81.18	95.33	
1923	35.5	0.69	73.92	93.69	
1924	30.3	0.59	62.97	92.13	
1925	32.8	0.62	66.47	90.64	
1926	35.6	0.67	71.47	89.22	
1927	35.4	0.68	72.43	87.89	
1928	37.0	0.72	76.74	86.63	
1929	35.0	0.68	72.59	85.44	
1930	35.0	0.70	74.48	84.34	
1931	35.0	0.77	81.67	83.31	
1932	35.0	0.86	91.05	82.35	
1933	35.0	0.90	95.98	81.48	
1934	35.0	0.87	92.87	80.68	
1935	35.0	0.85	90.61	79.95	
1936	35.0	0.84	89.73	79.31	
1937	35.0	0.81	86.60	78.74	
1938	35.0	0.83	88.25	78.24	
1939	35.0	0.84	89.52	77.83	
1940	35.0	0.83	88.67	77.48	
1941	35.0	0.79	84.44	77.22	
1942	31.5	0.65	68.68	77.03	
1943	31.5	0.61	64.70	76.92	
1944	31.5	0.60	63.60	76.89	
1945	31.5	0.58	62.18	76.93	
1946	35.0	0.60	63.66	77.05	
1947	35.0	0.52	55.67	77.25	
1948	40.0	0.55	59.03	77.52	
1949	40.0	0.56	59.61	77.87	
1950	50.5	0.70	74.52	78.29	
1951	56.5	0.73	77.27	78.80	
1952	56.5	0.71	75.62	79.37	
1953	60.0	0.75	79.70	80.03	
1954	64.5	0.80	85.25	80.76	
1955	64.5	0.80	85.57	81.57	
1956	74.0	0.91	96.73	82.46	
1957	74.0	0.88	93.40	83.42	
1958	74.0	0.85	90.92	84.46	

Figure III-10

NICKEL (contd)

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1959	74.0	0.85	90.19	85.57	
1960	74.0	0.83	88.77	86.76	
1961	81.0	0.90	96.19	88.03	
1962	79.0	0.87	92.78	89.38	
1963	79.0	0.86	91.66	90.80	
1964	79.0	0.85	90.48	92.30	
1965	78.0	0.83	87.82	93.87	
1966	85.0	0.87	93.05	95.52	
1967	94.0	0.94	100.01	97.25	
1968	103.0	0.99	105.17	99.05	
1969	128.0	1.17	124.04	100.94	
1970	128.0	1.10	117.10	102.89	
1971	133.0	1.10	116.66	104.93	
1972	140.0	1.12	118.88	107.04	
1973	153.0	1.15	122.31	109.23	
1974	174.0	1.18	125.35	111.49	
1975	203.0	1.26	133.99	113.83	
1976	220.0	1.29	137.29	116.25	
1977	217.0	1.20	127.21	118.74	
1978	208.0	1.06	113.26	121.31	
1979	241.0	1.10	117.95	123.96	
1980	341.0	1.38	147.01	126.68	
1981	343.0	1.26	133.98	129.48	
1982	320.0	1.11	117.77	132.36	
1983	220.0	0.74	78.45	135.32	
1984	222.0	0.71	76.02	138.35	104.91

Figure III-11

COPPER

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1870	18.6	0.49	126.82	169.16	141.36
1871	20.3	0.56	146.10	167.09	
1872	30.8	0.86	221.67	165.04	
1873	26.6	0.74	191.45	163.02	
1874	22.8	0.67	173.75	161.02	
1875	21.4	0.65	168.02	159.05	
1876	18.4	0.58	148.98	157.10	
1877	17.8	0.56	144.12	155.18	
1878	15.0	0.52	134.02	153.29	
1879	15.0	0.54	138.80	151.42	
1880	17.7	0.61	158.14	149.58	
1881	15.4	0.53	137.59	147.76	
1882	17.0	0.59	151.89	145.97	
1883	14.2	0.51	131.40	144.20	
1884	13.0	0.48	124.75	142.47	
1885	10.4	0.39	99.80	140.75	
1886	9.4	0.35	90.21	139.07	
1887	9.3	0.34	89.25	137.41	
1888	15.4	0.57	147.78	135.77	
1889	13.5	0.50	129.55	134.16	
1890	15.2	0.56	145.86	132.58	
1891	12.6	0.47	120.91	131.02	
1892	11.1	0.41	106.52	129.49	
1893	10.5	0.39	100.76	127.99	
1894	9.1	0.35	90.69	126.51	
1895	10.4	0.42	107.79	125.05	
1896	10.6	0.42	109.86	123.62	
1897	10.9	0.44	112.97	122.22	
1898	11.5	0.46	119.19	120.85	
1899	17.0	0.68	176.19	119.50	
1900	16.0	0.64	165.82	118.17	
1901	16.3	0.65	168.93	116.87	
1902	11.6	0.45	115.60	115.60	
1903	13.2	0.49	126.67	114.36	
1904	12.6	0.47	120.91	113.14	
1905	15.2	0.56	145.86	111.94	
1906	19.3	0.71	185.21	110.77	
1907	20.0	0.71	185.07	109.63	
1908	13.2	0.49	126.67	108.51	
1909	13.0	0.48	124.75	107.42	
1910	12.7	0.45	117.52	106.36	
1911	12.4	0.44	114.74	105.32	
1912	16.3	0.56	145.63	104.31	
1913	15.3	0.52	133.48	103.32	
1914	13.6	0.45	117.07	102.36	
1915	17.3	0.57	147.45	101.42	

Figure III-11

COPPER (contd)

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1916	27.2	0.83	215.52	100.51	
1917	27.2	0.71	183.53	99.63	
1918	24.6	0.55	141.33	98.77	
1919	18.7	0.36	93.54	97.94	
1920	17.5	0.29	75.57	97.13	
1921	12.5	0.23	60.42	96.35	
1922	13.4	0.27	69.16	95.60	
1923	14.4	0.28	73.01	94.87	
1924	13.0	0.25	65.79	94.17	
1925	14.0	0.27	69.09	93.49	
1926	13.8	0.26	67.46	92.84	
1927	12.9	0.25	64.28	92.22	
1928	14.6	0.28	73.74	91.62	
1929	18.1	0.35	91.42	91.05	
1930	13.0	0.26	67.37	90.50	
1931	8.1	0.18	46.02	89.98	
1932	5.6	0.14	35.48	89.49	
1933	7.0	0.18	46.74	89.02	
1934	8.4	0.21	54.28	88.57	
1935	8.6	0.21	54.21	88.16	
1936	9.5	0.23	59.31	87.76	
1937	13.2	0.31	79.54	87.40	
1938	10.0	0.24	61.40	87.06	
1939	11.0	0.26	68.51	86.75	
1940	11.3	0.27	69.71	86.46	
1941	11.8	0.27	69.33	86.20	
1942	11.8	0.24	62.65	85.96	
1943	11.8	0.23	59.02	85.75	
1944	11.8	0.22	58.01	85.57	
1945	11.8	0.22	56.72	85.41	
1946	13.8	0.24	61.12	85.28	
1947	21.0	0.31	81.33	85.17	
1948	22.0	0.31	79.06	85.09	
1949	19.2	0.27	69.67	85.04	
1950	21.2	0.29	76.18	85.01	
1951	24.2	0.31	80.59	85.01	
1952	24.2	0.30	78.87	85.03	
1953	28.8	0.36	93.16	85.08	
1954	29.7	0.37	95.59	85.15	
1955	37.5	0.47	121.15	85.25	
1956	41.8	0.51	133.05	85.38	
1957	29.6	0.35	90.98	85.53	
1958	26.3	0.30	78.69	85.71	
1959	30.7	0.35	91.12	85.92	
1960	32.1	0.36	93.77	86.15	
1961	30.0	0.33	86.75	86.40	

Figure III-11

COPPER (contd)

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1962	30.8	0.34	88.08	86.69	
1963	30.8	0.34	87.03	87.00	
1964	32.6	0.35	90.92	87.33	
1965	35.4	0.37	97.06	87.69	
1966	36.6	0.38	97.56	88.08	
1967	38.6	0.39	100.01	88.49	
1968	42.2	0.40	104.93	88.93	
1969	47.9	0.44	113.03	89.39	
1970	58.2	0.50	129.66	89.88	
1971	52.0	0.43	111.07	90.39	
1972	51.2	0.41	105.87	90.94	
1973	59.5	0.45	115.83	91.50	
1974	77.3	0.52	135.60	92.10	
1975	64.2	0.40	103.19	92.72	
1976	69.6	0.41	105.77	93.36	
1977	66.8	0.37	95.36	94.03	
1978	66.5	0.34	88.18	94.73	
1979	93.3	0.43	111.20	95.45	
1980	101.3	0.41	106.35	96.20	
1981	84.2	0.31	80.09	96.98	
1982	72.8	0.25	65.25	97.78	
1983	76.5	0.26	66.42	98.60	
1984	66.9	0.22	55.79	99.46	71.67

Figure III-12a

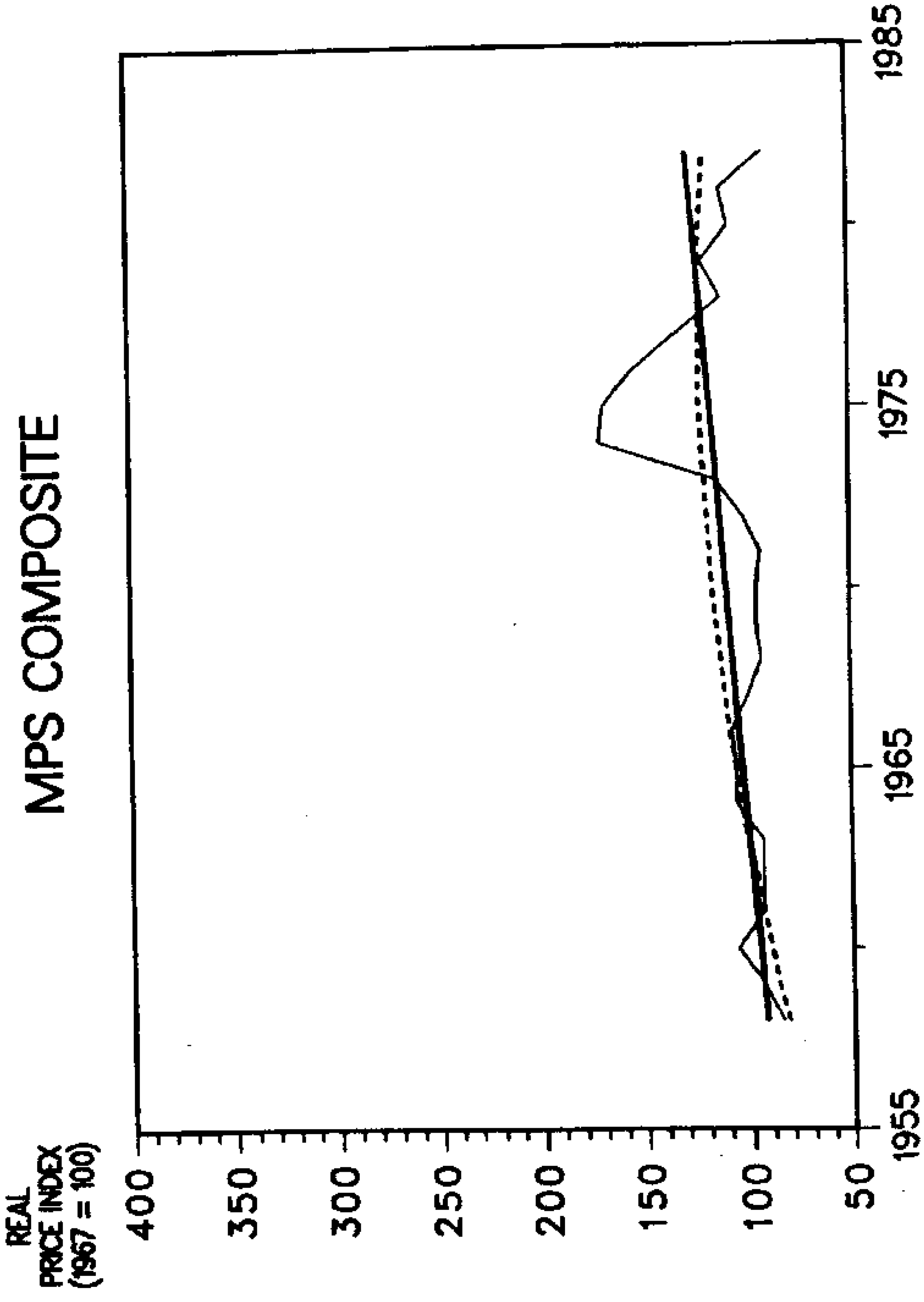


Figure III-12b

	Marine Polymetallic Sulfide Composite		
Year	Index (1967=100)	Quadratic Fit	Linear Fit
1958	85	82	93
1959	94	87	
1960	106	90	
1961	94	94	
1962	94	97	
1963	94	101	
1964	106	104	
1965	106	106	
1966	108	109	
1967	100	111	
1968	94	113	
1969	96	115	
1970	96	117	
1971	94	118	
1972	102	119	
1973	115	120	
1974	171	121	
1975	169	122	
1976	154	122	
1977	133	122	
1978	112	122	
1979	121	122	
1980	108	121	
1981	112	120	
1982	92	127	127

Figure III-13

ZINC

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1870	7.0	0.18	132.52	145.94	134.99
1871	7.0	0.19	139.88	145.12	
1872	7.0	0.19	139.88	144.32	
1873	8.6	0.24	171.86	143.53	
1874	7.0	0.21	148.11	142.74	
1875	7.4	0.22	161.32	141.97	
1876	7.2	0.23	161.87	141.21	
1877	5.9	0.18	132.64	140.45	
1878	4.5	0.16	111.63	139.71	
1879	4.5	0.16	115.62	138.97	
1880	5.5	0.19	136.44	138.25	
1881	5.2	0.18	129.00	137.53	
1882	5.3	0.18	131.48	136.83	
1883	4.5	0.16	115.62	136.13	
1884	4.4	0.16	117.24	135.45	
1885	4.3	0.16	114.57	134.77	
1886	4.4	0.16	117.24	134.11	
1887	4.6	0.17	122.56	133.45	
1888	4.9	0.18	130.56	132.80	
1889	5.0	0.19	133.22	132.17	
1890	5.6	0.21	149.21	131.54	
1891	5.0	0.19	133.22	130.92	
1892	4.6	0.17	122.56	130.32	
1893	4.1	0.15	109.24	129.72	
1894	3.5	0.13	96.84	129.13	
1895	3.6	0.14	103.59	128.55	
1896	3.9	0.16	112.23	127.99	
1897	4.1	0.16	117.98	127.43	
1898	4.6	0.18	132.37	126.88	
1899	5.8	0.23	166.90	126.34	
1900	4.4	0.18	126.61	125.81	
1901	4.1	0.16	117.98	125.29	
1902	4.9	0.19	135.58	124.78	
1903	5.6	0.21	149.21	124.28	
1904	5.2	0.19	138.55	123.79	
1905	6.0	0.22	159.87	123.31	
1906	6.3	0.23	167.86	122.84	
1907	6.2	0.22	159.30	122.38	
1908	4.7	0.17	125.23	121.93	
1909	5.5	0.20	146.54	121.49	
1910	5.7	0.20	146.45	121.06	
1911	5.9	0.21	151.59	120.64	
1912	7.1	0.24	176.13	120.23	
1913	5.8	0.20	140.49	119.83	
1914	5.3	0.18	126.67	119.43	
1915	14.4	0.47	340.77	119.05	
1916	13.8	0.42	303.61	118.68	
1917	9.1	0.24	170.48	118.32	
1918	8.3	0.18	132.40	117.96	
1919	7.4	0.14	102.77	117.62	
1920	8.1	0.14	97.12	117.29	

Figure III-13

ZINC (contd.)

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1921	5.2	0.10	69.79	116.97	
1922	6.1	0.12	87.42	116.65	
1923	7.0	0.14	98.55	116.35	
1924	6.7	0.13	94.14	116.05	
1925	8.0	0.15	109.62	115.77	
1926	7.7	0.15	104.52	115.49	
1927	6.6	0.13	91.31	115.23	
1928	6.4	0.12	89.75	114.98	
1929	6.8	0.13	95.36	114.73	
1930	4.9	0.10	70.50	114.49	
1931	4.0	0.09	63.11	114.27	
1932	3.3	0.08	58.04	114.05	
1933	4.4	0.11	81.58	113.85	
1934	4.5	0.11	80.73	113.65	
1935	4.7	0.11	82.27	113.46	
1936	5.3	0.13	91.88	113.29	
1937	6.9	0.16	115.44	113.12	
1938	5.0	0.12	85.24	112.96	
1939	5.5	0.13	95.11	112.82	
1940	6.7	0.16	114.76	112.68	
1941	7.9	0.18	128.87	112.55	
1942	8.7	0.18	128.25	112.43	
1943	8.7	0.17	120.83	112.32	
1944	8.6	0.16	117.40	112.23	
1945	8.6	0.16	114.78	112.14	
1946	9.1	0.16	111.91	112.06	
1947	11.0	0.16	118.29	111.99	
1948	14.2	0.20	141.68	111.93	
1949	12.9	0.18	129.98	111.88	
1950	14.6	0.20	145.68	111.84	
1951	18.6	0.24	171.99	111.81	
1952	17.0	0.21	153.83	111.79	
1953	11.5	0.14	103.28	111.78	
1954	11.2	0.14	100.09	111.78	
1955	12.8	0.16	114.82	111.79	
1956	14.0	0.17	123.73	111.81	
1957	11.9	0.14	101.55	111.84	
1958	10.3	0.12	85.56	111.88	
1959	11.5	0.13	94.77	111.92	
1960	13.0	0.15	105.44	111.98	
1961	11.6	0.13	93.14	112.05	
1962	11.6	0.13	92.11	112.13	
1963	12.0	0.13	94.14	112.22	
1964	13.6	0.15	105.32	112.31	
1965	14.5	0.15	110.38	112.42	
1966	14.5	0.15	107.32	112.54	
1967	13.9	0.14	100.00	112.66	
1968	13.5	0.13	93.20	112.80	
1969	14.7	0.13	96.31	112.95	
1970	15.3	0.13	94.64	113.10	

Figure III-13

ZINC (contd.)

Year	Price ¢/lb	Deflated Price	Index (1967=100)	Quadratic Fit	Linear Fit
1971	16.1	0.13	95.49	113.27	
1972	17.8	0.14	102.20	113.44	
1973	20.7	0.16	111.88	113.63	
1974	36.0	0.24	175.34	113.82	
1975	39.0	0.24	174.05	114.03	
1976	37.0	0.22	156.12	114.24	
1977	34.4	0.19	136.35	114.47	
1978	31.0	0.16	114.13	114.70	
1979	37.3	0.17	123.43	114.95	
1980	37.4	0.15	109.02	115.20	
1981	44.6	0.16	117.79	115.46	
1982	38.5	0.13	95.80	115.74	
1983	41.4	0.14	99.81	116.02	
1984	48.6	0.16	112.53	116.31	105.46

Section IV: Elasticity of Reserves

One way to examine the potential for resource depletion is to determine how rapidly consumption of a mineral increases relative to additions to the size of the resource. It is generally thought that the depletion of onshore resources in the face of stable or rising consumption trends will trigger the search for and recovery of other resources, including ocean minerals. Mineral consumption might increase because of population expansion, technological advances, and economic growth. As minerals are produced and consumed, current economic resources are depleted. Usually, this depletion is more than compensated for through increases in resources from higher prices (expanding economically accessible quantities) exploration effort and new discovery, and technological advances that allow the development of lower-grade or less-accessible minerals. Changes in other basic economic phenomena such as substitution, recycling, and conservation also condition the rate of depletion. Although long-term price changes are probably the most useful scarcity (depletion) indicator, idiosyncratic factors in individual minerals markets may be hidden by an analysis of price alone. Thus it is useful to examine consumption behavior, changes in the size of the resource, as well as price movements, to focus in on those minerals that could become promising offshore prospects.

We compare the rate of change in reported reserves with the rate of change in consumption and with the rate of change in price for those minerals that might be recovered from seabed resources. This comparison is conducted over the 16 year period from 1970 to 1985, during which consistent data was available from the U.S. Bureau of Mines, Mineral Facts and Problems (BOM/MFP) (Tables IV-1, IV-2, IV-3, IV-4, IV-5). "Reserves," a more restrictive category than "resources," has been used here because BOM has not reported world resources consistently over that period but instead recently has replaced that category with "reserve base." Because of this replacement, it has not been possible to obtain data on the change in size of world resources over the 16 year period.

Figures IV-1 and IV-2 show the results of the comparisons. The units represent percent increases or decreases in consumption or price, along the x-axes and size of reported reserves along the y-axes. Because these are percentage changes, they show the "elasticity" or the ratio of the rate of change in the size of reserves to changes in consumption or price. Figure IV-1 is the "consumption elasticity of reserves" and figure IV-2 is the "price elasticity of reserves." The diagonal line extending from quadrant III to quadrant I is a reference line indicating relative rates of change. To the right of the reference line, consumption or price is either (1) increasing faster than the increase in the size of reserves (quadrant I); (2) increasing as reserves decrease (quadrant IV); or (3) decreasing more slowly than the decrease in the size of reserves (quadrant III). To the left of the reference line, consumption or price is either (4) decreasing faster than decreases in the size of reserves (quadrant III); (5) decreasing as reserves increase (quadrant II); or (6) increasing more slowly than increases in the size of reserves (quadrant I). Tables IV-1, IV-2, IV-3, IV-4, and IV-5 present the data incorporated into the figures.

Several general statements can be made. First, minerals that are positioned to the right of the reference line show a relatively inelastic response in reserves to changes in consumption or price relative to those minerals positioned to the left of the line. Those minerals in quadrant IV (all to the right of the line) fall into the extreme case of decreases in the size of reserves with increases in consumption or price. The minerals such as yttrium and chromite in figure IV-1 and sulfur and phosphate in figure IV-2 may deserve closer study. In particular, one might conclude from this analysis alone that these minerals are depleting.

This type of analysis appears most useful as a method to help set priorities for more detailed analyses of prospective seabed minerals. Using both figures, one might want to make a closer examination of the markets for sulfur and phosphate, for example, which over the 16 year period show decreases in the size of reserves while both consumption and price have increased. Other minerals like manganese and hafnium, for example, might receive a lower priority.

There are shortcomings to this type of analysis. They include the short time period, the generally small changes in any of the variables (although gold has a very large increase in the size of reserves), and the reliance upon reserve data that may be affected, for example, by tax policy. Used in conjunction with other information, however, elasticity of reserves can be a useful tool for examining the relative potential for depletion of resources.

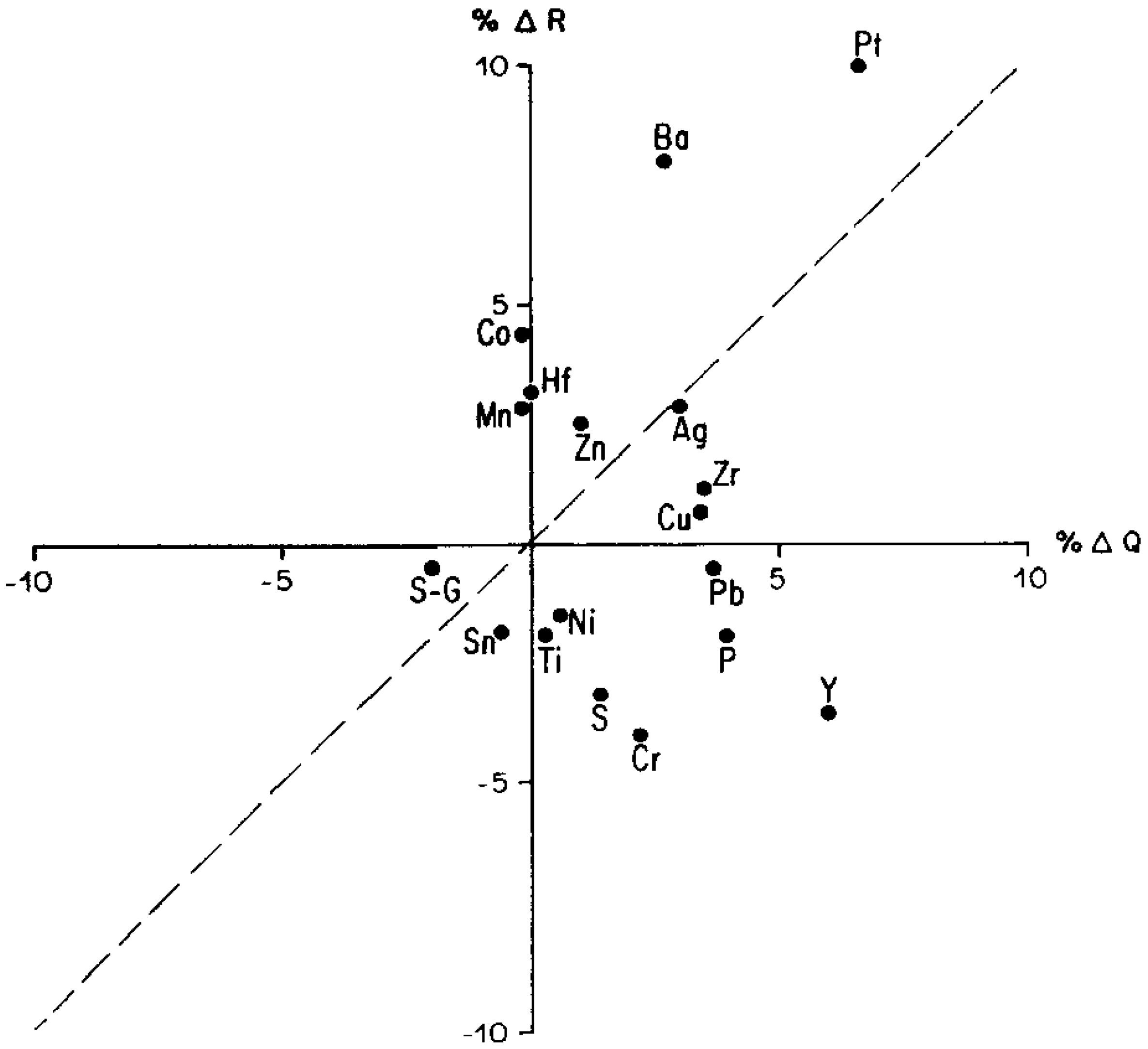


Figure IV-1: CONSUMPTION ELASTICITY OF MINERAL RESERVES: 1970-1985

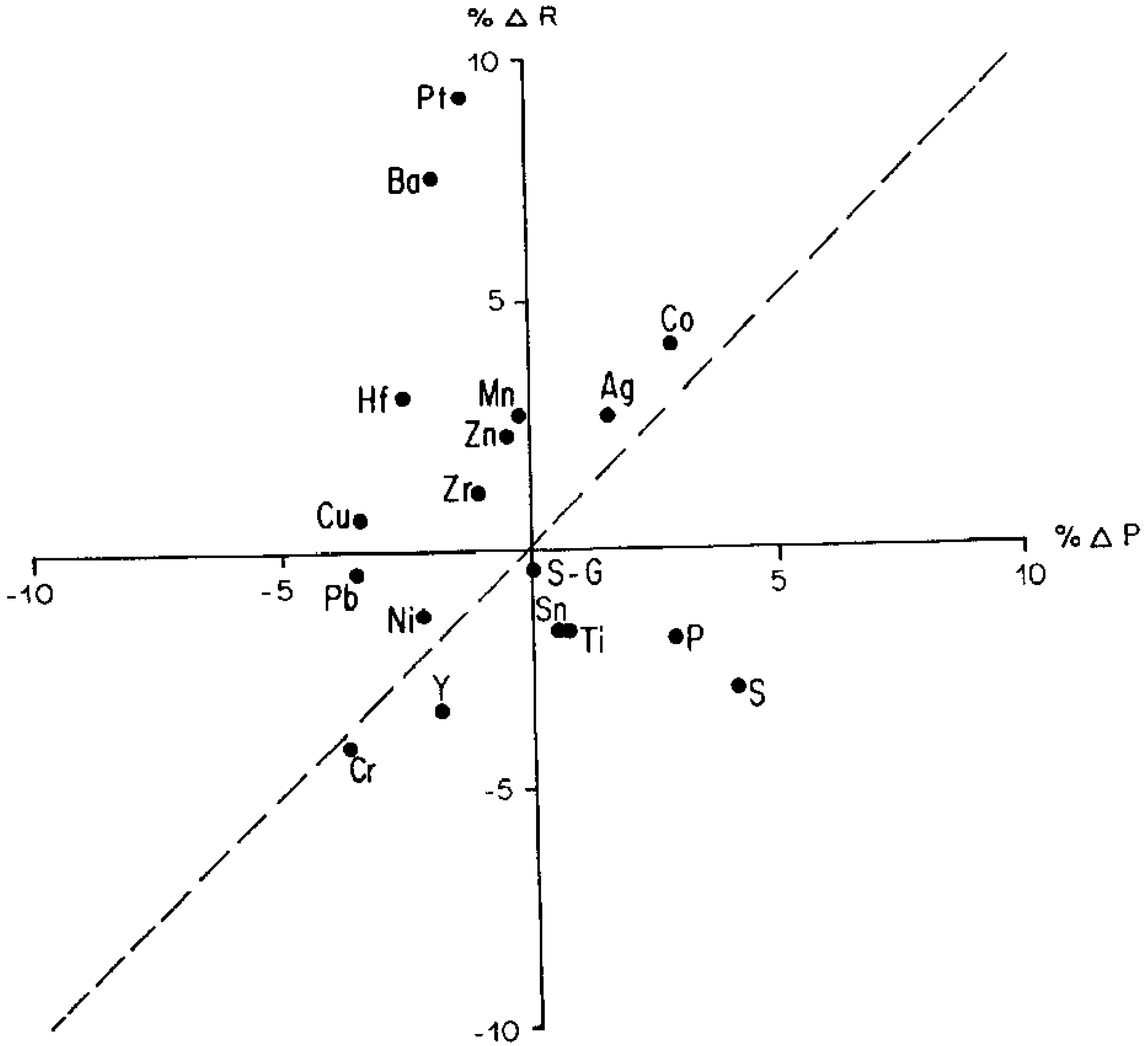


Figure IV-2: PRICE ELASTICITY OF MINERAL RESERVES: 1970 - 1985

Table IV-1: WORLD RESERVES
(000MT)

	1965	1970	1975	1980	1985*
Sand/Gravel[1]	"Sufficient"	15,000,000	14,000,000	14,000,000	14,000,000
Cobalt	43,100[2]	2,182	2,450	2,404	3,629
Nickel	—	68,040	53,978	54,432	52,618
Copper	192,326	279,418	408,240	448,157	308,448
Manganese	—	635,040	1,814,400	1,360,800	907,200
Platinum[3]	1	12	17	35	30
Zinc	77,112	112,493	135,173	146,966	154,224
Lead	45,360[4]	93,442	149,688	115,214	86,184
Silver	(99)	165	180	244	235
Gold	(30)	10	39	31	38
Cadmium[5]	408	644	753	585	503
Phosphate	47,635,280	19,776,960	16,057,440	34,500,000	14,000,000
Rutile[6]	—		94,349	73,483	46,267
Ilmenite[6]	—		245,851	199,584	127,008
Titanium[8]	(196,000-240,000)[7]		340,200	273,067	173,275
Zirconium	21,138[9]	15,695	19,686	25,129	20,866
Hafnium	212[10]	281	394	503	417
Thorium	667[11]	612	708	994	1,034
Yttrium[15]	—	97	35	46	45
Tin	4,626	4,232	9,842	10,000	3,060
Barite[12]	—	76,205	90,720	115,214	167,832
Chromite	2,618,956[13]	2,658,324[13]	4,291,963[13,14]	3,356,640	1,056,888
Sulfur	—	2,460,500	1,968,400	1,765,000	1,290,000

[1] U.S. only; crude estimate (may be as much as $45x10^9$ MT reserve base in U.S.)

[2] Overestimate, includes "resources."

[3] Platinum group.

[4] Measured and indicated reserves.

[5] Associated with Zinc and measured as such.

[6] "Contained Titanium."

[7] TiO_2 estimated "resource."

[8] Sum of rutile and ilmenite contained metal.

[9] "Resources."

[10] "Resources."

[11] "Resources"

[12] Barium content.

[13] "Resources."

[14] "High chromium."

[15] 1980 and 1985—include yttrium and other rare earths.

Sources: BOM/MFP for years shown.

Table IV-2: CHANGE IN WORLD RESERVES

	1970-75	1975-80	1980-85	1975-80 % CHANGE
Sand/Gravel	-0.07	0.00	0.00	-0.41
Cobalt	0.12	-0.02	0.51	+4.14
Nickel	-0.21	0.01	-0.03	-1.42
Copper	0.46	0.10	-0.31	+0.64
Manganese	1.86	-0.25	-0.33	+2.67
Platinum	0.42	1.06	-0.14	+9.38
Zinc	0.20	0.09	0.05	+2.32
Lead	0.60	-0.23	-0.25	-0.49
Silver	0.90	0.36	-0.04	+2.65
Gold	2.90	-0.21	0.23	+17.50
Cadmium	0.17	-0.22	-0.14	-1.37
Phosphate	-0.18	1.15	-0.59	-1.83
Rutile	--	-0.22	-0.37	---
Ilmenite	—	-0.19	-0.36	---
Titanium	0.42	-0.20	-0.37	-1.73
Zirconium	-0.26	0.25	0.28	+1.18
Hafnium	0.40	0.28	-0.17	+3.03
Yttrium	-0.64	0.31	-0.02	-3.35
Tin	1.33	0.02	-0.69	-1.73
Barite	0.19	0.27	0.46	+7.51
Chromite	0.61	-0.22	-0.69	-3.77
Sulfur	-0.20	-0.10	-0.27	-2.97

Table IV-3: WORLD CONSUMPTION[a]
(000MT)

	1965	1970	1975	1980	1985*
Sand & Gravel[1]		856,397	691,286	692,194	594,216
Cobalt		24	26	31	23
Nickel		628	577^{+}	709^{+}	691^{+}
Copper		6,022	$7,444^{+}$	$9,390^{+}$	$9,116^{+}$
Manganese		8,205	9,798	9,707	7,983
Platinum		0.1	0.2	0.2	0.2
Zinc		5,464	$4,980^{+}$	$6,176^{+}$	$6,355^{+}$
Lead		3,394	$4,759^{+}$	$5,392^{+}$	$5,285^{+}$
Silver[2]		(9)	12	13	13
Gold[3]		(1)	1	0.5	1
Cadmium		17	13^{+}	17^{+}	18^{+}
Phosphate		84,927	107,557	139,000	135,000
Rutile		—	—	—	--
Ilmenite		—	—	—	--
Titanium[4]		1,609	1,539	1,926	(1,674)
Zirconium[5]		236	249	340	361
Hafnium		0.1	0.1	0.1	0.1
Thorium[5]		0.7	0.9	1	1
Yttrium[6]		19	23	32	36
Tin		232	222	247	212
Barite		3,933	4,916	7,532	5,522
Chromite		1,869	2,540	2,973	2,490
Sulfur		41,937	50,678	54,920	50,472

[1] U.S. production.

[2] World consumption data from BOM/MFP for 1975, 1979, 1983; world production data for 1970.

[3] World "fabrication" (gross usage), Consogold (1986), Table 4, p. 37 for 1975, 1980, 1985.

[4] Ilmenite and rutile, metal content (1985 figure used here is actually 1982 production).

[5] Does not include U.S. production (proprietary).

[6] Yttrium and other rare earths.

[a] Production data used, unless otherwise noted.

Table IV-4: CHANGE IN WORLD CONSUMPTION

	1970-75	1975-80	1980-85	1975-80 % CHANGE
Sand/Gravel	-0.19	0.00	-0.14	-1.91
Cobalt	0.08	0.19	-0.26	-0.26
Nickel	-0.08	0.23	-0.03	+0.63
Copper	0.24	0.26	-0.03	+3.22
Manganese	0.19	-0.01	-0.18	-0.17
Platinum	1.00	0.00	0.00	+6.25
Zinc	-0.09	0.24	0.03	+1.02
Lead	0.40	0.13	-0.02	+3.48
Silver	0.33	0.08	0.00	+2.78
Gold	0.00	-0.50	1.00	0.00
Cadmium	-0.24	0.31	0.06	+0.37
Phosphate	0.27	0.29	-0.03	+3.68
Rutile	--	--	--	--
Ilmenite	--	--	--	--
Titanium	-0.04	0.25	-0.13	+0.25
Zirconium	0.06	0.37	0.06	+3.31
Hafnium	0.00	0.00	0.00	0.00
Yttrium	0.21	0.39	0.13	+5.59
Tin	-0.04	0.11	-0.14	-0.53
Barite	0.25	0.53	-0.27	+2.52
Chromite	0.36	0.17	-0.16	+2.07
Sulfur	0.21	0.08	-0.08	+1.28

Table IV-5: CHANGE IN WORLD PRICE

	(A) Adjusted[1] 1985 Price	(B) Adjusted[1] 1970 Price	$\dfrac{\frac{(A-B)}{(B)} \times 100}{16}$	Units for Columns (A), (B)
Phosphate	704	499	+2.57	/MT
Tin	163[2]	150	+0.54	/lb
Rutile	24	40	-2.50	/lb
Titanium Metal	124	113	+0.61	/lb
Chromite	13	62	-4.93	$/ST
Cobalt[3]	355	189	+2.93	/lb
Nickel	70	110	-2.27	/lb
Manganese	44	46	-0.27	/LTU
Copper	22	50	-3.50	/lb
Zinc	12	13	-0.48	/lb
Sand/Gravel	95	95	0.00	/ST
Barite	903	1289	-1.88	/ST
Platinum	90	114	-1.31	$/TROZ
Hafnium	43[4]	73	-2.57	$/lb
Silver	191	152	+1.60	/TROZ
Zircon	83[4]	100	-1.06	$/ST
Lead	6	14	-3.57	/lb
Sulfur	33	20	+4.06	$/MT
Yttrium[5]	24	32	-1.80	/KG
Gold	99	31	+13.71	$/TROZ

[1] Prices adjusted to 1967 dollars.

[2] Tin price prior to market collapse.

[3] Cathode price.

[4] 1983 prices.

[5] Monazite price (containing 55-60% rare-earths).

Section V: Trends in Exploration Inputs

The following tables and figures give a preliminary look at exploration effort spent toward minerals that have potential seabed sources. It should be stressed that the information represents, in most cases, inputs into the exploration and discovery process. As such it tells us little about the "effectiveness" or productivity of exploration efforts. Some studies have attempted to examine outputs or success rates for exploration effort (Rose, 1982; Quick, 1982), but no attempt is made to do so here. Although Rose found decreases in exploration effectiveness for uranium and oil over a forty year interval from 1940 to 1980, he found no decrease in exploration effectiveness for copper. He recommends the "collection of better data on expenditures for metallic mineral exploration." Rose and Eggert (1983) have examined exploration effectiveness in the United States for metals other than iron ore and uranium and have estimated increased costs of discovery by multiples of two to three (and thus lower productivity of exploration effort) during the period 1955 to 1975.

The Exploration Survey Committee (ESC) of the Society of Economic Geologists recently has begun tabulating exploration information for minerals in the United States and Canada. Some of the results of this tabulation are combined in Table V-1. ESC estimates that the 1985 data represent only about 60 percent of exploration activities by major U.S. companies and 55 percent of exploration activities by Canadian companies. ESC (1985) concludes that: "clearly less exploration, by fewer people, is being sparingly funded by the major companies. More effort appears to be directed toward drilling at the apparent expense of traditional grand-scale multidisciplinary reconnaissance programs."

Over a longer term, Figure V-1 displays patterns in mineral exploration in North America. The United States data is from 30 mining companies, both U.S. and foreign, over the period 1961 through 1979. (Eggert, 1984). The Canadian data are from a number of Canadian government sources (the total number of companies is unknown) over the period 1961 through 1977 (Verleun, 1984). In order to complete the time series for 1978 and 1979, we estimate Canadian expenditures during those two years as an average of the relative size of Canadian expenditures to U.S. expenditures (36 percent) during the seven preceding years of 1971 to 1977. The data from 1980 through 1985 are taken from the composite expenditures found in Table V-1. It should be noted that the 1980-1985 data do not include expenditures made by Canadian companies in the United States or U.S. companies in Canada and, as such, may underestimate total North American exploration expenditures. Also note that before aggregation, the United States data show an increase until the 1980s, and the Canadian data show a drop in exploration expenditures during the late 1970s. The unaggregated ESC data show drops in exploration in both the United States and Canada during the 1980s. By the mid-1980s real exploration expenditures in both countries have dropped to the level of the early 1960s.

Figure V-2 displays the data accumulated on an annual basis by the Society of Exploration Geophysics on worldwide expenditures for geophysics. Geophysical data is an important component of exploration effort for hydrocarbons and is used to a lesser, but not unimportant, extent for hard minerals. The data is broken into expenditures of all types for the total world; seabed deposits of petroleum; hard minerals (including seabed deposits); seabed deposits of hard minerals; and oceanographic research. Figure V-3, a reprint from the journal "Geophysics: The Leading Edge of Exploration" 6(8): 76 (1987), displays exploration effort as measured by average number of crews per month searching for oil and gas onshore and offshore. For the field of geophysics generally, note the peak in exploration effort around 1981, measured either in expenditures or crews, followed by a rapid decline almost to the level of the early 1970s. In terms of geophysical expenditures, total exploration effort in hard minerals has seen a general long term decline since a high of $117 million in 1968, with a short resurgence during 1975-1977. During that same period, North American exploration expenditures for metals (Figure V-1) remained fairly constant. It is possible that geophysical methods assumed a less important role in exploration during the 1970s. During 1968-69, 1975-76, and 1984-85, geophysical exploration is seen in seabed hard minerals (Figure V-2). It is uncertain what minerals were being explored, although the mid-to late 1970s was the heighth of manganese nodule exploration (Figure V-4). Some recent attention has been given to the use of induced polarization as a geophysical method useful for the exploration of heavy mineral placers (Grosz, 1987; Wynn and Grosz, 1986) and marine polymetallic sulfides (Muirhead and Sternberg, 1986).

Figure V-5 displays U.S. federal government expenditures on nonliving resources from 1966 through 1986. Of particular interest is the large increase in expenditures, mostly associated with oil and gas development programs, in the mid- to late-1970s. These expenditures include basic scientific research as well as "resource assessment" both of which might be considered types of exploration activity. They also include administrative and management activities, such as entitlement transfers, revenue collections, and environmental impact assessment and monitoring. There is a marked decline in real expenditures since 1980, reflecting a reallocation of federal budgets as well as the lack of a "steady hand" approach to management (Broadus and Hoagland, In press).

Finally, it is interesting to refer ahead to Figures VII-1 and VII-2, which display discovery effort in MPS deposits, and to compare those figures to general trends in exploration. In particular it is noted that scientific research concerning MPS, which has elucidated some fundamental "resource" knowledge, has proceeded even during a period when private exploration efforts in metals have decreased considerably. This may be evidence of the government's steady-hand approach to science policy as an integral part of mineral resource policy. More likely, however, attention to MPS has been driven by a general phenomenon in science whereby "waves" of interest accompany startling advances on a particular problem or in a particular discipline, such as the discovery in 1977 of marine hydrothermal venting and associated massive sulfide deposits.*

***We attribute this idea of shifting efforts among scientific problems to Derek Spencer, Associate Director for Research, Woods Hole Oceanographic Institution.**

Table V-1: Combined Mineral Exploration Statistics: 1980-1985[1]

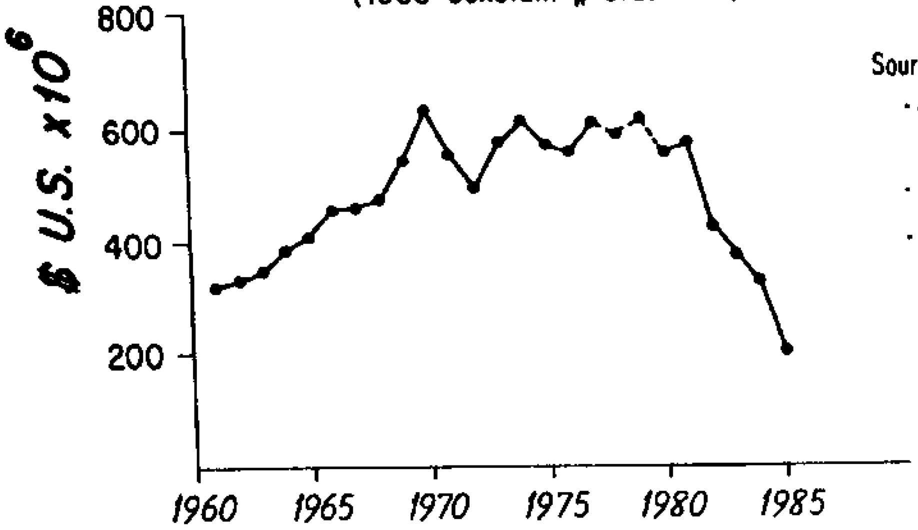
Commodity Group (Current $US million)	1980	1981	1982	1983	1984	1985
Base and Precious Metals	270	401	341	333	304	205
Other Metals	43	37	22	11	8	3
Uranium	146	82	47	33	25	9
Industrial Minerals	22	32	33	18	14	9
Total	481	552	443	395	351	226
Number of Drill Holes (thousands)	14	12	13	8	10	9
Net Exploration Acres (millions)	35	26	26	27	29	14

[1] Total of United States companies' exploration in the United States plus Canadian companies' exploration in Canada.

Source: After Exploration Survey Committee (1985).

Figure V-1: *NORTH AMERICAN MINERAL EXPLORATION EXPENDITURES*

Composite Private Expenditures For Private Corporations In The United States And Canada (1983 Constant \$ U.S. x10^6)



Sources:
- 1961 - 1977: Verleun (1984)
  Eggert (1984)
- 1978 - 1979: Our Own Estimate
- 1980 - 1985: ESC (1986)

Figure V-2: ***WORLDWIDE GEOPHYSICAL EXPENDITURES***

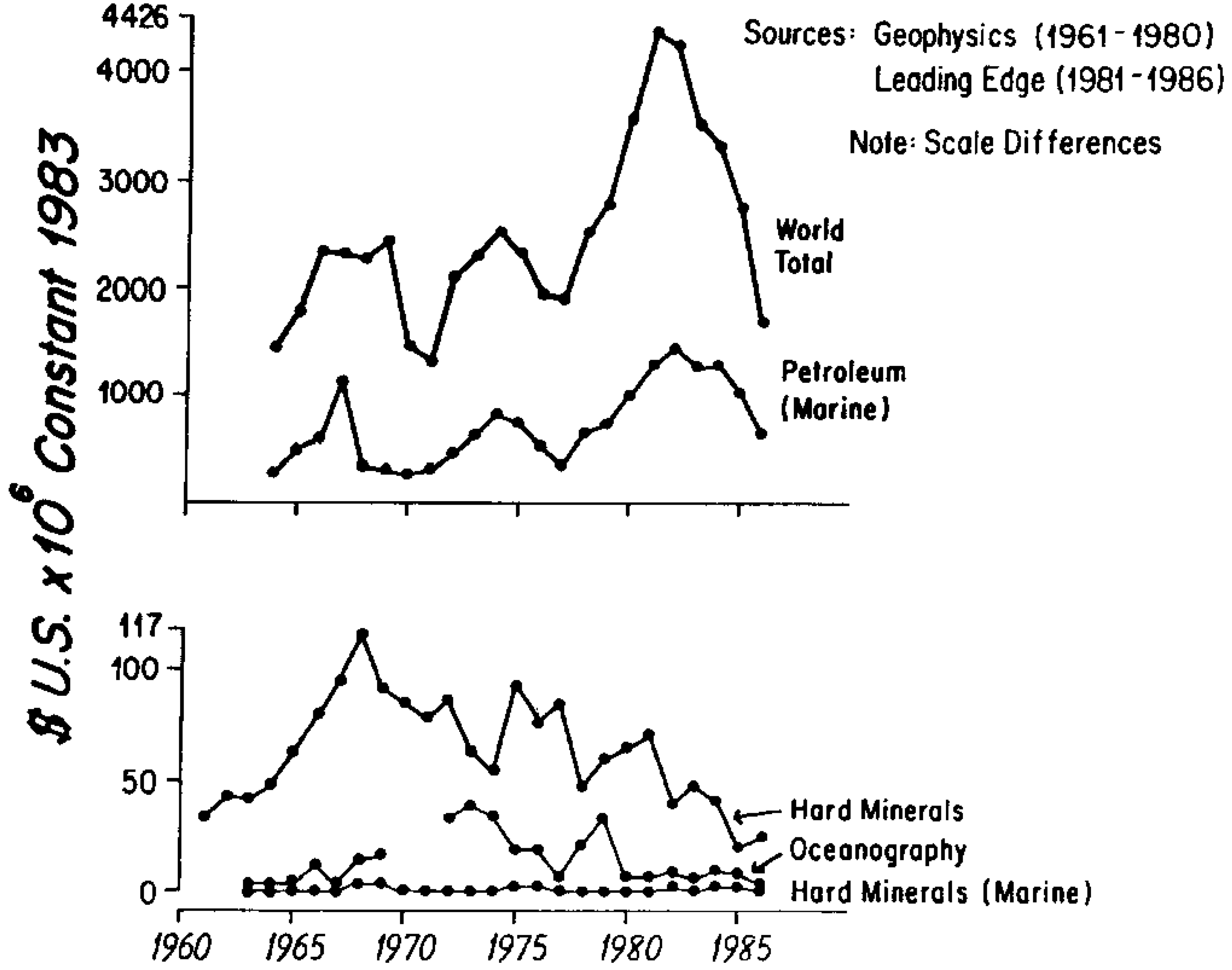
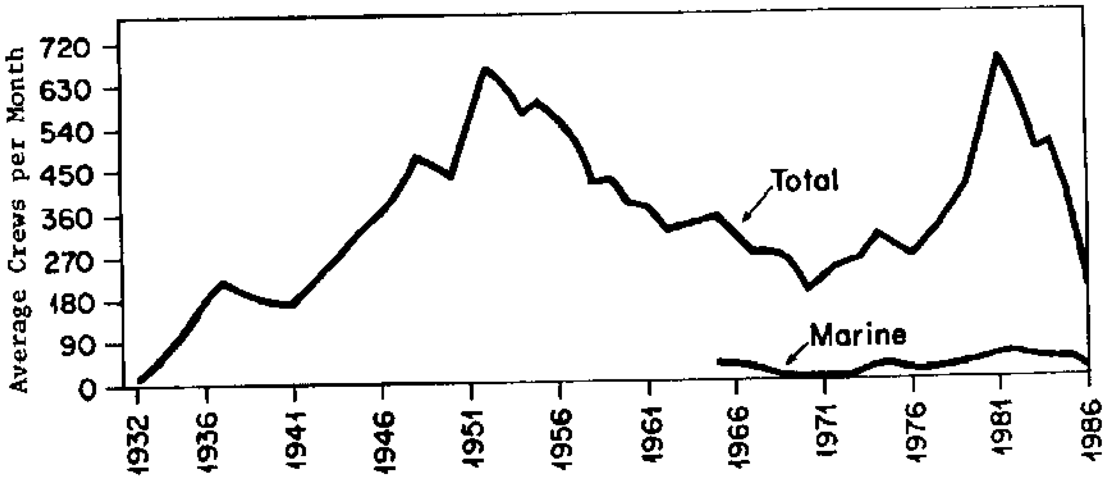
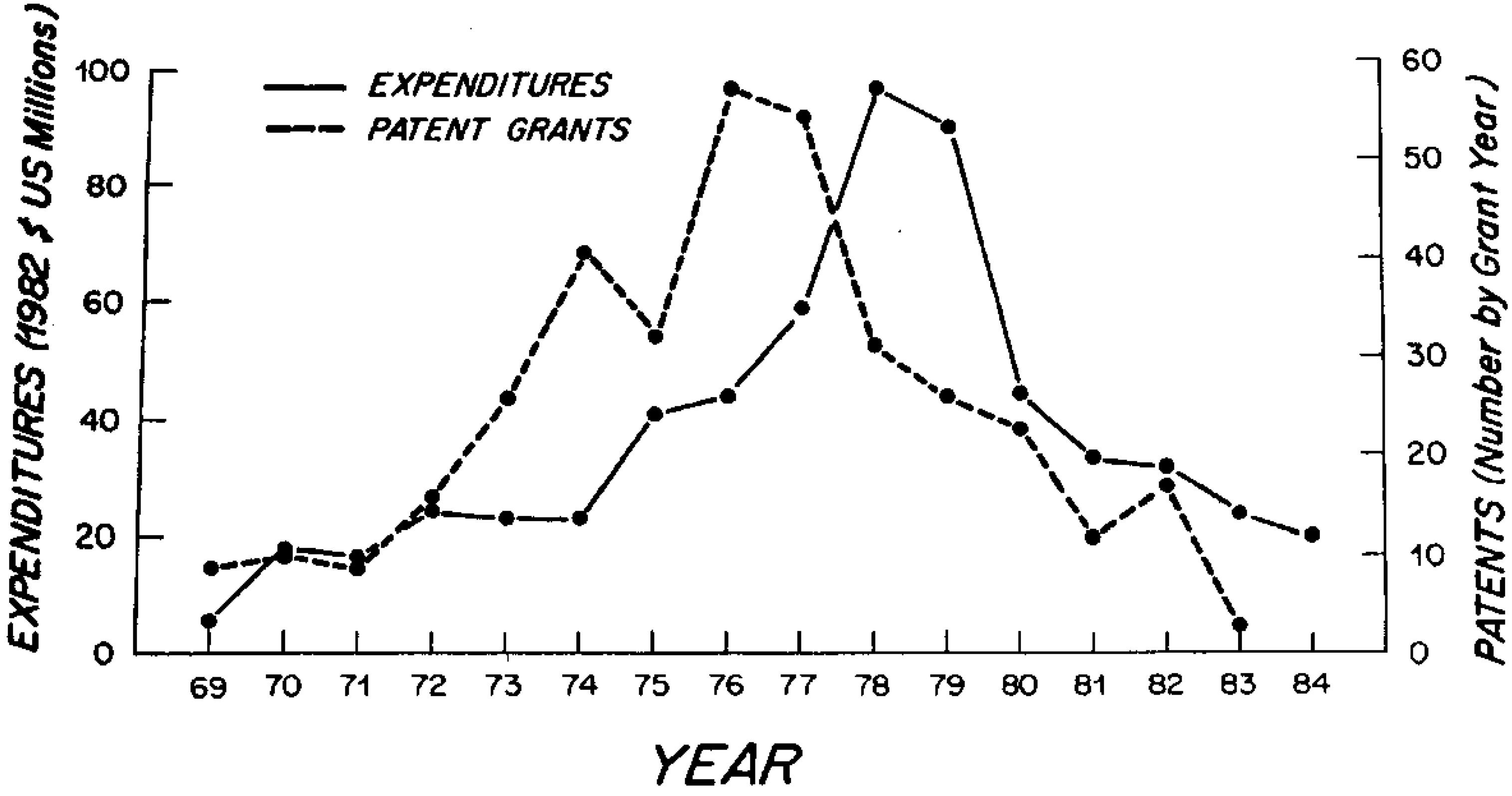


Figure V-3: **History Of Seismic Exploration In The United States**
(Seismic Crews Searching For Oil & Gas)



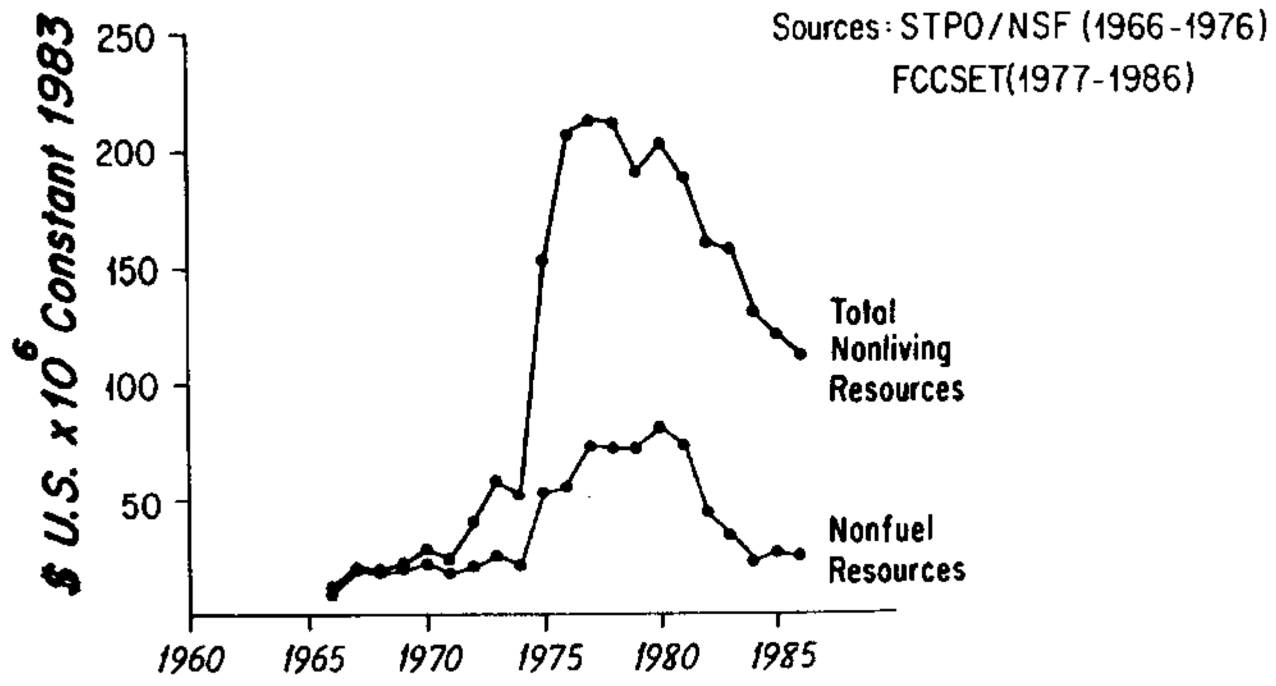
Source: Leading Edge (1986)

Figure V-4: Worldwide Exploration and R&D Expenditures and Patent Grants in Manganese Nodules (1969-1984)



Source: Broadus (1986)

Figure V-5: *U.S. FEDERAL GOVERNMENT EXPENDITURES ON NONLIVING RESOURCES*



Sources: STPO/NSF (1966-1976)
FCCSET(1977-1986)

Section VI: Worldwide Locations, Entitlements, and Areas of Interest

This section compiles information on the general location of marine minerals of different types, entitlements (permits, licenses, leases) for marine mineral development, and other areas of interest. The following figures have been included:

Figure	Description
VI-1	World map of seabed materials and exclusive economic zones[1] (Broadus, 1987)
VI-2	Publicly-disclosed, licensed deep seabed mining exploration areas[2] (Hoagland, 1987)

(continued)

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[1] Several references were used in the construction of Figure VI-1. McKelvey's and Wang's (1970) seminal effort was relied upon primarily for the initial data. Other general sources were used to confirm this early work. Minerals that may have been discovered or delineated more carefully since 1970 were added according to the mineral-specific references below. Of special interest, this map includes a detailed location of marine polymetallic sulfide (MPS) occurrences not yet found on all-encompassing maps of this type. The approximate exclusive economic zone (EEZ) boundaries have been included as located on a base map drawn informally by the U.S. Department of State. Licensed deep seabed exploration areas can be used as rough approximations for high-grade ferromanganese nodule zones. Nodules with combined nickel-copper grades higher than 2.0% have been identified with symbols outside the exploration areas.

[2] Data of the locations of publicly-disclosed, licensed deep seabed mining areas for U.S. licenses are found in the Federal Register (NOAA, 1985). A copy of the Kennecott Consortium's license from the United Kingdom, which includes the location of the licensed area, was obtained from the Minerals and Metals Division, Department of Trade and Industry in London. The location of the Ocean Management Incorporated license from the West German government was obtained from industry contacts. Nodule exploration areas under license from France, Japan, India and one of two from West Germany have not been included. The Indian exploration area is located in the Indian Ocean at roughly where the nodule symbol in Figure VI-1 lies. The Japanese and French consortia are thought to have additional claims in the western Pacific Ocean. Note: In the summer of 1987, agreement was reached to resolve overlapping claims between potential pioneer investors under the Law of the Sea Convention. This resolution must be reviewed and approved by the LOS Preparatory Commission (scheduled for late 1987). All of the U.S. exploration licenses will be affected by this rearrangement. The cartography was done by Frank Gable, Marine Policy Center, WHOI.

Figure	Description
VI-3	Prospecting licenses offshore New Zealand for gold placers and phosphorites (Glasby, 1986)
VI-4	Mining locations offshore Southeast Asia for tin and titaniferous magnetite (Morgan and Valencia, 1983)
VI-5	Proposed lease tracts for U.S. arctic sand and gravel lease sale (MMS, 1983)
VI-6	Proposed lease tracts for cobalt enriched ferromanganese encrustations offshore Hawaii and Johnston Island (MMS, 1987)
VI-7	Proposed lease area for marine polymetallic sulfide deposits, leased tracts for phosphorites, and played-out barite deposit at Castle Island, Alaska (DOI, 1960; Thompson and Smith, 1970; MMS, 1983)
VI-8	Areas of interest for marine hard minerals: U.S. Atlantic coast (MMS, 1987)

The following references where used to construct Figures VI-1 and VI-2. The full citations may be found in the bibliography of Section X.

GENERAL (these references include a range of mineral types and locations):

Ballard and Bischoff (1983)
Circum-Pacific Council for Energy and Mineral Resources (1984)
Clague, Bischoff and Howell (1984)
Dillon (1984)
Geological Survey (1979)
Hale and McLaren (1984)
Holser, Rowland and Goud (1981)
McKelvey (1986)
McKelvey and Wang (1970)
Siddiquie et al. (1984)

AGGREGATE (sand, gravel, calcium carbonate, or shell):

Duane (1976)
Earney (1986)
Earney (1980)
Gauss et al. (1983)

PHOSPHORITES:

Baturin (1972)
Giresse et al. (1984)
Katz and Glasby (1979)

HEAVY MINERALS OR PLACERS:

El Gemmizi (1985)
Emery and Noakes (1968)
Hill and Parker (1970)
MacDonald (1971)
Noakes (1977)
Noakes (1972)

FERROMANGANESE ENCRUSTATIONS AND NODULES:

Commeau et al. (1984)
Cronan (1984)
Exon (1982)
Frazer and Fisk (1977)
Manheim (1986)

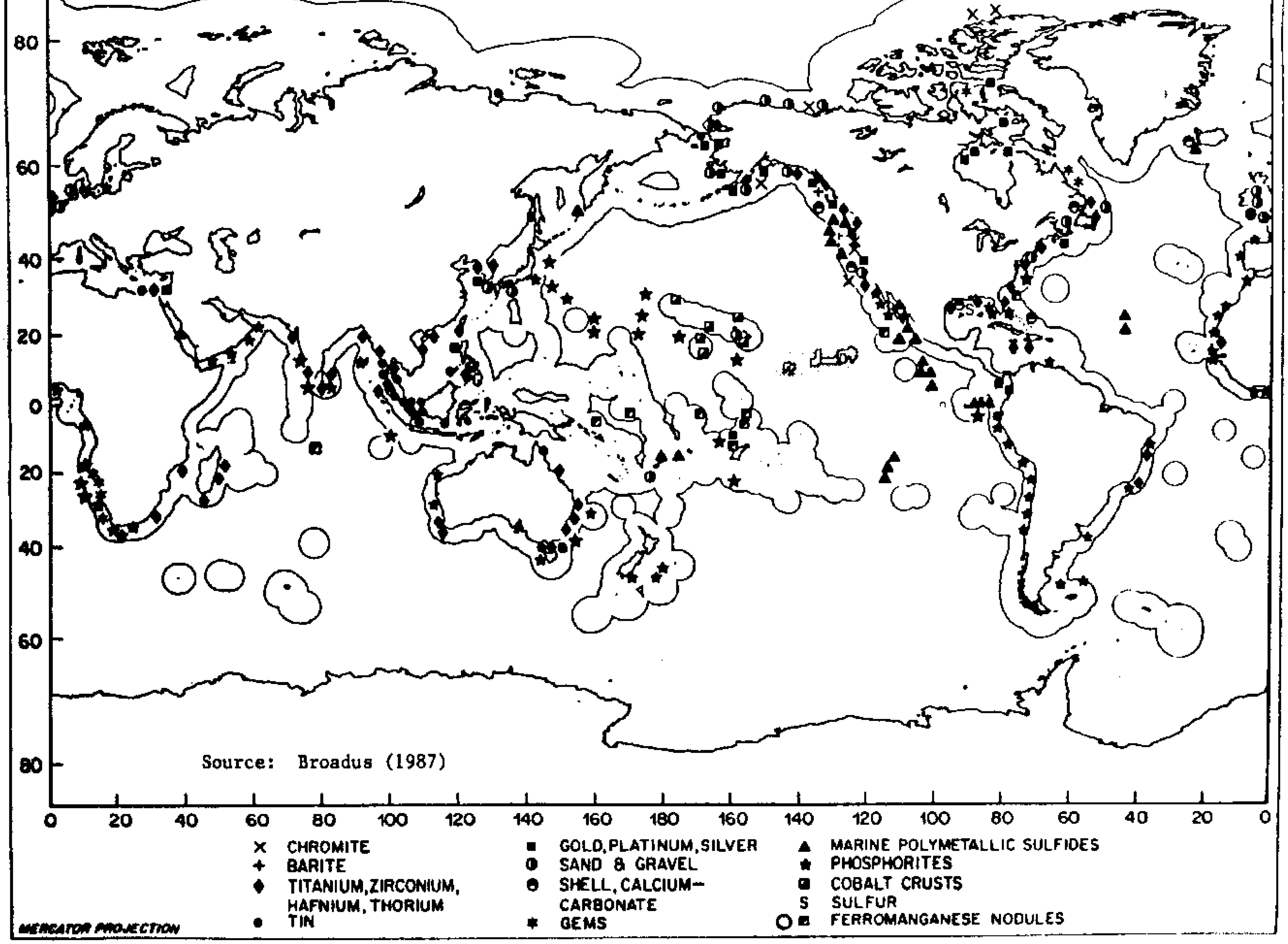
MARINE POLYMETALLIC SULFIDES:

Broadus (1984)
Several references in this report (see Section IV)

OTHER GEOGRAPHICAL DATA:

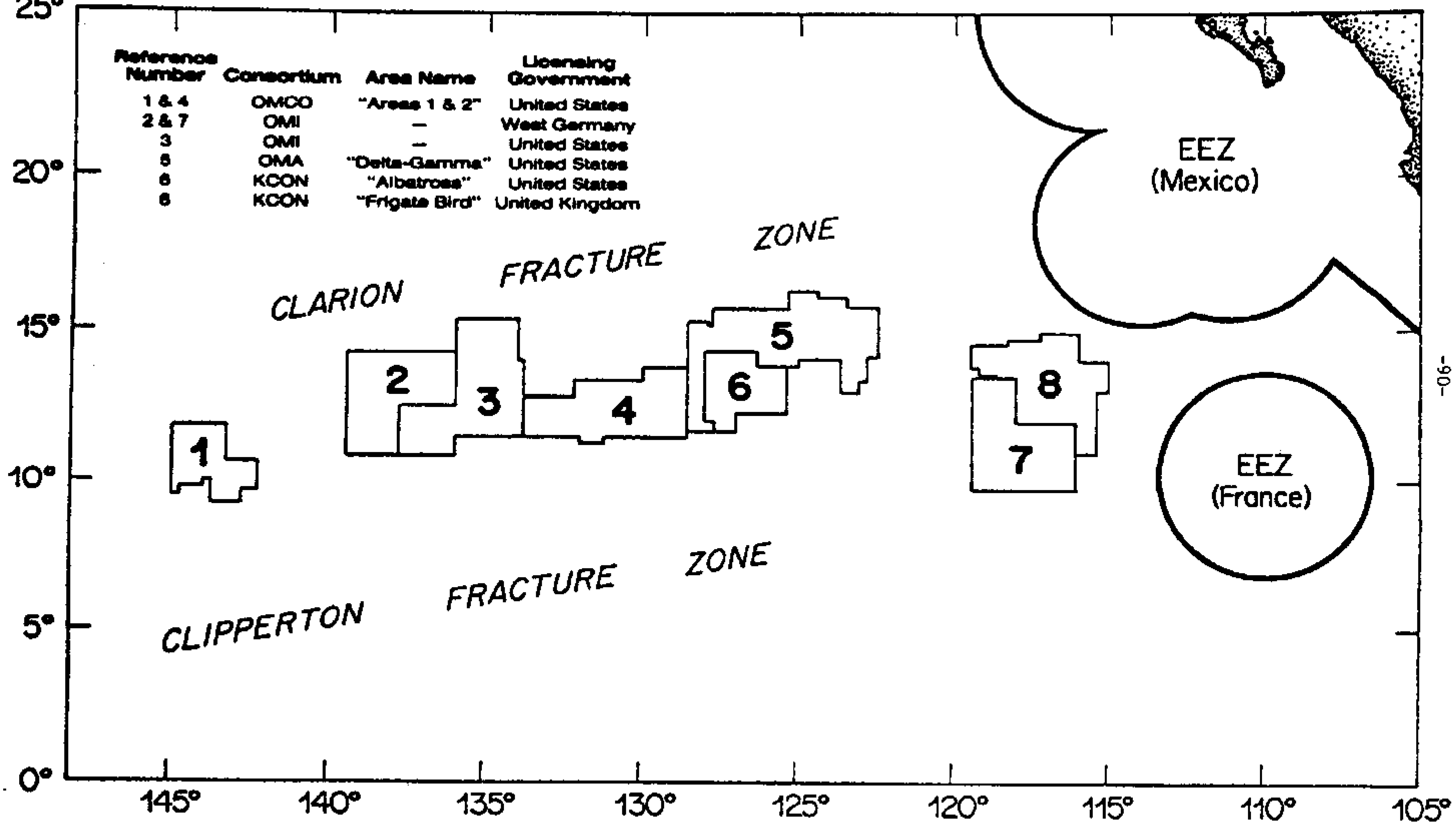
DOI (1960): "Phosphate Lease File" from the Pacific Region, Minerals Management Service, Los Angeles, California
Department of State (Undated): Base map with exclusive economic zones
MMS (1983): Arctic Sand and Gravel lease area
MMS (1983): Gorda Ridge proposed marine polymetallic sulfides lease area
NOAA (1985): deep seabed exploration areas under U.S. license
Turner et al. (1977)

Figure VI-1: World Map of Seabed Materials and EEZs



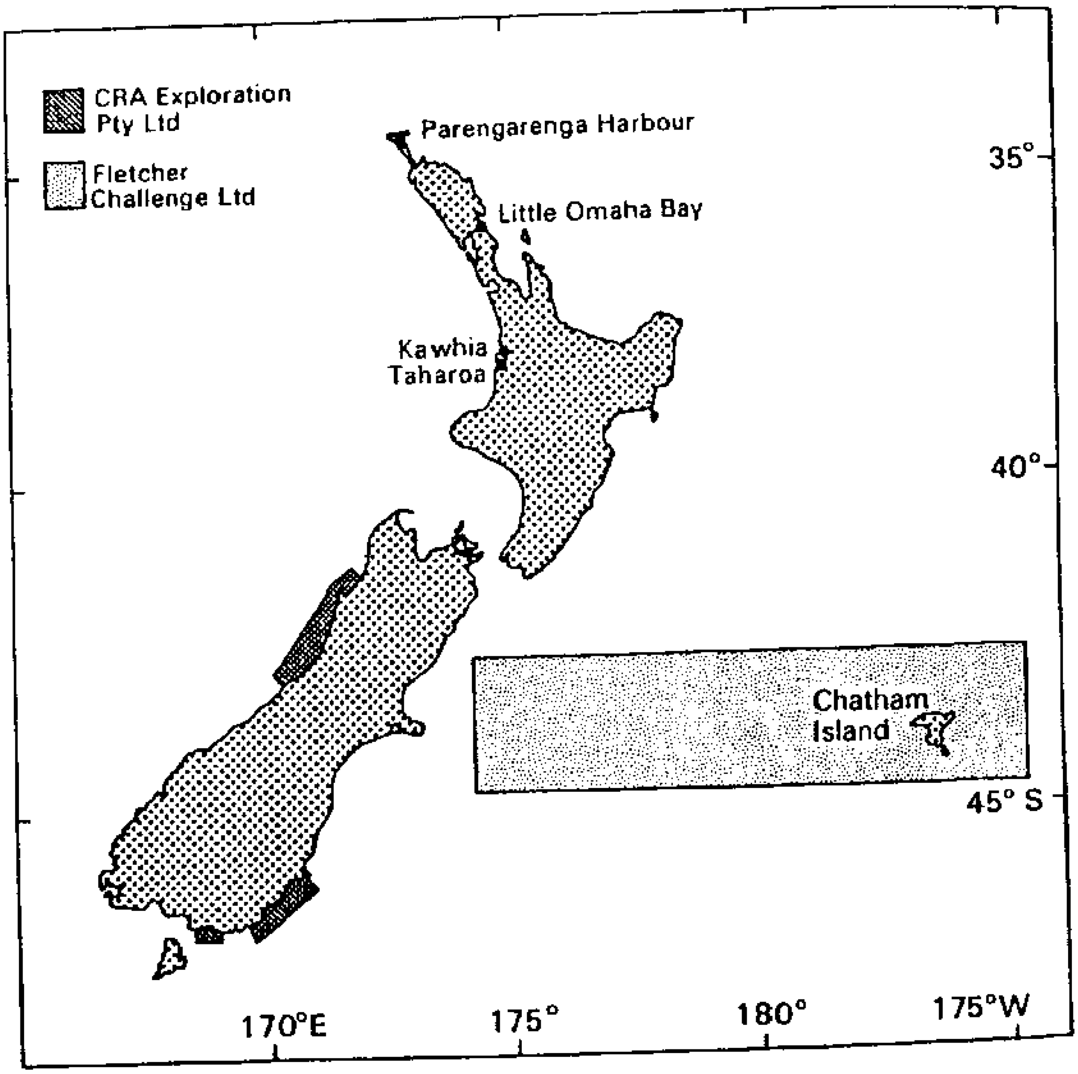
Source: Broadus (1987)

Figure VI-2: **DEEP SEABED MINING:**
LICENSED EXPLORATION AREAS



Reference Number	Consortium	Area Name	Licensing Government
1 & 4	OMCO	"Areas 1 & 2"	United States
2 & 7	OMI	—	West Germany
3	OMI	—	United States
5	OMA	"Delta-Gamma"	United States
6	KCON	"Albatross"	United States
8	KCON	"Frigate Bird"	United Kingdom

Figure VI-3



OFFSHORE PROSPECTING LICENSES IN NEW ZEALAND: (GLASBY, 1986)

- GOLD PLACERS: CRA EXPLORATION PTY. LTD.
- PHOSPHORITES: FLETCHER CHALLENGE LTD.

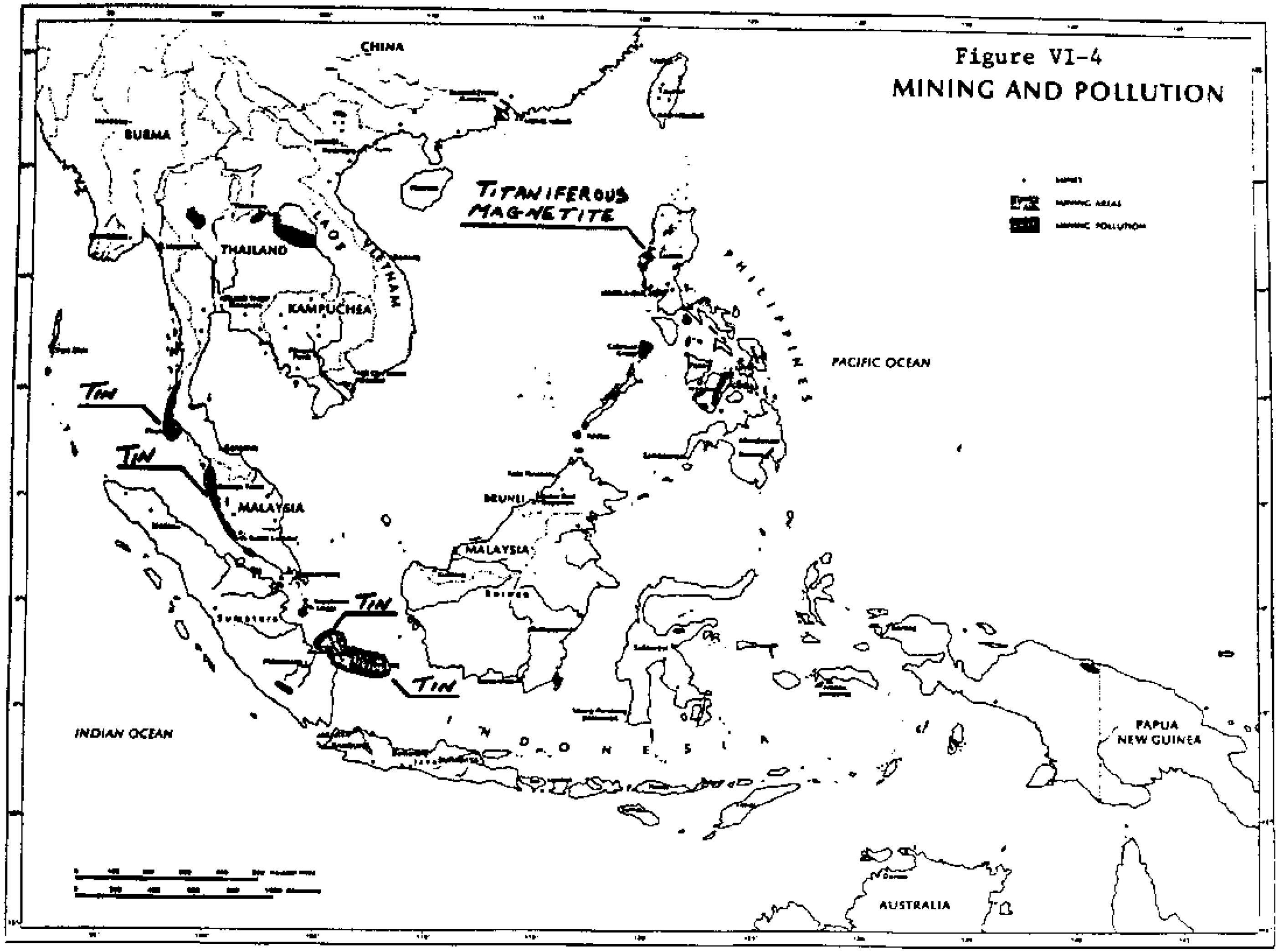


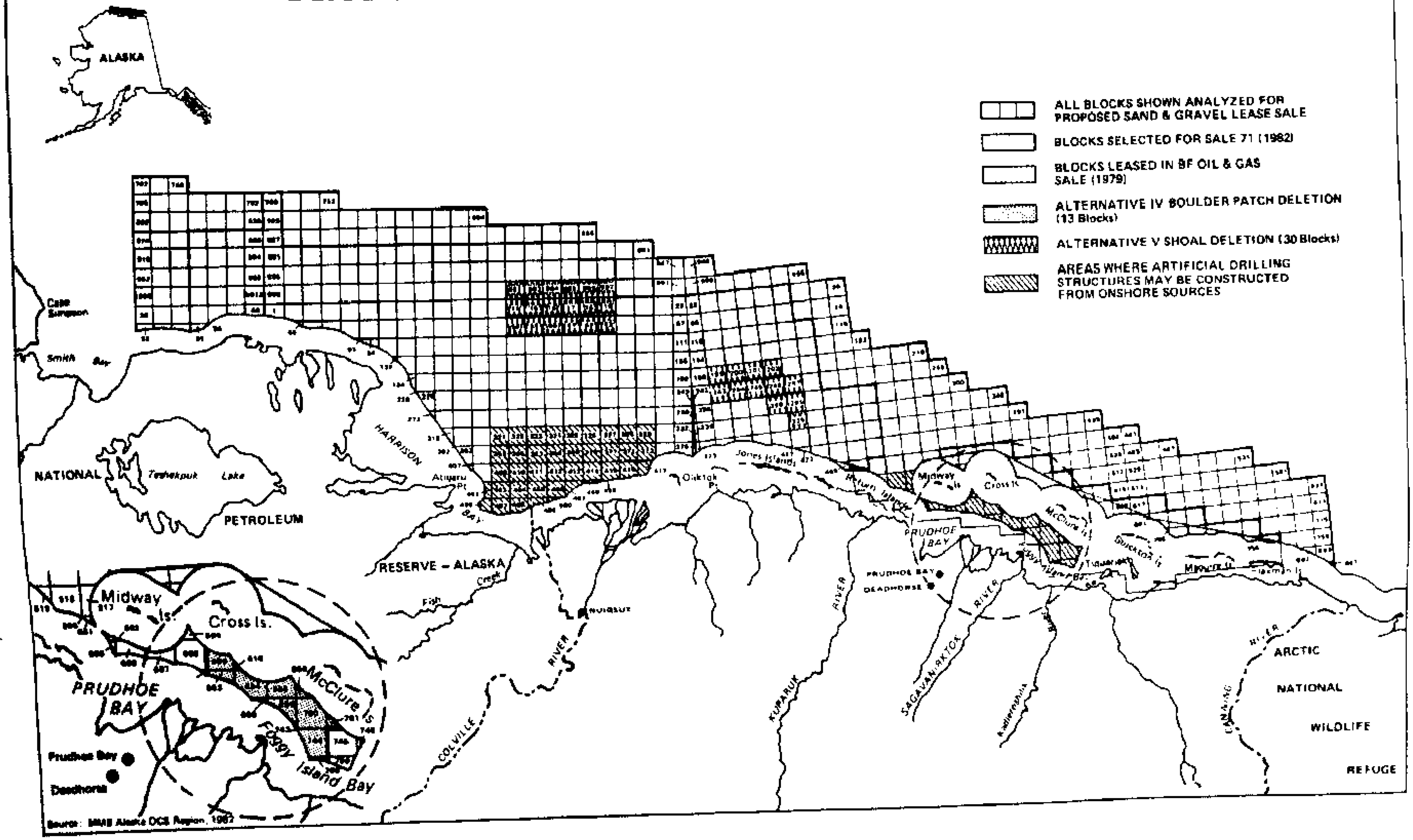
Figure VI-4
MINING AND POLLUTION

<u>OFFSHORE MINING LOCATIONS IN SOUTHEAST ASIA</u>: (MORGAN AND VALENCIA, 1983)

- TIN: THAILAND, INDONESIA
- TITANIFEROUS MAGNETITE:
  PHILLIPINES (1979)

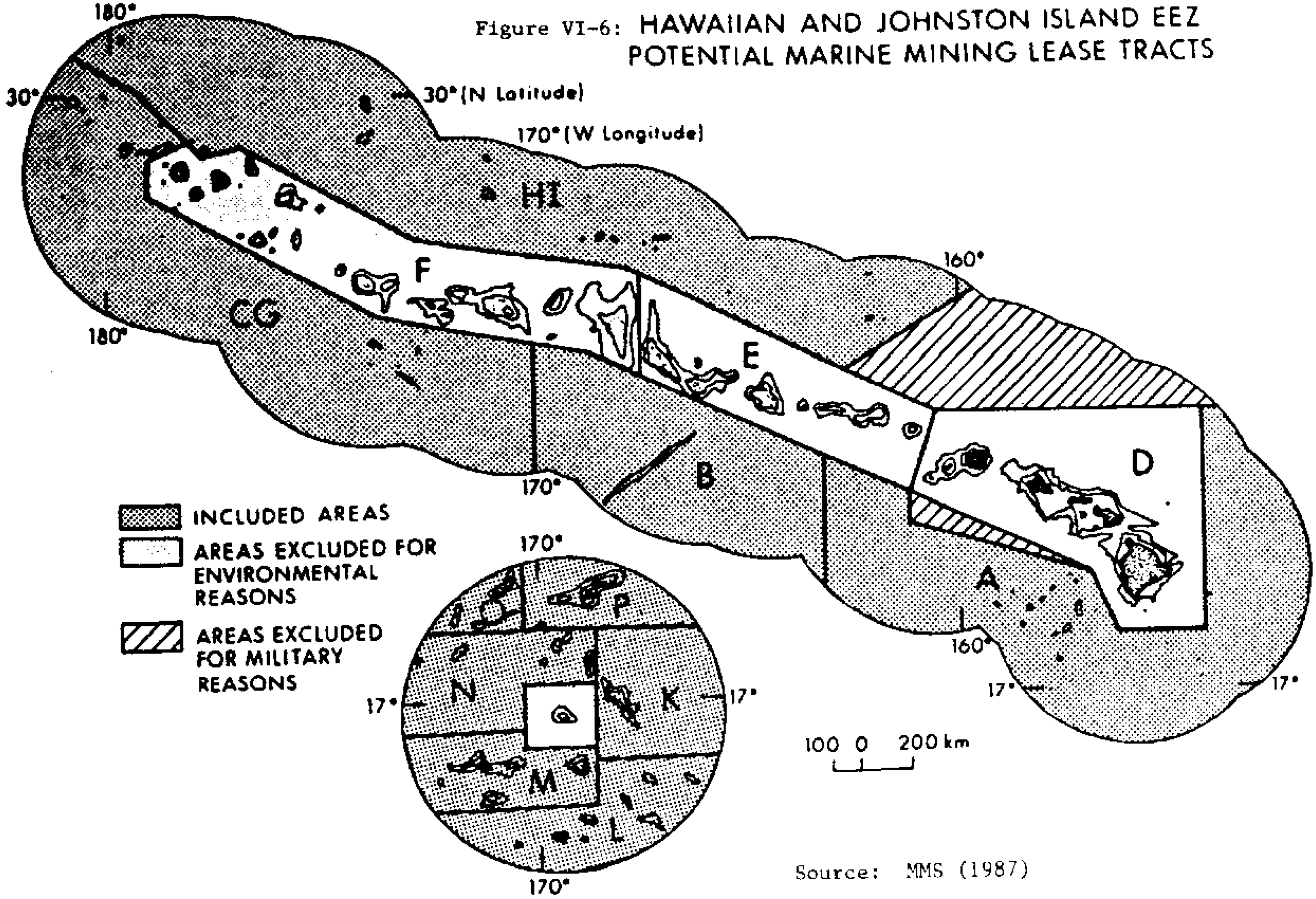
Figure VI-5

PROPOSED ARCTIC SAND & GRAVEL LEASE SALE



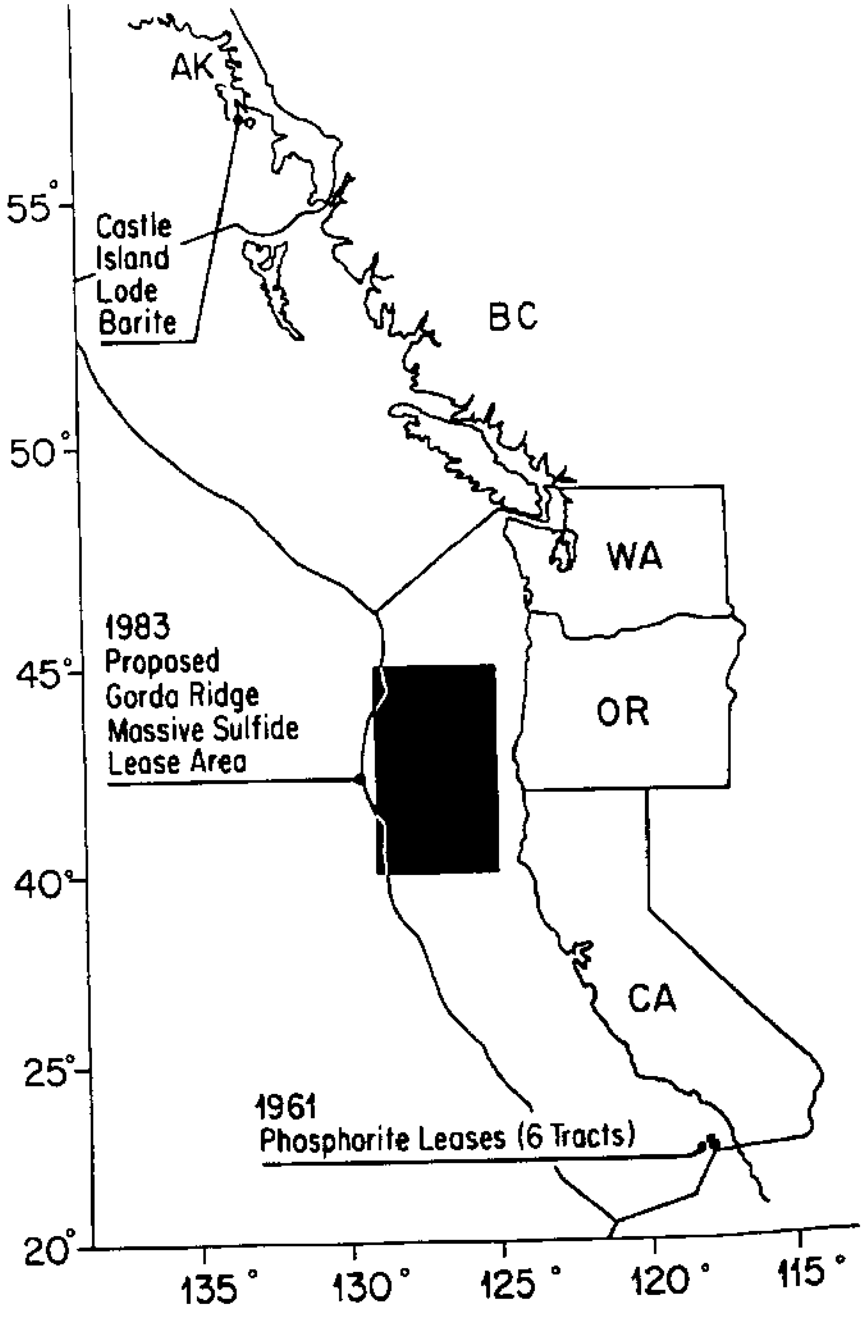
Source: MMS Alaska OCS Region, 1982

Figure VI-6: HAWAIIAN AND JOHNSTON ISLAND EEZ POTENTIAL MARINE MINING LEASE TRACTS



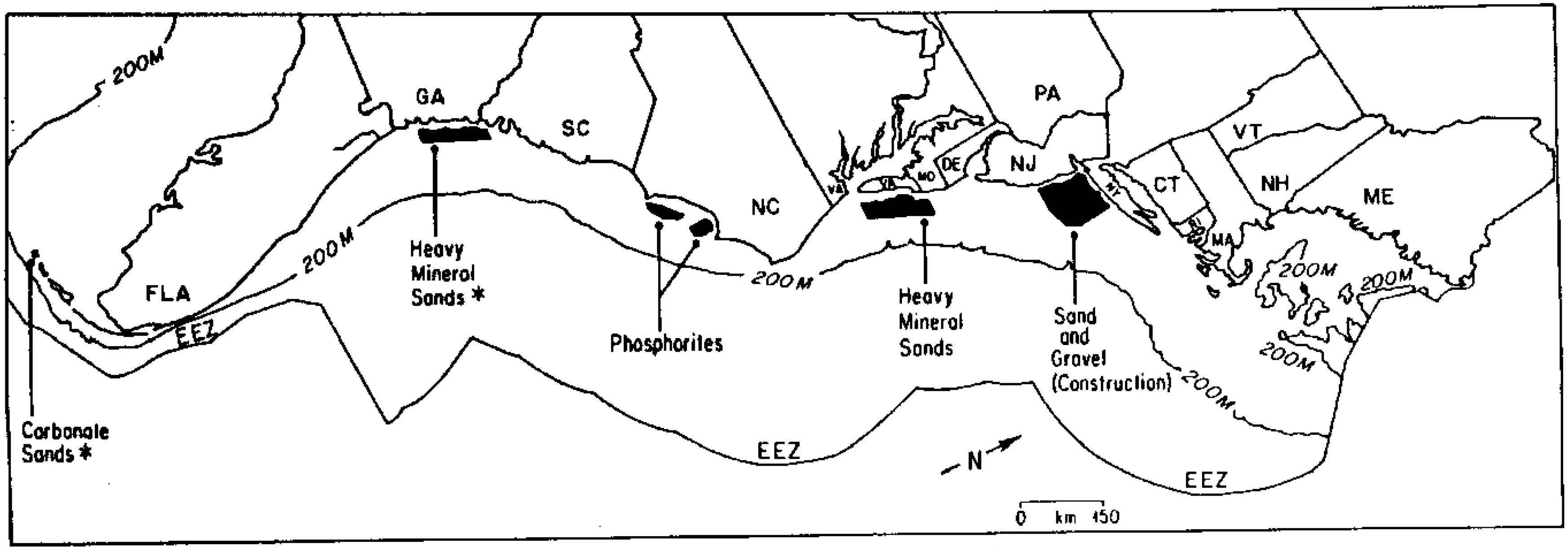
Source: MMS (1987)

Figure VI-7: Areas of Interest for Marine Hard Minerals: U.S. Pacific Coast



Sources: DOI, 1960; Thompson and Smith, 1970; MMS, 1983

Figure VI-8



"Areas Of Interest" For Marine Hard Minerals: U.S. Atlantic Coast (MMS, 1987)

(* Recent Prelease Exploration)

Section VII: Marine Polymetallic Sulfides: Discovery, Location, and Generalized Composition

This section is concerned with marine polymetallic sulfides (MPS), found at oceanic crustal spreading centers. Rona (1983) gives an exhaustive summary of the potential for sulfide deposition at these centers and lists identified MPS occurrences through 1983. Bischoff et al. (1983a) provide an excellent economic geological description of sulfide minerals. This section updates some of the previous works. The purpose of this section is to characterize generally the existing state of knowledge concerning MPS locations and to give a rough indication of the extent of scientific interest in these deposits. This section is divided into four parts: an update of submersible dive data, the jurisdictional status of MPS deposits, a record of MPS locations, and a generalized composition of MPS samples. References used in the record of MPS locations are appended to this section.

Figure VII-1 displays the annual number of locations of MPS occurrences from 1976 when the first MPS deposit was located at the Galápagos Ridge through 1986. Here the term "location" refers to a geographic location that may encompass one or more sulfide "deposits." These data were taken from Table VII-2, described below. Figure VII-1 gives a rough idea of the output of scientific discovery efforts on MPS and hydrothermal systems.

Figure VII-1: Annual Locations* of MPS Occurrences

* (May include more than one deposit)

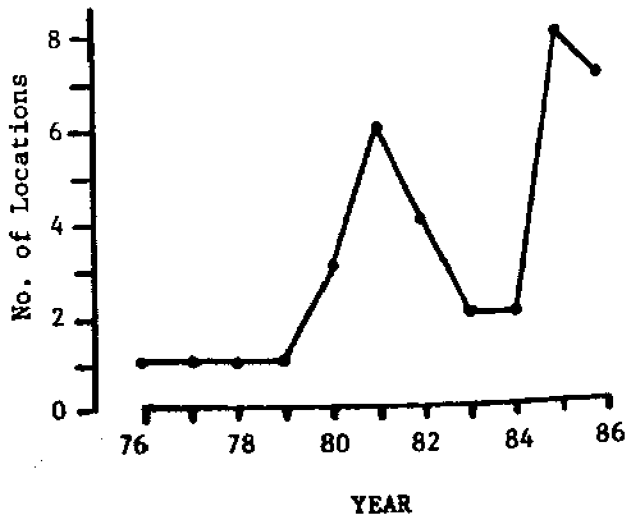


Figure VII-2 displays dive data for the Alvin submersible on hydrothermal vent locations. Dive data can be used to estimate scientific interest and activity in marine hydrothermal deposits at a general level. From 1977 to 1984, this information was compiled for dives in U.S., Canadian, and French submersibles by Jones et al. (1985). Following this work, Figure VII-2 shows dives from 1977 through 1986 for Alvin only. (In the past, the majority of dives have been conducted in Alvin.) We would like to acknowledge the assistance of Rick Chandler, Alvin Operations, WHOI, in providing this data. Since 1977, considerable effort has been devoted to scientific exploration of the world ocean ridge system. Even so, less than one percent of the ridge system has been studied in detail (Malahoff, 1985).

Thus far, MPS deposits have been located within the maritime jurisdictions of 10 countries. Table VII-1 matches locations with country and form of jurisdiction. Marine scientific research on MPS within internal waters and the territorial sea of a coastal nation is subject to local regulation. Marine scientific research on MPS located on the continental shelf or within the EEZ of a coastal nation may be subject to the "consent" and possible participation of the coastal nation. The degree to which regulation restricts or precludes marine science varies among jurisdictions (see: Ross and Landry, 1987). Beyond national jurisdiction, marine science remains unregulated. At the Preparatory Commission for the Law of the Sea (LOS) Convention, there has been some discussion concerning the distinction between marine science and "prospecting" beyond national jurisdiction, with the possible (but unlikely) result that marine science directed at geological resources like MPS might come to be regulated (Bowen, 1985). The exploration or development of MPS as a mineral resource within internal waters, the territorial sea, or on the continental shelf of a coastal nation is subject to local regulation. Until the entry into force of the Law of the Sea Convention, the exploration and development of MPS beyond national jurisdiction may be unregulated. Even with its entry into force, the LOS Convention does not speak directly to hard rock minerals other than manganese nodules, and the potential for and degree of regulation for minerals such as MPS beyond national jurisdiction remains uncertain (Bleicher, 1984).

Table VII-2 records the location, expressed in longitudinal and latitudinal coordinates, of MPS discoveries to date. Also listed along with each location is the name and date of the oceanographic expedition(s) associated either with discovery or with subsequent observation, sampling, and

Figure VII-2: Annual ALVIN Dives on Hydrothermal Systems for Geological or Biological Research

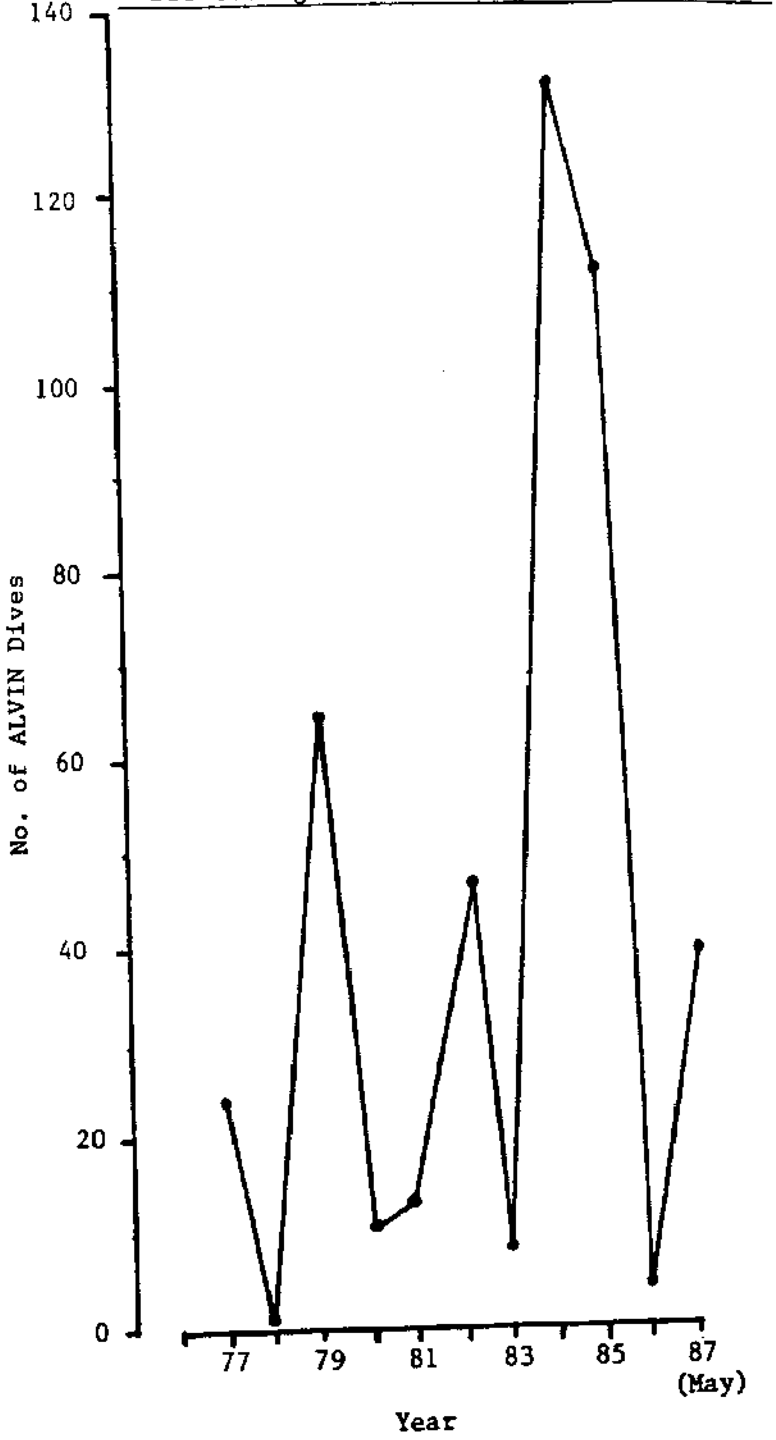


Table VII-1: Jurisdictional Status of MPS Deposits

Country	Location	Jurisdiction
Canada	Explorer Ridge	Continental Shelf[1]
	Juan de Fuca Ridge	"
	• Middle Valley	"
	• Endeavor Segment	"
Ecuador	Galápagos Rift	Continental Shelf[2]
Fiji	Fiji Basin	Exclusive Economic Zone
(Iceland	Icelandic Ridge?	Exclusive Economic Zone)
International Seabed Authority	Juan de Fuca Ridge	The Area[3]
	• Axial Seamount	"
	• USGS Study Area	"
	13°N EPR	"
	11°N EPR	"
	7°N EPR	"
	Clipperton Transform	"
	20°S EPR	"
	Manus Basin	"
	Mariana Trough	"
	Woodlark Basin	"
	Mid-Atlantic Ridge	"
Japan	Okinawa Trough	Exclusive Economic Zone[4]
Mexico	Guaymas Basin	Territorial Sea
	21°N EPR	Continental Shelf or Exclusive Economic Zone
Soviet Union	Sea of Okhotsk	Territorial Sea
Tonga	Lau Basin	Exclusive Economic Zone
United States	Gorda Ridge	Continental Shelf[1] or Exclusive Economic Zone

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[1] Continental Shelf jurisdiction possible under the Geneva Convention of 1958.

[2] Strength of this jurisdictional claim (asserted by Ecuador on 19 September 1985) may be questioned under international law (Ramakrishna et al., 1986).

[3] Jurisdiction established under the Law of the Sea Convention of 1982, which has not yet entered into force.

[4] Japan is a signatory to the Law of the Sea Convention, but has not unilaterally declared either an exclusive economic zone or a claim to a continental shelf.

experimentation. For each location, a brief description of the type of MPS occurrence, including information about water depth, number of vents, estimated deposit size and published reference source is included. This record was modeled after Rona (1983) and is simlar to, but more inclusive than, Samson (1985). We would like to acknowledge assistance in the identification of MPS locations from Tim McConachy (University of Toronto), Sarah Little (Department of Geology and Geophysics, WHOI), Cindy Van Dover (Department of Biology, WHOI), Mike Mottl (University of Hawaii), and Geoff Thompson (Deparment of Chemistry, WHOI).

Athough 36 "locations" are recorded here in Table VII-2, there are potentially many more locations that have yet to be identified. The recent discovery of black smokers on the Mid-Atlantic Ridge, for example, greatly increased this potential, because it had been thought that such occurrences were unlikely to be found on slow-spreading ridges (Rona et al., 1986). The detection of water column signals, such as particulates or anomalous values of helium isotopes or methane, suggest that several more deposits exist at oceanic spreading centers (McConachy, 1986). Other methods of detection, such as photographic surveys (Kastens and Ryan, 1986), the remote sensing of biological communities (Van Dover et al., in press), or identification of sound frequencies (Little, S., personal communication, WHOI, 1986) increasingly may be used. Each location may actually consist of several vents or individual massive sulfide deposits. Determination of the three-dimensional size of these deposits has been hampered due to their geo-structural properties, making continuous vertical cores nearly impossible (Edmond, J., personal communication, Massachusetts Institute of Technology, 1987).

Table VII-3 tabulates "generalized compositions" of sulfide mineral samples for each location. The table allows a comparison of the compositions of sulfide minerals among locations, especially for metals of likely industrial interest. Here, generalized compositions are averages of several samples as reported in the literature or our own average from individual samples reported in the literature. It is important to note two things about these "grade" figures. First, it is uncertain whether the sampling processes have been random. In fact, the majority of sulfide samples have been taken from vent chimneys either by dredge haul or submersible. In many cases, these samples are "high grades" and may not be truly representative of an associated ssive sulfide deposit. Second, in most cases only a small number of samples ve been analyzed. It may not be possible to consider reported compositions statistically reliable indicators of deposit grade. Both of these points phasize the preliminary nature of economic-geological understanding about S deposits and suggest that a high degree of uncertainty exists. For rposes of comparison with land based "ores" (commercially producing massive lfide deposits), Tables VII-4 through VII-7 are reproduced from the terature for some of the well-known mines: Cyprus, Kuroko, Besshi, unswick, Kidd Creek, MacArthur River, and others. Care should be taken in rect comparisons of generalized compositions of MPS to the relatively tter-understood, land-based massive sulfide deposits.

Table VII-2: LOCATIONS OF MARINE POLYMETALLIC SULFIDES

Location	Project and Date	Type of Occurrence
EXPLORER RIDGE AREA 51°31'N, 130°53'W Tuzo Wilson Seamounts	U. Toronto, U. British Columbia September 1985	transmissometer and conductivity anomalies suggest hydrothermal activity at foot of continental slope (Scott et al., 1985)
49°42'-46'N, 130°16'-19'W "Magic Mountain and AGOR 171"	CASM 3, CASM 4, SCHISM 1 May, June, Aug 1984; U. Toronto, U. British Columbia May 1985	60 sulfide deposits over 8km ridge crest; faulted massive sulfide "lens" with Cu-rich base and Zn-rich top; southern sulfides inactive, degrading; northern sulfides inactive, but relatively intact; twelve of the 60 deposits exceed 150m in length by 7-10m thick; seven of the largest deposits estimated to be 1.5 million metric tons of massive sulfides; 1850m depth (Tunnicliffe et al., 1986; Hannington and Scott, 1985a, 1985b; Chase et al., 1985a; Tunnicliffe et al. 1985; Scott et al., 1985, 1984)
JUAN DE FUCA RIDGE AREA 49°N, 128°W (approx.) "Middle Valley"	PGC, GSC June 1986 PGC, GSC, AWIPR September 1985	sulfide outcrops including one 50m high by 600m in diameter; seven "mounds" up to 60m high by several hundred meters across; hosted by 300m thick sediments; depth approx 2220m; relatively low concentrations of Zn, Cu, Cd, Ag (but some high Ba) compared to unsedimented ridge deposits elsewhere; "texturally" different from other MPS, except possibly Guaymas (Davis, 1986; Davis et al., forthcoming)

Location	Project and Date	Type of Occurrence
JUAN DE FUCA RIDGE AREA		
47°57'-58'N, 129°06'W "Endeavor Segment"	MERGE October 1982; NOAA/GSC August 1984; ALVIN Expedition U. Washington 1985	140 kg. of sulfides recovered; actively venting and inactive sulfide structures; these structures average 10-15m in height, with 25m the largest; groups of structures are 30m long, 10-15m wide; Cu-Fe sulfides deposited by high temperature fluids; Zn- and Fe-rich sulfides deposited from low temperature fluids (Tivey and Delaney, 1985; Johnson and Tunnicliffe, 1985; Karsten et al., 1984; Hammond et al., 1984; Kingston et al., 1983)
45°57'N, 130°02'W "Axial Seamount"	ASHES Expedition 1986; NOAA, U. Victoria CGS 1986	small (100m diameter) vent field, 200m from base of southeast wall of caldera; 1540m depth; 4 major sulfide edifices; one clear vent (Hammond et al., 1986)
45°59'N, 130°03'W "Axial Seamount, Central Segment"	CASM I, II June, August 1983	three sulfide/sulfate chimneys up to 25m in height at 1580-92m depth; 1.7m, 160kg spire recovered; samples from spire rich in Zn; poor in Cu; also a "field" of clear, white, and black smokers found on the west wall of caldera; some are 5m high by 9m in diameter (Hannington and Scott, 1987; Canadian American Seamount Expedition, 1985, 1983)
44°40'N, 130°22'W "USGS Study Area"	USGS/U. Washington September 1981; USGS Juan de Fuca Study Group Sept-Oct 1984	12kg of massive sulfides dredged from one site in 1981; 1984 work showed sulfides as fields of spires and chimneys at 3 vent sites along 6km segment at 2200m depth; recovered sulfides typically more than 80 weight percent ZnS; Zn weight percent averages 50%; Pb up to 2% in some samples; Cu over 1% in four chimney samples; Cd, Ag interesting (Philpotts et al., 1985; Normark et al., 1985, 1983, 1982; Koski et al., 1982)

Location	Project and Date	Type of Occurrence
GORDA RIDGE AREA 40°45'-41°N, 127°30'W "Escanaba Trough: SESCA, NESCA"	USGS, NOAA, MMS US Navy, OSU June 1986; USGS, NOAA, OSU September 1985	at least 10 sulfide occurrences in 5x10km area on spreading ridge axis at 3400m depth; largest deposit at NESCA occurs within turbidite siltstone; outcrops may have been uplifted as much as 100m; no active venting, but some chimneys located; up to 43% Zn, 14% Pb, 5% Cu, 680ppm Ag, and 1-2ppm Au; concurrent formation of asphaltic petroleum (Zierenberg et al., 1986; Morton et al., 1986; Koski and Kvenvolden, 1986; USGS, 1985)
GUAYMAS BASIN 27°20'N, 111°30'W "Seacliff Hydrothermal Deposit"	US Navy November 1977	hydrothermal talc deposit at 2000m with pyrrhotite (FeS) precipitated around vent (Lonsdale et al., 1980)
27°01'N, 111°25'W "Southern Trough"	Scripps 1980	Kuroko-like sulfide deposits sampled from hydrothermal cones and pinnacles at "Dredge 7D," 2000m; petroliferous sulfide-rich mud; more than 100 hydrothermal deposits, 10-100m in diameter; high sedimentation rate buries inactive or stagnant discharge sites (Koski et al., 1985; Kastner, 1985; Peter and Scott, 1985; Lonsdale, 1980)
21°N EAST PACIFIC RISE 20°54'N, 109°03'W	CYAMEX: Project RITA Feb/Mar 1978	massive sulfides recovered by submersible CYANA at 2625m (Hekinian et al., 1980; Francheteau et al., 1979)

Location	Project and Date	Type of Occurrence
21°N EAST PACIFIC RISE		
20°50'N, 109°06'W	MIT September 1985; Protea I 1983; RISE Expedition Mar-May 1979; 1981	sites of actively forming massive sulfide mineral deposits along EPR axis, 2600m, at high temperature springs in SW section of 7km strip with 25 vents; sulfide mound deposits occur slightly off-axis from cooler vents to NE of strip; 13 vents found with Deep-Tow on summit graben in 1983 between 20°S and 21°S (MacDonald et al., 1986; Bowers et al., 1985; Speiss et al., 1980)
20°48.2'N, 109°17'W "Green Volcano" or "Volcano B"	Scripps, Washington Univ. (St. Louis), Smithsonian 1982	volcano "B" up to 500 m^2 of varicolored sulfides sampled; 2000m depth (Lonsdale et al., 1982a, 1982b)
13°N EAST PACIFIC RISE		
12°38'-54'N, 103°49'-104°01'W "Zone A"	Clipperton Cruise May-June 1981	"about 30" massive sulfide sites on floor of central graben--2600m depth; sulfides dredged with locally high concentrations of cobalt; sulfides more massive than any pyritic deposits dredged thus far (1981) from EPR (Hekinian et al., 1983b, 1981)
12°41'-53'N, 103°55'-58'W "Zone A"	Cyatherm Program Jan-Mar 1982; Geocyarise Feb/Mar 1984	20 active hydrothermal sites located along 20km ridge axis; 84 sites at 2620-40m depth (possible under-estimate) of sulfide deposition found; average diameter less than 50m; largest are 80m long by 30m wide (Ballard et al., 1984; Hekinian et al., 1984, 1983c)

Location	Project and Date	Type of Occurrence
13°N EAST PACIFIC RISE		
12°43'N, 103°52'W "Seamount C" or "Clipperton Seamount"	Clipperton Cruise May-June 1981; Cyatherm Program Jan-Mar 1982; Geocyarise Feb/Mar 1984	800m by 500m by (3m?) marine sulfide capped with ochreous oxidation products on western limb of an apron of seamount at (2300?)-2600m depth; estimated at 2 million mt; self-potential survey indicates that sulfides might be up to 15m thick in places; much hydrated silica (Hekinian et al., 1984, 1983b, 1983c)
11°N EAST PACIFIC RISE		
11°30'N, 104°W "Zone B"	CNEXO/COB: Cyatherm Program Jan-Mar 1981	active hydrothermal deposition and associated sulfide deposition (Ballard et al., 1984; Hekinian et al., 1983a)
10°55.6'N, 103°40.6'W "Feather Duster"	WHOI: Protea 9 May 1984	Massive sulfides (approx. 200 mt) associated with fissure-collapsed lava lake immediately east of axial graben; depth of 2520-25m; 6-8 black smokers; up to 5% Cu and 40% Zn (McConachy et al., 1986b, 1984; Ballard, 1984a, 1984b)
10°45'-47.7'N, (102°W)	ARGORISE Expedition December 1985	three active low-temperature vents observed by video photography from ARGO system at 2600m depth; three additional vents predicted from observed distribution of brachyuran crabs (Van Dover et al., in press)
7°N EAST PACIFIC RISE		
6°42'-44'N, 102°36'-38'W	CNEXO/COB: Searise Cruise Summer 1980	iron sulfides with small amounts of copper sulfide minerals, ferromanganese and other oxides dredged from 2740-2880m depth (Boulegue et al., 1984)

Location	Project and Date	Type of Occurrence
GALAPAGOS RIFT AREA		
0°47'-49'N, 86°04'-13'W	US Navy SASS; WHOI Angus/Alvin Programs 1976, 1977, 1979	photographic identification of sulfide deposits 20km west of Alvin Dive 1001 site at average depth of 2500m; some deposits associated with active hydrothermal venting (Ballard et al., 1982; Francheteau and Ballard, 1983)
0°45.3'N, 85°49.5W "ALVIN Dive 1001"	GRAFZI Project 1980	visual discovery of sulfide precipitate field (inactive vents) extending 2km west of dive site at depth of 2850m; some sulfides sampled (Malahoff et al., 1987, 1983; Embley et al., 1986; Malahoff, 1985, 1982c, 1981; Skirrow and Coleman, 1982)
0°45'N, 85°50'W	NOAA: NOS Aug-Sept 1981	4 sites of massive poly-metallic sulfide deposition mapped at depth of 2600m: represents "several million tons of sulfides"; largest is 1000m long, 35m thick, 150m wide; series of mounds of coalesced chimneys up to 30m high; up to 6% Cu and 3% Zn reported; previously discovered sulfides (see above) located along same fault system, approximately 2km east of these discoveries (Malahoff et al., 1987; Law et al., 1981; Malahoff, 1982a, 1982b, 1982c)
CLIPPERTON TRANSFORM		
10°10'S, 104°21'E	PASC-01 Lamont-Doherty, URI 1986	site of recent volcanism mapped with Sea-MARC I at 2600m depth on East Pacific Rise just south of Clipperton transform fault; temperature anomaly and hydrothermal communities indicate likelihood of sulfide deposit (Kastens et al., 1986)

Location	Project and Date	Type of Occurrence
20°S EAST PACIFIC RISE 17°26'S, 113°12.5W	CNEXO-COB January 1984	sulfide edifices discovered within drained lava ponds at 2600m depth; one black smoker site; many low temperature vents (Renard et al., 1985)
18°30'-33'S, 113°24.5'W;	CNEXO-COB January 1984 GEOMETEP 3 March 1983	4 deposits near 18°30'-33'S at 2600m depth; inactive chimney similar to 21°30'S; the latter contains stockwork mineralizations as well as massive sulfides (Renard et al., 1985; Bäcker et al., 1985; Halbach, 1984)
20°06'-10'S, 113°42'-44'W	CNEXO-COB January 1984 WHOI, Stanford, IPGP 1981	active high-temperature sulfide deposition fields; sulfide deposits photographed; 2850m average depth of axial ridge (Renard et al., 1985; Francheteau and Ballard, 1983; Ballard et al., 1981)
21°30'S, 114°20'W	CNEXO-COB January 1984 GEOMETEP 3 1983	over a dozen active chimneys up to 30m in height including black smokers; depth of 2800m; some edifices up to 15m base diameter and 10m high; sulfides sampled from blocks near bottom of graben; enriched in Cu (Renard et al., 1985; Bäcker et al., 1985)
LAU BASIN (15°S, 175°W)	Papatua I; SIO January 1986; UCSB 1986	Lau Basin, within EEZ of the Kingdom of Tonga; fragments from a dead black smoker were dredged from 2100m depth along axial ridge; samples contain Zn, Fe, and Cu-Fe sulfides; (Craig et al., 1987; Hawkins, 1986)
FIJI BASIN 18°08'S, 173°E	Papatua I: Legs 5, 6 SIO 1986	active hydrothermal vent sites identified by large methane and helium-3 plumes in North Fiji Basin along central spreading axis (Craig et al., 1987)

Location	Project and Date	Type of Occurrence
MANUS BASIN 3°09.7'S, 150°16.8'E	CCOP/SOPAC January 5, 1986	Inactive hydrothermal chimneys photographed using Deep Tow over 150m distance; mass-wasted chimney debris and possible sulfide-enriched sediments also seen; includes "scenic University of Hawaii photographic safari vent site" at 3°S; no sulfides recovered in dredge sample 100m from site; 2500m depth; chimneys "morphologically similar" to those reported from other spreading centers (Craig et al., 1987; Both et al., 1986; Taylor et al., 1986)
MARIANA TROUGH 18°11'-15'N, 144°42'E	Papatua III: Leg 9 SIO 1986; CEPHEUS Expedition 1982	off-ridge hydrothermal vents identified by methane anomalies at 3600m depth; methane uncorrelated with helium-3; no evidence of hydrothermal activity at "Mounds" site to west (18°01'N, 144°18'E, 3534m depth) from methane measurement (Horibe and Craig, 1987; Horibe et al., 1986, 1983)
WOODLARK BASIN 19°55'S, 151°50'E "Beaujolais"	PACLARK 1986	Hydrocast, CTD, transmissometer and chemical measurements and recovery of Fe-Mn ochreous oxide crust indicate hydrothermal activity and potential new vent field (Binns et al., 1986; McConachy et al., 1986; McConachy and Scott, 1986)
OKINAWA TROUGH 27°34.4'N, 127°08'E	U. of Ryukyu, U. of Tokyo, JAMSTEC Summer 1986	Active hydrothermal venting discovered in back-arc setting; water depth of 1540m; dives made in Shinkai 2000; mound discovered in summit crater of small seamount; mound 5-6m high, 15-25m diameter; no recognizable biological activity; chemical composition of mound different from mid ocean deposits (Uyeda, 1987; Hotta, 1987)

Location	Project and Date	Type of Occurrence
SEA OF OKHOTSK (50-55°N, 155°E)	R.V. Vulkanolog; Vulcanology Inst. of the Far Eastern Ctr. of the Soviet Acad. of Sciences January 1986	Hot water springs or "torches" observed on seafloor near Paramushir Island in the Kurile Island Chain (back arc basin?); active 5m cone (vent?) at depth of 800m; (Ocean Science News, 1986; Tarasov et al., 1986)
MID-ATLANTIC RIDGE 26°08'N, 44°49'W "TAG Hydrothermal Field"	NOAA, Cambridge U., Florida Inst. Tech. NOAA Vents Program July-August 1985	Eleven black smokers discharging through rocks in a 150m diameter area at a depth of 3620-3675m; dredge recovered Cu, Fe, Zn sulfides, sulfates, and Fe-Mn oxides and hyrdoxides from "inner mound" (200m by 60m high); possible 4.5 million mt deposit; at least 35 inactive chimneys also observed 2km northeast of mound at 3600m depth (Schroeder et al., 1986; Rona et al., 1986a, 1986b, 1985)
22°55'-23°22'N, 44°53'-57'W "Snake Pit" and "MARK Area" (ODP Site 649)	WHOI, NOAA, Alvin Summer 1986; Ocean Drilling Program, Leg 106 Autumn 1985	Twelve or more small chimneys up to 10m high; large active black smoker more than 13m high, 3-4m in diameter; 10 short holes drilled westward from smoker; minerals include Zn, Fe sulfides at site 649b; Cu, Zn, and Fe sulfides at site 649g (Sulanowski et al., 1986; Honnorez et al., 1986; Humphris, 1986)
ICELANDIC RIDGE ? (24°W?, 64°N?)	NR-1 Voyage Summer 1985	hydrothermal activity and marine sulfide occurrences?

Table VII-3:
GENERALIZED COMPOSITION OF MARINE POLYMETALLIC SULFIDES

	Weight Percent (%)						ppm				Source
	Zn	Cu	Pb	Ba	Fe	S	Ag	Au	Cd	Co	
Explorer Ridge											
51°31'N	—	—	—	—	—	—	—	—	—	—	
49°46'N	6.96	0.57	0.39	23.89	2.82	32.41	93	1	271	—	Tunnicliffe et al., 1986 (n = 7)*
Juan de Fuca Ridge											
48°30'N	3.56	0.42	0.06	1.48	36.00	37.70	5	tr	47	19	Davis et al., 1987 (n = 10)
47°57'N	6.25	0.51	0.10	—	—	—	30	tr	260	25	Tivey and Delaney, 1985 (n = ?)
45°59'N	22.70	0.43	0.35	8.70	5.80	18.60	189	5	522	—	Hannington and Scott, submitted (n = 14)*
45°57'N	—	—	—	—	—	—	—	—	—	—	
44°40'N	53.95	0.22	0.25	0.06	8.90	34.70	260	tr	775	15	Bischoff et al., 1983 (n = 2)
Gorda Ridge											
41°00'N	14.16	0.89	4.52	0.57	33.02	—	242	tr	536	—	Koski, 1986, p.c. (n = 5)*
40°45'N	5.39	1.82	1.43	6.46	30.43	—	127	1	280	—	Koski, 1986, p.c. (n = 4)*
Guaymas Basin											
27°20'N	0.03	0.70	0.01	tr	—	—	< 7	< 7	—	200	Lonsdale et al., 1980 (n = 1)
27°03'N	3.96	0.59	0.34	2.22	33.57	24.57	99	—	110	—	Koski et al., 1985 (n = 9)*
21°N East Pacific Rise											
20°54'N	33.15	0.57	0.05	—	22.30	39.29	330	—	357	337	Hekinian et al., 1980 (n = 3)*
20°50'N	32.33	0.81	0.32	0.23	19.20	35.30	156	tr	560	3	Bischoff et al., 1983 (n = 3)
20°48.2'N	—	—	—	—	—	—	—	—	—	—	
13°N East Pacific Rise											
12°43-50'N	11.20	9.07	0.07	—	25.61	36.14	57	—	279	748	Hekinian and Fouquet, 1985 (n = 5)*
12°43'N	0.06	1.30	0.02	—	31.98	34.39	7	—	2	550	Hekinian and Fouquet, 1985 (n = 2)*

* Our own average of reported values.

Table VII-3 (continued)
GENERALIZED COMPOSITION OF MARINE POLYMETALLIC SULFIDES
(continued)

	Weight Percent (%)						ppm				Source
	Zn	Cu	Pb	Ba	Fe	S	Ag	Au	Cd	Co	
11°N East Pacific Rise											
11°30'N	—	—	—	—	—	—	—	—	—	—	
10°56'N	28.60	1.83	0.07	0.06	19.80	36.50	46	tr	—	9	McConachy, 1987, p.c. (n = ?)
7°N East Pacific Rise											
6°42-44'N	—	—	—	—	—	—	—	—	—	—	
Galapagos Rift											
0°47-49'N	—	—	—	—	—	—	—	—	—	—	
0°45.3'N	0.14	4.98	0.07	tr	44.10	52.20	10	tr	32	482	Bischoff et al. 1983 (n = 1)
(0°45'N)	1.00	6.50	0.02	tr	43.00	48.00	66	—	tr	250	Malahoff, 1982a, 1982b; Kingston, 1983 (n = ?)
20°S East Pacific Rise											
17°30'N	—	—	—	—	—	—	—	—	—	—	
18°30-33'S	41.30	5.50	—	—	16.30	32.50	—	—	—	—	Bäcker et al. 1985 (n = 1)
20°06-10'S	—	—	—	—	—	—	—	—	—	—	
21°30'S	9.1	6.80	0.05	—	35.80	45.50	—	—	—	—	Bäcker et al. 1985 (n = 1)
Lau Basin											
15°S	—	—	—	—	—	—	—	—	—	—	
Fiji Basin											
18°08'S	—	—	—	—	—	—	—	—	—	—	
Manus Basin											
3°09.7'S	—	—	—	—	—	—	—	—	—	—	
Woodlark Basin											
19°55'S	—	—	—	—	—	—	—	—	—	—	

* Our own average of reported values.

Table VII-3

GENERALIZED COMPOSITION OF MARINE POLYMETALLIC SULFIDES
(continued)

	Weight Percent (%)						ppm				Source
	Zn	Cu	Pb	Ba	Fe	S	Ag	Au	Cd	Co	
Mariana Trough											
18°11'-15'N	—	—	—	—	—	—	—	—	—	—	
Sea of Okhotsk											
(155°E?)	—	—	—	—	—	—	—	—	—	—	
Mid-Atlantic Ridge											
22°55'-23°22'N	—	—	—	—	—	—	—	—	—	—	
26°08'N	2.70	10.60	0.11	0.02	27.10	36.40	300	—	—	20	Rona et al. 1986 (n = 5)*
Icelandic Ridge											
(24°W?)	—	—	—	—	—	—	—	—	—	—	

* Our own average of reported values.

Table VII-4

TABLE 1. Distribution of Cu, Zn, Ni, S, and Co in Mathiati, Skouriotissa, Agrokipia B, and Kokkinoyia Ore Bodies

Ore body	Zone	Depth (meters)	Number of samples	Percent		ppm			
				S	Cu	Zn	Ni	Co	
Mathiati	A	Surface	12	nd	0.29	1,050	44	53	
	B	Surface	8	nd	0.09	10,450	36	33	
	C brecciated	Surface	25	nd	0.15	770	27	62	
	C pillows	Surface	7	nd	0.04	324	27	42	
Skouriotissa	A conglom.	Surface	6	nd	2.78	206	20	359	Bischoff
	A compact	Surface	1	nd	0.30	960	44	610	
Agrokipia B (Drill Hole A-103)	A	140	1	22	0.34	78,000	30	25	Kingston
	A	142	1	30	12.20	42,000	45	20	
	A	146	1	41	2.07	10,100	30	35	Kingston
	A	148	1	42	0.94	6,000	15	35	
	A	154	1	39	0.03	415	45	50	
	C	161–293	22	19	0.04	520	36	81	
Kokkinoyia (Drill Hole M49)	A	183–186	2	47	1.80	3,020	60	33	
	A	189–192	2	43	3.95	1,100	53	38	
	A	195–198	2	41	1.75	1,300	83	45	
	A	201–204	2	48	1.85	1,650	60	39	
	A	207	1	48	5.50	1,000	60	25	
	B	210–213	2	34	1.75	630	30	51	
	C	216–222	3	20	0.40	294	30	100	
	C	225–234	4	12	0.20	189	34	78	
Kokkinoyia (Drill Hole M72)	A	183–186	2	nd	3.64	2,750	60	75	
	A	189–192	2	nd	11.10	5,850	76	15	
	A	195–198	2	nd	4.10	8,170	65	33	
	A	201	1	nd	4.60	3,900	100	40	
	C	204–209	2	nd	1.82	2,000	110	40	
	C	212–215	2	nd	2.48	2,725	118	40	
	C	218	1	nd	2.00	600	125	50	
Kokkinoyia (Drill Hole M45)	A	202–205	2	nd	1.71	700	60	73	
	A	208–211	2	nd	2.62	708	38	130	
	A	214–217	2	nd	2.74	1,220	38	118	
	B	223–227	2	nd	0.83	555	45	115	
	C	230–236	2	nd	1.21	443	45	118	
	C	242–245	2	nd	0.50	234	30	70	

nd = not determined.

SOURCE: Constantinou, G. and Govett, G.J.S. 1973. "Geology, Geochemistry, and Genesis of Cyprus Sulfide Deposits." <u>Economic Geology</u> 68 (1973): 843-858.

Table VII-5

TABLE 1. Details of Kuroko Deposits in the Hokuroku District. Abbreviations: nd = not determined, — = low, but not analyzed. Updated from Takeuchi (1970).

Name of mine	Name of ore deposit	Year of discovery	Size of ore deposit (meters)	Grade of crude ore (%) Cu	Pb	Zn	S	Production in 1972 (per month)	Size of mine[5]
Kosaka[1]	Motoyama	1861	300 × 700 × 50	2.2	0.8	4.5	23.7	Crude ore = 45,000 tons Acid leached Cu = 70 tons	25 million tons
	Uchinotai-Nishi	1959	400 × 350 × 20	2.8	1.1	4.0	19.8		
	Uchinotai-Higashi	1960	300 × 400 × 16	2.0	1.5	4.4	15.6		
	Uwamuki No. 1	1962	150 × 100 × 7	0.6	4.2	11.5	4.7		
	Uwamuki No. 2	1965	200 × 150 × 40	0.8	1.8	7.8	8.8		
	Uwamuki No. 4	1966	350 × 100 × 17	0.8	2.8	8.3	6.3		
Hanaoka[1]	Tsutsumizawa	1885	350 × 120 × 120	1.2	0.7	1.9	nd	Cu ore = 25,000 tons Pyritic ore = 10,000 tons	35 million tons
	Doyashiki	1916	600 × 350 × 20	2.5	0.5	1.8	nd		
	Kamiyama	1919	260 × 60 × 40	1.5	0.7	4.1	nd		
	Ochiaizawa	1942	150 × 100 × 30	2.4	1.5	5.9	nd		
	Matsumine	1963	800 × 800 × 30	3.2	0.8	2.5	23.9	Crude ore = 50,000 tons	
Fukazawa[1]	Kanayamazawa	1969	210 × 90 × 8	1.6	6.8	19.0	nd	Crude ore = 10,000 tons	8 million tons
	Manzaku	1969	190 × 190 × 13	1.0	1.5	10.1	nd		
	Tsunokakezawa	1970	480 × 400 × 24	1.1	3.2	15.9	nd		
Shakanai[3]	Shakanai No. 1	1962	300 × 150 × 12	2.3	3.2	14.6	14.0	Crude ore = 35,000 tons	10 million tons
	Shakanai No. 3	1963	400 × 120 × 6	1.1	6.2	10.0	12.0		
	Shakanai No. 4	1963	400 × 300 × 40	1.7	0.7	2.9	22.0		
	Shakanai No. 5	1964	350 × 70 × 13	1.9	1.0	3.4	17.0		
	Shakanai No. 7	1965	350 × 250 × 15	1.3	0.9	3.2	26.0		
	Shakanai No. 8	1965	430 × 170 × 40	0.7	0.2	1.0	33.0		
	Shakanai No. 11	1967	400 × 110 × 10	1.9	3.4	11.8	18.0		
Hanawa[1]	Motoyama	>1960	120 × 100 × 150	0.6	—	0.3	24.0	Crude ore = 11,000 tons	2 million tons[6]
	Sandaira	1951	180 × 70 × 190	0.4	—	0.3	23.0		
	Ajiro	1957	130 × 40 × 100	0.8	—	2.5	15.0		
	Akedoshi	1962	650 × 150 × 8	1.5	3.5	10.0	12.0		
	Osaki	1965	70 × 30 × 45	2.0	0.5	3.0	23.0		
Furutobe[3]	Yunosawa	1959	250 × 100 × 15	1.9	0.9	4.3	20.0	Crude ore = 15,000 tons	7 million tons
	Daikokuzawa-Higashi	1959	100 × 80 × 20	2.8	1.4	6.2	28.0		
	Daikakuzawa-Nishi	1960	250 × 70 × 60	1.1	0.1	1.0	17.6		
	Magariyazawa	1962	200 × 150 × 10	1.9	0.3	2.1	20.8		
	Higashimatazawa	1968	150 × 150 × 10	2.3	1.0	2.9	23.0		
Matsuki[3]	Takadate	1963	540 × 120 × 10	3.0	1.0	2.0	23.0	Crude ore = 10,000 tons	10 million tons
	Matsuki	1964	400 × 100 × 10						
Ainai[4]	Yunosawa	1942	150 × 200 × 50	0.7	—	—	25.0	Crude ore = 9,000 tons	10 million tons
	Suehiro	1955	40 × 50 × 30	4.7	1.7	8.3	20.0		
	Daikoku	1956	80 × 180 × 50	2.2	1.3	5.1	18.5		
	Benten	1957	60 × 200 × 20	1.9	1.2	3.1	18.0		
	Yokodawara	1960	150 × 80 × 20	2.0	0.7	2.9	21.0		
	Hagoromo	1967	80 × 150 × 10	1.9	3.5	10.3	23.0		

[1] Dowa Mining Co.
[2] Nippon Mining Co.
[3] Mitsubishi Metal Mining Co.
[4] Nitto Metal Mining Co.
[5] Estimate of total crude ore mined plus reserves (from Watanabe, 1973).
[6] Excluding low-grade ores.

SOURCE: Lambert, I.B. and Sato, T. 1974. "The Kuroko and Associated Ore Deposits of Japan: A Review of Their Features and Metallogenesis." Economic Geology 69: 1215-1236.

Table VII-6

Table 1. Metal contents of some massive sulfide ores

Type	Location	% Pb	% Zn	% Cu	ppm Ag	ppm Sb	ppm Bi
Archean Cu-Zn (Canada)[a]	Horne mine (Noranda)	n.s	n.s	2.19	n.s		
	Quemont (Noranda)	n.s	1.86	1.27	17		
	Mattagami Lake (Matagami)	n.s	10.4	0.69	36		
	Mattabi (Sturgeon Lake)	0.84	7.6	0.91	100		
	Flin Flon (Manitoba)	n.s	4.24	2.99	40		
	Fox Mine (Lynn Lake)	n.s	2.70	1.84	n.s		
	Kidd Creek (Timmins)	0.40	9.75	1.52	138		
Kuroko (Japan)[b]	Kosaka and Hanakoa						
	Black ore	16.0	22.5	2.2	312	290	20
	Semi-black ore	0.6	7.0	4.5	92	60	170
	Yellow ore	0.2	2.0	7.4	36	30	180
	Pyrite ore	0.07	0.2	0.4	15	20	80
	Siliceous ore	0.06	0.2	1.9	11	80	140
	Kosaka (mean)	0.8	4.5	2.2	95		
	Hanakoa (mean)	0.7	1.9	1.2			
Cyprus[c]	Cyprus (various)		0.7	2.7			
	Ergani, Turkey			10	22		
Besshi[c]	Besshi, Japan		0.92	10	30		
Not specified (Precambrian Australia)[d]	McArthur River	4	10	0.2	45		
	Broken Hill	12	4		115		
	Mount Isa	7.8	60		130		
	Hilton	7.7	9.6		125		

[a] Sangster and Scott, 1976
[b] Lambert and Sato, 1974
[c] Mercer, 1976
[d] Lambert, 1976

SOURCE: Amcoff, O. 1984. "Distribution of Silver in Massive Sulfide Ores." *Mineralium Deposita* 19: 63-69.

TABLE 1

Table VII-7: BRUNSWICK MINING AND SMELTING PRODUCTION

YEAR	No. 12 Mine					No. 6 Mine					No. 6 and No. 12 Mines				
	TONNES	% Pb	% Zn	% Cu	g/t Ag	TONNES	% Pb	% Zn	% Cu	g/t Ag	TONNES	% Pb	% Zn	% Cu	g/t Ag
1964	877,000	4.06	9.46	0.30	89						877,000	4.06	9.46	0.30	89
1965	1,504,000	3.96	9.51	0.30	95						1,504,000	3.96	9.51	0.30	95
1966	1,497,000	3.64	9.26	0.22	76	273,000	2.75	6.19	0.35	59	1,770,000	3.50	8.79	0.24	73
1967	1,514,000	3.47	9.07	0.29	82	786,000	2.93	5.96	0.40	61	2,300,000	3.29	8.01	0.33	75
1968	1,564,000	3.38	8.56	0.27	66	892,000	2.47	5.66	0.35	52	2,456,000	3.05	7.51	0.30	61
1969	1,538,000	3.04	8.05	0.33	73	974,000	2.28	5.78	0.35	64	2,512,000	2.75	7.17	0.34	70
1970	1,343,000	2.93	7.54	0.32	75	999,000	2.12	5.86	0.33	63	2,342,000	2.58	6.82	0.32	70
1971	1,421,000	3.25	8.11	0.30	84	768,000	2.11	5.76	0.36	64	2,189,000	2.85	7.29	0.32	77
1972	1,365,000	3.62	9.10	0.28	96	1,593,000	2.05	5.48	0.37	72	2,958,000	2.77	7.15	0.33	83
1973	1,701,000	3.43	8.58	0.34	96	1,317,000	2.02	4.98	0.35	75	3,018,000	2.81	7.01	0.34	87
1974	1,429,000	3.58	8.00	0.35	89	953,000	2.03	4.65	0.41	65	2,382,000	2.96	6.66	0.37	79
1975	1,982,000	3.54	8.48	0.36	91	1,126,000	1.93	4.94	0.50	68	3,108,000	2.96	7.20	0.41	83
1976	1,473,000	3.53	8.63	0.32	96	774,000	1.60	4.41	0.50	68	2,247,000	2.87	7.18	0.38	86
1977	2,456,000	3.51	8.70	0.31	91	678,000	1.70	4.65	0.58	61	3,134,000	3.12	7.82	0.37	85
1978	2,685,000	3.77	9.31	0.28	97	373,000	2.07	5.85	0.39	72	3,058,000	3.56	8.89	0.29	94
1979	2,722,000	3.71	9.13	0.30	97	249,000	2.60	6.78	0.41	78	2,971,000	3.62	8.93	0.31	95
1980	1,746,000	3.61	8.90	0.31	99	102,000	2.75	7.18	0.31	75	1,848,000	3.56	8.81	0.31	98
1981	3,401,000	3.51	8.75	0.35	98	22,000	2.69	7.38	0.14	84	3,423,000	3.50	8.74	0.35	98
1982	3,535,000	3.64	9.04	0.31	102	99,000	3.15	8.62	0.15	94	3,634,000	3.63	9.03	0.31	102
1983	3,264,000	3.56	9.00	0.30	99	147,000	2.57	6.90	0.52	86	3,411,000	3.52	8.91	0.31	98
1984	3,560,000	3.57	8.91	0.32	100	-	-	-	-	-	3,560,000	3.57	8.91	0.32	100
TOTAL	42,577,000	3.55	8.81	0.31	93	12,125,000	2.16	5.43	0.39	67	54,702,000	3.24	8.06	0.33	87

Source: Brunswick Mining and Smelting Corporation Limited (N.P.L.). 1985. Bathurst, New Brunswick.

Appendix VII-1: References

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Section VIII: World Consumption, Production, and Trade in Zinc and Copper

This section summarizes world consumption, production, and trade for two metal commodities, zinc and copper, over the 75 year period from 1908 through 1983. Both commodities are traded in world markets. We identify zinc and copper as the two commodities most likely to be examined first for future production from marine polymetallic sulfide (MPS) deposits. Copper might also be produced from manganese nodule deposits. In any consideration of potential production from offshore sources, it is important to understand patterns in and national shares of world consumption, production, and trade of metal commodities, like zinc and copper. In general, to the extent that one or more nations might exert market control over trade in metal commodities, resulting price effects or heightened national concerns about sources of supply for defense needs might call offshore sources of minerals into production. Furthermore, an analysis of this sort is a first step at identifying the "winners" and "losers" or the relative position of nations in the world trade of metal commodities.

It would be useful to compile this information for all of the prospective marine mineral resources. Some marine minerals, like sand and gravel, shell, and, in some cases, phosphorites, are traded in local markets and so a worldwide analysis would be inappropriate. Others like hydrocarbons, sulfur, and tin, have experienced periods during which market control was exercised by producers or by combinations of producers and consumers. It is interesting to note that in these latter cases, offshore production already has occurred. Still others, like cobalt, platinum, manganese, and chromite, have attracted considerable interest as "strategic" minerals (OTA, 1985). In the United States, the Department of the Interior's Office of Strategic and International Minerals has spent several million dollars to draft an environmental impact statement on the potential lease sale of OCS lands off the coast of Hawaii containing cobalt-rich ferromanganese crusts (MMS, 1987). We restrict ourselves to an examination of zinc and copper, as potential MPS commodities, and present this as an example for the analysis of other minerals, should the interest arise.

The data were compiled for the 25 and 50 year intervals: 1908, 1933 and

1983. The world's leading consumer countries, producer countries, and trading countries are listed in order of amounts consumed or produced in 1983. The tables describing the zinc market are presented first in Figures VIII-1 to VIII-8, with the copper tables following in Figures VIII-9 to VIII-12. Copper production involves three phases during which statistics are available: minehead, smelting, and refining. Zinc production involves only the two phases of mining and smelting.

Next, in Figures VIII-4 to VIII-7 (zinc) and Figures VIII-13 to VIII-16 (copper), the leading exporters and importers are ranked in terms of zinc or copper exports or imports as a percentage of, respectively, total country exports or imports and as a percentage of gross national product (GNP). Only 1981 was examined, using recent data from the World Bank, the U.N. Conference on Trade and Development, and the U.S. Census Bureau. Finally, in Figure VIII-8 (zinc) and Figure VIII-17 (copper), a net value trade or difference between the value of exports and imports in 1981 was computed. Those nations with the highest trade surpluses or the lowest trade deficits are ranked.

Perhaps the most striking aspect of the production data is the decreasing international concentration in both zinc and copper production from 1908 and 1933 through 1983. In 1933, the United States held the largest share of copper production in the mine (16%), smelter (22%), and refined (32%) phases. By 1983, those shares had decreased to 13%, 12%, and 16% respectively. In zinc production, the leading shares held by the United States of 30% in the mine phase and 28% in the smelter phase decreased to 5% each by 1983. A similar phenomenon occurred in zinc and copper consumption where the United States as the leading consumer in 1933 of zinc (29%) and copper (28%) consumed a smaller share of the total market in 1983 of zinc (15%) and copper (19%). It is interesting that, over the 75 year period, the volume of zinc and copper in world trade increased substantially (9 times for zinc and 13 times for copper); market concentration in zinc and copper decreased, with a substantial increase in the number of producer countries; and the real prices of zinc and copper (see section II) fell during this period.

In Figure VIII-18, constructed for copper only, net trade flows where placed into a matrix that displays net trade volume for the years 1973, 1978, and 1983. The matrix identifies the <u>net flow</u> of copper from exporting nations to importing nations. The data were compiled from Metallgesellschaft, 1984. It also identifies the <u>gross flow</u> of copper from net exporters to gross importers (nonproducers) and gross flow from gross exporters (nonconsumers) to net importers. In 1983, the United States, as a net importer of copper, received most of its imports from Chile, Canada, Zambia, and Peru, although it received copper from several other countries as well. The United States did export copper, as shown in Figure VIII-17, valued in 1981 at about a third of its imports. Copper exports from net importers and imports from net exporters are not shown in Figure VIII-18. China has recently become a large consumer of Canadian copper, second only to the United States and may become a larger factor in the copper market.

Zinc exports, in most cases, represent a small share of the leading export nations' total exports and GNP (Figures VIII-4 and VIII-5). Only in the case of Peru do zinc exports exceed one percent of GNP. Conversely, for several countries including Zambia, Zaire, Papua New Guinea, Chile, and Peru, copper exports, shown in Figures VIII-13 and VIII-14, represent a substantial portion of total exports and GNP. Belgium still remains a large export market for Zaire (formerly the Belgian Congo); Belgium imports more than half of Zairean copper ore. Copper exports are almost one-third the size of Zambia's GNP. The United States is the largest export market for Chilean and Peruvian refined copper.

Imports of copper or zinc do not represent very large proportions of total imports or GNP of any country, as seen from Figures VIII-6, VIII-7, VIII-15, VIII-16. Belgium and Luxembourg, counted together as important metal commodity entrepots, have the highest proportion of copper and zinc imports as a percent of GNP, with 0.38% for zinc and 2.00% for copper. Copper exports are more than one percent of GNP for these two countries as well (Figure VIII-14). Belgium and Luxembourg trade copper with more countries than any other, with the possible exception of West Germany.

Examination of the balance of value trade in zinc and copper (Figures VIII-8 and VIII-17) shows that Canada, Australia, and Peru benefit greatly from export trade in zinc while Chile, Zambia, Canada, Zaire, and Peru hold the highest trade surpluses in copper. The United States has the leading trade deficit in zinc at more than $600 million, with a comparable trade deficit in copper of $584 million. Japan has the largest trade deficit in copper by far with more than $2.2 billion. Japan is followed by several European countries and the United States. The trade balance data demonstrate the general dependence of the developed European countries and the United

States upon developing countries and Canada and Australia for zinc and copper. The extent to which the general balance of trade, and the country rankings, will remain stable over time is uncertain. However, new sources of high-grade zinc and copper deposits, such as MPS, have the potential in the distant future of rearranging national trade balances in these markets.

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Figure VIII-1: REFINED ZINC CONSUMPTION

	1908		1933		1983	
	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)
Soviet Union	18	2	22	2	1050	17
United States	188	26	297	29	934	15
Japan	-	-	58	6	771	12
West Germany1/	180	25	148	14	406	6
China	-	-	-	-	300	5
France	78	11	94	9	271	4
Italy	8	1	22	2	208	3
United Kingdom	139	19	141	14	181	3
Belgium2/	68	9	91	9	166	3
Canada	-	-	11	1	144	2
Poland	-	-	21	2	143	2
India3/	-	-	13	1	120	2
South Korea	-	-	-	-	113	2
Brazil	-	-	-	-	102	2
Spain	5	1	9	1	99	2
Australia	-	-	23	2	77	1
Austria4/	33	5	5	1	25	1
Others	13	2	68	7	1245	20
TOTAL	730	101*	1023	100	6355	102*

Notes:

1/West Germany and East Germany are combined in 1933 data.
2/Includes Luxembourg.
3/"British India" in 1933.
4/Austria and Hungary combined in 1908.

Source: Metallgesellschaft, 1910, 1936, 1984.

*Columns may not total 100 due to rounding error.

Figure VIII-2: ZINC MINE PRODUCTION

	1908		1933		1983	
	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)
Canada[1]			159	14	1070	16
Soviet Union[2]			22	2	1025	16
Australia			126	11	695	11
Peru			-	-	553	9
United States			349	30	293	5
Mexico			89	8	275	4
Japan			15	1	256	4
Sweden	No data available		25	2	203	3
Poland			42	4	189	3
Ireland			-	-	186	3
Spain			35	3	169	3
China			2	1	160	2
North Korea			-	-	120	2
West Germany[3]			107	9	114	2
South Africa			-	-	108	2
Yugoslavia			44	4	87	1
Italy			29	3	43	1
Zambia[4]			19	2	42	1
India[5]			33	3	37	1
Others			54	5	873	13
TOTAL			1150	101*	6498	102*

[1] 1933 data includes Newfoundland.
[2] 1933 data includes Russia in Europe and Russia in Asia.
[3] 1933 data includes West Germany and East Germany.
[4] 1933 data is for "Rhodesia".
[5] 1933 data is for "British India".

Source: Metallgesellschaft, 1936, 1984.

*Columns may not total 100 due to rounding error.

Figure VIII-3: ZINC SMELTER PRODUCTION

	1908[1]		1933		1983	
	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)
Soviet Union[2]	9	1	17	2	1060	17
Japan	-	-	31	3	701	11
Canada	-	-	83	8	617	10
West Germany[3]	217	30	51	5	356	6
United States	190	26	279	28	305	5
Australia	1	-	55	6	299	5
Belgium[4]	165	23	137	14	263	4
France[5]	56	8	56	6	250	4
Spain	-	-	9	1	190	3
Netherlands	17	2	19	2	188	3
China	-	-	-	-	185	3
Mexico	-	-	27	3	180	3
Poland	-	-	83	8	170	3
Finland	-	-	-	-	155	2
Peru	-	-	-	-	154	2
South Korea	-	-	-	-	108	2
Brazil	-	-	-	-	100	2
North Korea	-	-	-	-	95	2
Norway	-	-	45	5	91	1
United Kingdom	54	7	42	4	88	1
Others	13	2	52	5	744	12
TOTAL	722	99*	986	100	6299	101*

Notes:

[1] "Spelter" production.
[2] 1933 data = Russia in Europe & Asia
[3] 1933 data = West Germany & East Germany or Old Germany.
[4] Includes Luxembourg.
[5] Includes Spain (1908).

Source: Metallgesellschaft, 1910, 1936, 1984.

*Columns may not total 100 due to rounding error.

Figure VIII-4: ZINC EXPORTS AS A PERCENT OF TOTAL EXPORTS: 1981

	Value of Total Zinc Export Trade Current $US x 10^6	Value of Total Exports Current $US x 10^9	Zinc Export Values as a Percent of Country's Total Exports (%)
Peru	233.74	3.94	5.94
Bolivia	38.27	1.02	3.76
Honduras	12.25	0.87	1.41
Australia	281.58	26.35	1.07
Zambia	12.95	1.22	1.06
Canada	626.55	79.55	0.79
Burma	2.71	0.46	0.59
Ireland	45.08	10.49	0.43
Finland	102.86	17.01	0.60
Mexico	84.71	28.60	0.30

Source: United Nations, 1982; World Bank, 1983.

Figure VIII-5: ZINC EXPORTS AS A PERCENT OF GNP: 1981

Country	Total Zinc Export Trade Values Current $US x 10^6	Share of World Total Zinc Export Trade Values (%)	Gross National Product Current $US x 10^9	Zinc Export Trade Values as a % of GNP (%)
Peru	233.74	9.08	21.92	1.07
Bolivia	38.27	1.49	7.60	0.50
Honduras	12.25	0.48	2.50	0.49
Zambia	12.95	0.50	3.14	0.41
Belgium	180.24	7.00	46.93	0.38
Ireland	45.08	1.75	16.37	0.28
Canada	626.55	24.33	274.75	0.23
Finland	102.86	3.99	48.09	0.21
Australia	281.58	10.93	168.58	0.17
Sweden	80.25	3.12	111.62	0.07

Source: World Bank, 1983; United Nations, 1982; Census Bureau, 1983.

Figure VIII-6: ZINC IMPORTS AS A PERCENT OF TOTAL IMPORTS: 1981

	Value of Total Zinc Import Trade	Value of Total Imports	Zinc Import Values as a Percent of Country's Total Imports
	Current $US x 10^6	Current $US x 10^9	(%)
India	63.55	16.82	0.38
Thailand	37.08	10.71	0.35
Finland	41.71	16.23	0.26
Belgium[1/]	176.82	69.98	0.25
United States	647.44	306.20	0.21
Tanzania	2.20	1.12	0.20
Philippines	18.17	9.35	0.19
France	232.05	143.16	0.16
Greece	16.15	10.11	0.16
West Germany	292.92	197.17	0.15

Notes:

[1/] Includes Luxembourg.

Source: United Nations, 1982; World Bank, 1983.

Figure VIII-7: ZINC IMPORTS AS A PERCENT OF GNP: 1981

	Total Zinc Import Trade Values	Share of World Total Zinc Import Trade Values	Gross National Product	Zinc Import Trade Values as a % of GNP
	Current $US x 10^6	(%)	Current $US x 10^9	(%)
Belgium[1/]	176.82	6.51	46.93	0.38
Singapore	19.08	0.70	12.95	0.15
Hong Kong	36.02	1.33	25.05	0.14
Thailand	37.08	1.37	35.76	0.10
Finland	41.71	1.54	48.09	0.09
Netherlands	106.49	3.92	140.11	0.08
New Zealand	16.61	0.61	24.48	0.07
Malaysia	17.24	0.63	24.07	0.07
Kenya	4.65	0.17	6.48	0.07
Portugal	13.01	0.48	22.76	0.06

Notes:

[1/] Includes Luxembourg.

Source: World Bank, 1983; United Nations, 1982; Census Bureau, 1983.

Figure VIII-8: BALANCE OF VALUE TRADE IN ZINC: 1981

	Value of Total Zinc Export Trade Current $\$US \times 10^6$	Value of Total Zinc Import Trade Current $\$US \times 10^9$	Net Value Trade Balance in Zinc Current $\$US \times 10^6$
Surplus			
Canada	626.55	33.07	593.48
Australia	281.58	0.01	281.57
Peru	233.74	0.00	233.74
Mexico	84.71	0.05	84.66
Spain	80.15	14.26	65.90
Finland	102.86	41.71	61.15
Sweden	80.25	28.24	52.01
Netherlands	152.48	106.49	46.00
Norway	69.09	29.62	39.46
Bolivia	38.27	0.00	38.27
Deficit			
Hong Kong	2.83	36.02	-33.19
Brazil	2.53	39.20	-36.67
Thailand	0.31	37.08	-36.77
India	0.07	63.55	-63.49
Italy	22.28	128.65	-106.37
United Kingdom	40.80	152.77	-111.96
France	110.40	232.05	-121.65
West Germany	151.59	292.92	-141.33
Japan	48.27	249.91	-201.64
United States	37.55	647.44	-609.89

Source: United Nations, 1982; World Bank, 1983.

Figure VIII-9: REFINED COPPER CONSUMPTION

	1908		1933		1983	
	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)
United States	209	30	346	28	1775	19
Soviet Union	21	3	53	4	1360	15
Japan[1]	9	1	83	7	1216	13
West Germany[2]	181	26	238	19	737	8
China	-	-	-	-	410	4
France	74	11	110	9	390	4
United Kingdom	128	18	155	13	358	4
Italy	22	3	60	5	325	4
Belgium[3]	11	2	28	2	258	3
Canada	-	-	30	2	195	2
Poland	-	-	7	1	177	2
South Korea	-	-	-	-	152	2
Brazil	-	-	-	-	148	2
Sweden	-	-	30	2	113	1
Austria[4]	34	5	7	1	22	1
Others	9	1	91	7	1480	16
TOTAL	698	100	1238	100	9116	100

Notes:

[1] Includes Australia in 1908.
[2] Includes East Germany in 1908, 1933.
[3] Includes Luxembourg.
[4] Includes Hungary in 1908.

Source: Metallgesellschaft, 1910; 1936; 1984.

Figure VIII-10: COPPER MINE PRODUCTION

	1908		1933		1983	
	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)
Chile	39	5	163	16	1257	15
Soviet Union[1/]	20	3	33	3	1180	14
United States	430	55	173	16	1038	13
Canada	29	4	136	13	625	8
Zambia[2/]	-	-	106	10	543	7
Zaire[3/]	-	-	91	9	502	6
Poland	-	-	-	-	402	5
Peru	15	2	25	2	322	4
Philippines	-	-	-	-	271	3
Australia	40	5	15	1	264	3
South Africa[4/]	7	1	-	-	212	3
Mexico	41	5	40	4	206	2
Papua New Guinea	-	-	-	-	183	2
China	-	-	-	-	175	2
Yugoslavia	-	-	40	4	130	2
Spain[5/]	53	7	35	3	64	1
Japan	44	6	69	7	46	1
Norway	9	1	19	2	26	1
West Germany[6/]	21	3	32	3	1	1
Other	32	4	74	7	838	10
TOTAL	780	101*	1051	100	8285	101*

Notes:

[1/] Russia before 1983.
[2/] Zambia
[3/] Zaire
[4/] Cape Colony in 1908.
[5/] Includes Portugal in 1908.
[6/] Includes East Germany in 1908, 1933.

Source: Metallgesellschaft, 1910, 1936, 1984.

*Columns may not total 100 due to rounding error.

Figure VIII-11: COPPER SMELTER PRODUCTION

	1908		1933		1983	
	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)	Amount (000MT)	Share (%)
Soviet Union[1]	17	2	33	3	1280	16
Chile[2]	64	9	158	15	1058	13
Japan	41	6	69	7	945	12
United States	448	60	227	22	928	12
Zambia[3]	-	-	106	10	563	7
Zaire	-	-	67	6	466	6
Canada[4]	14	2	118	11	337	4
Poland	-	-	-	-	320	4
Peru	-	-	-	-	296	4
China	-	-	-	-	195	2
South Africa	-	-	-	-	192	2
Australia	35	5	14	1	174	2
West Germany[5]	30	4	50	5	159	2
Yugoslavia	-	-	40	4	87	1
Mexico	-	-	40	4	67	1
Belgium[6]	-	-	35	3	3	1
United Kingdom	71	10	12	1	-	-
Other	25	3	98	9	970	12
TOTAL	745	101*	1040	101*	8040	100

Notes:

[1] Russia before 1983.
[2] Includes South America/Central America in 1908.
[3] Zambia
[4] British North America in 1908.
[5] Includes East Germany in 1908, 1933.
[6] Includes Luxembourg.

Source: Metallgesellschaft, 1910, 1936, 1984.

*Columns may not total 100 due to rounding error.

Figure VIII-12: REFINED COPPER PRODUCTION

	1908		1933		1983	
	Amount (OOOMT)	Share (%)	Amount (OOOMT)	Share (%)	Amount (OOOMT)	Share (%)
United States	No data available		366	32	1584	16
Soviet Union[1]			45	4	1500	15
Japan			69	6	1092	11
Chile			138	12	833	8
Zambia[2]			-	-	575	6
Canada			102	9	464	5
West Germany[3]			160	14	420	4
Belgium[4]			71	6	405	4
Poland			-	-	360	4
China			-	-	310	3
Zaire[5]			-	-	227	2
Australia			11	1	202	2
Peru			-	-	191	2
Spain			7	1	159	2
South Africa			-	-	158	2
U.K.			45	4	144	1
Others			122	11	1370	14
TOTAL			1136	100	9994	101*

Notes:

[1] Russia before 1983.
[2] Zambia
[3] Includes East Germany in 1933.
[4] Includes Luxembourg.
[5] Zaire

Source: Metallgesellschaft, 1910, 1936, 1984.

*Columns may not total 100 due to rounding error.

Figure VIII-13: COPPER EXPORTS AS A PERCENT OF TOTAL EXPORTS: 1981

	Total Copper Export Trade Values	Value of Total Exports	Copper Export Values as a Percent of Country's Total Exports
	Current $US x 10^6	Current $US x 10^9	(%)
Zambia	1001.80	1.22	82.14
Zaire*	582.20	1.39	41.83
Papua New Guinea	331.40	0.96	34.70
Chile	1714.80	5.89	29.09
Peru	520.30	3.94	13.22
Mexico	216.40	3.32	6.51
Philippines	426.00	7.35	5.80
Canada	835.30	79.55	1.05
Australia	235.50	26.35	0.89
Belgium	534.40	62.77	0.85

*Data for 1980.

Source: World Bank, 1983; Census Bureau, 1983.

Figure VIII-14: COPPER EXPORTS AS A PERCENT OF GNP: 1981

	Total Copper Export Trade Values Current $US x 10^6	Share of World Total Copper Export Trade Values (%)	Gross National Product Current $US x 10^9	Copper Export Trade Values as a % of GNP (%)
Zambia	1001.80	11.88	3.14	31.93
Papua New Guinea	331.40	3.93	2.41	13.76
Zaire	582.20	6.90	5.14	11.33
Chile	1714.80	20.33	31.44	5.45
Peru	520.30	6.17	21.92	2.37
Belgium	534.40	6.34	46.93	1.14
Philippines	426.00	5.05	38.37	1.11
Canada	835.30	9.91	274.75	0.30
South Africa	190.40	2.26	82.68	0.23
Malaysia	36.10	0.43	24.07	0.15

*1980 Data on GNP

Source: World Bank, 1983; Census Bureau, 1983; UNCTAD, 1984.

Figure VIII-15: COPPER IMPORTS AS A PERCENT OF TOTAL IMPORTS: 1981

	Total Copper Import Trade Values Current $US x 10^6	Value of Total Imports Current $US x 10^9	Copper Import Values As a Percent of Country's Total Imports (%)
Belgium	939.80	66.72	1.41
Japan	2290.20	165.28	1.39
China	294.90	22.70	1.30
Brazil	295.80	25.77	1.15
Argentina*	56.80	5.82	0.98
Romania	127.20	13.46	0.94
South Korea	250.10	28.38	0.88
Yugoslavia	131.60	17.38	0.76
India	108.30	16.82	0.64
West Germany	1127.90	197.17	0.57
Italy	575.00	100.82	0.57

*Data for 1980.

Source: World Bank, 1983; Census Bureau, 1983.

Figure VIII-16: COPPER IMPORTS AS A PERCENT OF GNP: 1981

	Total Copper Import Trade Values Current $US x 10⁶	Share of World Total Copper Import Trade Values (%)	Gross National Product Current $US x 10⁹	Copper Import Trade Values as a % of GNP (%)
Belgium	939.80	9.70	46.93	2.00
South Korea	250.10	2.58	62.25	0.40
Japan	2290.20	23.64	1129.10	0.20
Yugoslavia	131.60	1.36	68.25	0.19
West Germany	1127.90	11.64	688.19	0.16
Italy	575.00	5.94	350.30	0.16
Romania	127.20	1.31	85.90*	0.15
Sweden	158.50	1.64	111.62	0.14
France	721.50	7.45	572.11	0.13
Finland	58.40	0.60	48.09	0.12

*1980 Data from 1980.

Source: World Bank, 1983; UNCTAD, 1984; Census Bureau, 1983.

Figure VIII-17: BALANCE OF VALUE TRADE IN COPPER: 1981

	Value of Total Copper Export Trade Current \$US x 10^6	Value of Total Copper Import Trade Current \$US x 10^9	Net Value Trade Balance in Copper Current \$US x 10^6
Surplus			
Chile	1714.80	0.00	1714.80
Zambia	1001.80	0.00	1001.80
Canada	835.30	68.30	767.00
Zaire	582.20	0.00	582.20
Peru	520.30	0.00	520.30
Philippines	426.00	12.10	413.90
Papua New Guinea	331.40	0.00	331.40
Poland	252.30	0.00	252.30
Australia	235.50	14.00	221.50
Mexico	216.40	6.00	210.40
Deficit			
Brazil	16.10	295.80	-279.70
China	3.40	294.90	-291.50
Belgium	534.40	939.80	-405.40
United Kingdom	45.20	510.20	-465.00
Italy	13.50	575.00	-561.50
United States	276.10	860.70	-584.60
France	40.20	721.50	-681.30
West Germany	175.60	1127.90	-952.30
Japan	80.50	2290.20	-2209.70

Source: **UNCTAD, 1984.**

Figure VIII -18: NET TRADE FLOWS: REFINED COPPER: 1973, 1978, 1983
(thousand metric tons)

		NET IMPORTERS								GROSS IMPORTERS					
		USA	FRG	FRANCE	ITALY	UK	SWEDEN	NETH.	JAPAN	CHINA	ARGENTINA	BRAZIL	INDIA	TAIWAN	OTHERS
Net Exporters															
Chile	1973	42	78	20	46	58	18		21	20	32	12			33
	1978	118	97	27	87	67	11	5	70	8	28	115		14	53
	1983	266	127	85	89	22	14	41	32	40	32	31		1	45
Zambia	1973	5	70	56	77	124	6	8	155	12		33	30	m	47
	1978	54	51	61	52	80	19	1	133	17			35		48
	1983	41	28	70	54	55	22	1	96	48		2	49		105
Canada	1973	102	27	12	7	92	4	1	10			1	m	1	17
	1978	58	19	18	12	70	7	1	15	6		1		2	30
	1983	91	25	13	3	46	3	35	3	67		m			6
Zaire	1973		18	21	62	7		8	10						103
	1978		16	5	28	2		6	12			0	7		18
	1983	35	60		20			35	2	11		6	11	4	31
Peru	1973	3	1	m	m	1		2	m						m
	1978	49	m	m	14	10	7	5	26						36
	1983	30	2	2	23	15	6	33	27						8
USSR	1973	m	19		4	14	5	28	16			m			330
	1978		3	m	m			5							138
	1983	m	4	m		3	1	m	2						159
Belgium*	1973	1	64	127	20	25	13	17	m			3			
	1978	10	30	97	32	35	8	10	m	m	m				
	1983	6	57	55	11	23	20	4		9		m	1		111
Australia	1973	m				18			7						1
	1978	3	9	12	2	19			2					m	11
	1983	m	5	13	m	33		19	m						7
Spain	1973		1	4		7	1	4							31
	1978	m	6	10	10	5		2							5
	1983	m	m	20	31	m		13							13
Austria	1973	4	5	m	m	m									3
	1978	3	2	m	6										4
	1983		5	m	11	m									2
Gross Exporters															
Mexico	1973	3							1		m	m			m
	1978	1	m												
	1983	5													
S.Africa	1973	m	8	1	8	20									
	1978	10	45	5	10	23									
	1983	14	47	3	16	5									
Norway	1973	m	7	3	1	6									
	1978	m	3	4	1	2									
	1983	m	4	4	1	3									
Others	1973	132													
	1978	46													
	1983	56	19												

"m" = minor trade of less than 1000 metric tons.

* includes Luxembourg.

Source: Metallgesellschaft, 1984.

Section IX: Value of U.S. Apparent Consumption, Imports and Recycling

For selected commodities with potential seabed sources, we have collected information on apparent consumption in the United States, net import reliance, and recycling. This information is published annually by the U.S. Bureau of Mines in its Mineral Commodity Summaries (see, e.g., BOM/MCS, 1986). Figure IX-1 is the commonly-displayed net import reliance as a percent of apparent consumption. For commodities that are underlined in the figure, we have calculated apparent consumption and net import reliance using BOM definitions. Figure IX-1 can be somewhat misleading because it does not include any information about the size of the markets for the metals for which the United States has a net import dependence. Figure IX-2 modifies Figure IX-1 to include this information. Note the change in scale between the two bar charts in Figure IX-2. In particular, for manganese, yttrium, platinum, cobalt, chromite, thorium, and barite, the markets are relatively small. It is interesting that in 1986 the United States imported more copper, in terms of value, than any of the aforementioned metal commodities (net copper imports represent less than 30 percent of the U.S. market for that commodity).

For many metal commodities with potential seabed sources, there exist well-developed and competitive technologies that recover metals from secondary sources. Figure IX-3 displays recycling activity as a share of apparent consumption. Some important exceptions to secondary recovery are cobalt, with less than 10 percent secondary production, manganese, phosphate rock, yttrium, thorium, barite, and zirconium. It should be noted that the size of the markets for some of these commodities (manganese, yttrium, thorium, barite, zirconium) are relatively small in the United States. It is probable that a combination of availability and cost may not support recycling activities in these markets. Further research into recycling may prove fruitful.

Figure IX-1

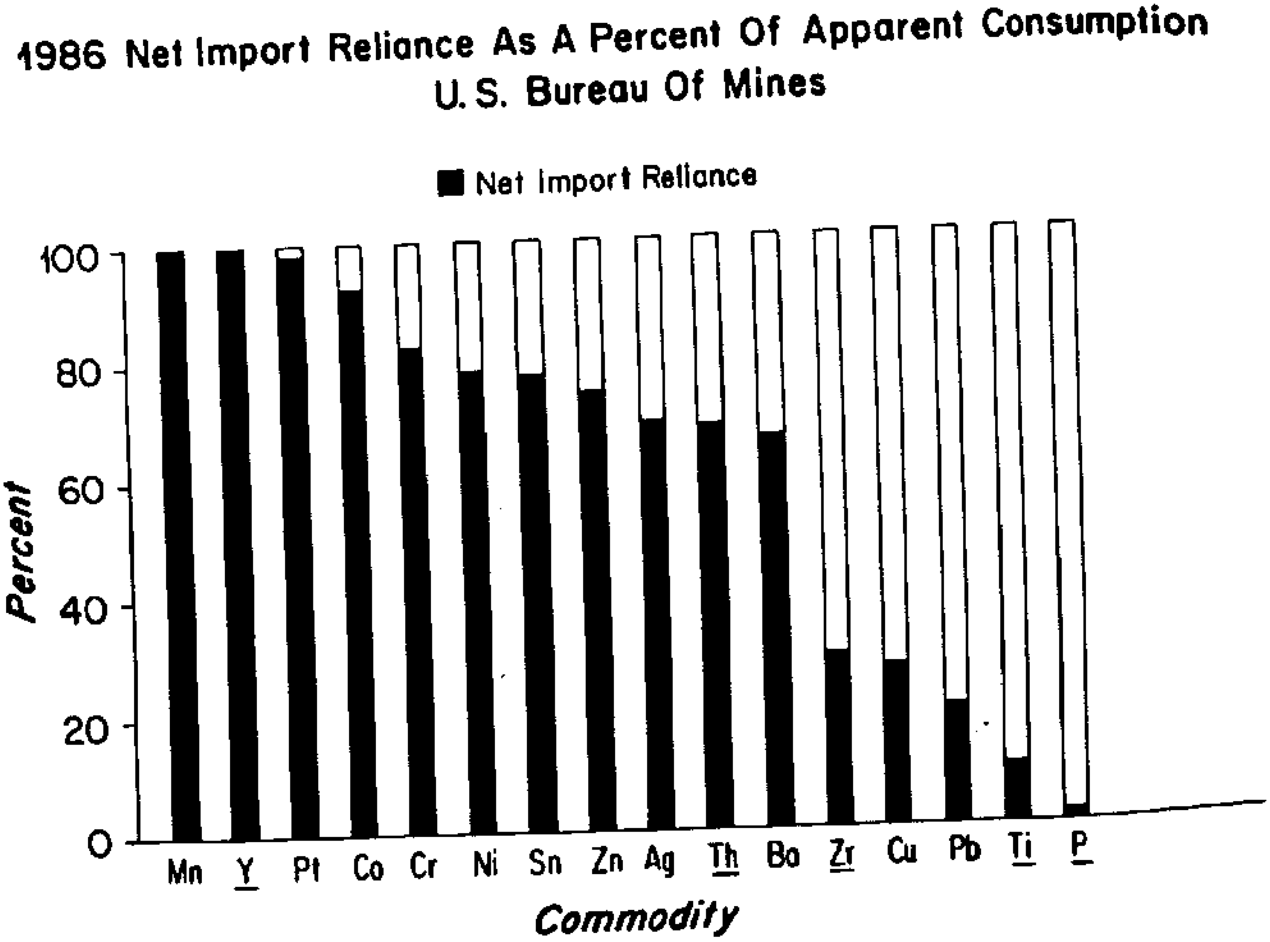

1986 Net Import Reliance As A Percent Of Apparent Consumption
U.S. Bureau Of Mines
■ Net Import Reliance
100
80
60
40
20
0
Percent
Mn
Y
Pt
Co
Cr
Ni
Sn
Zn
Ag
Th
Ba
Zr
Cu
Pb
Ti
P
Commodity

Figure IX-2: **Apparent Consumption And Net Import Reliance In The United States: 1986**

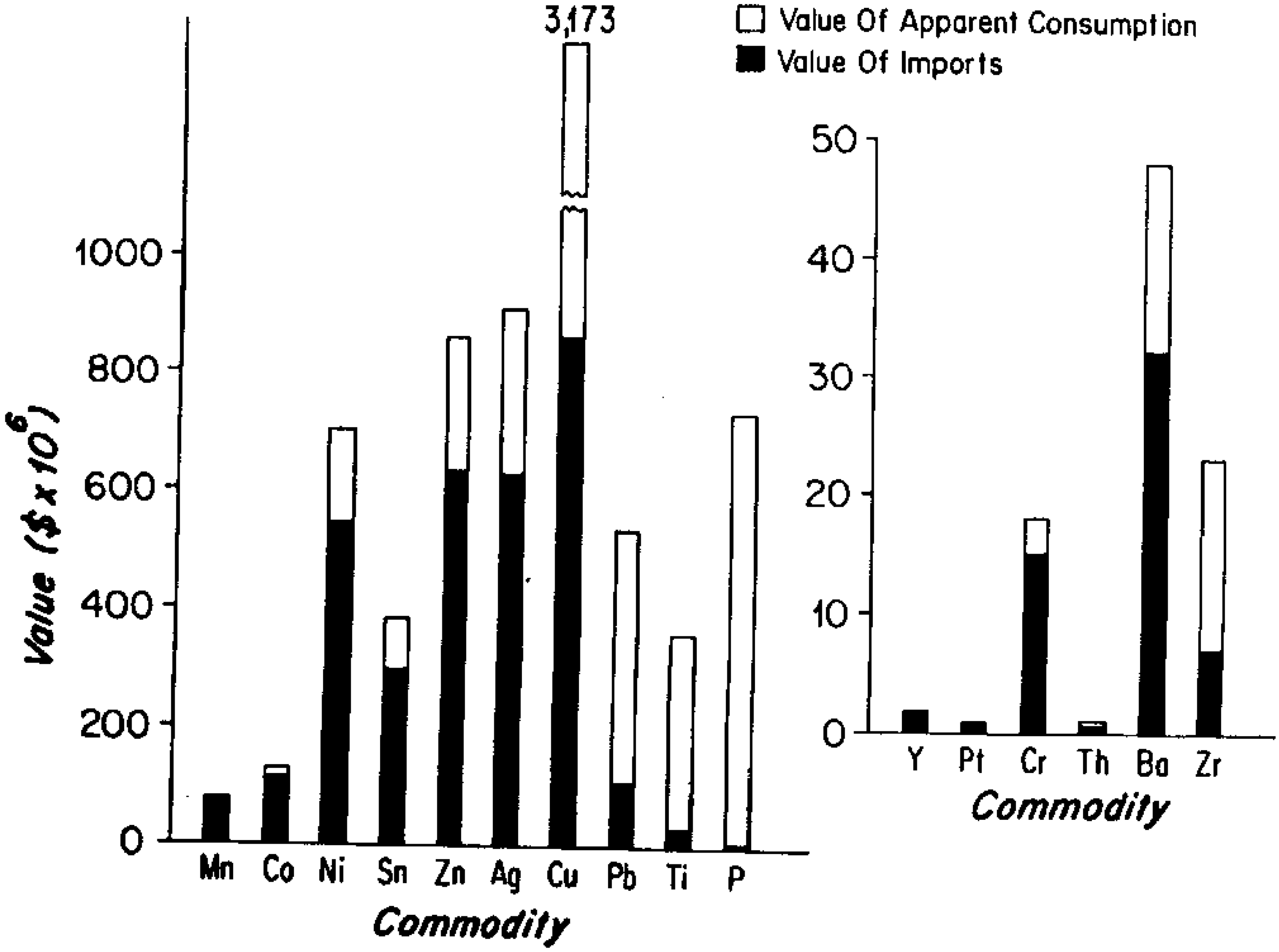
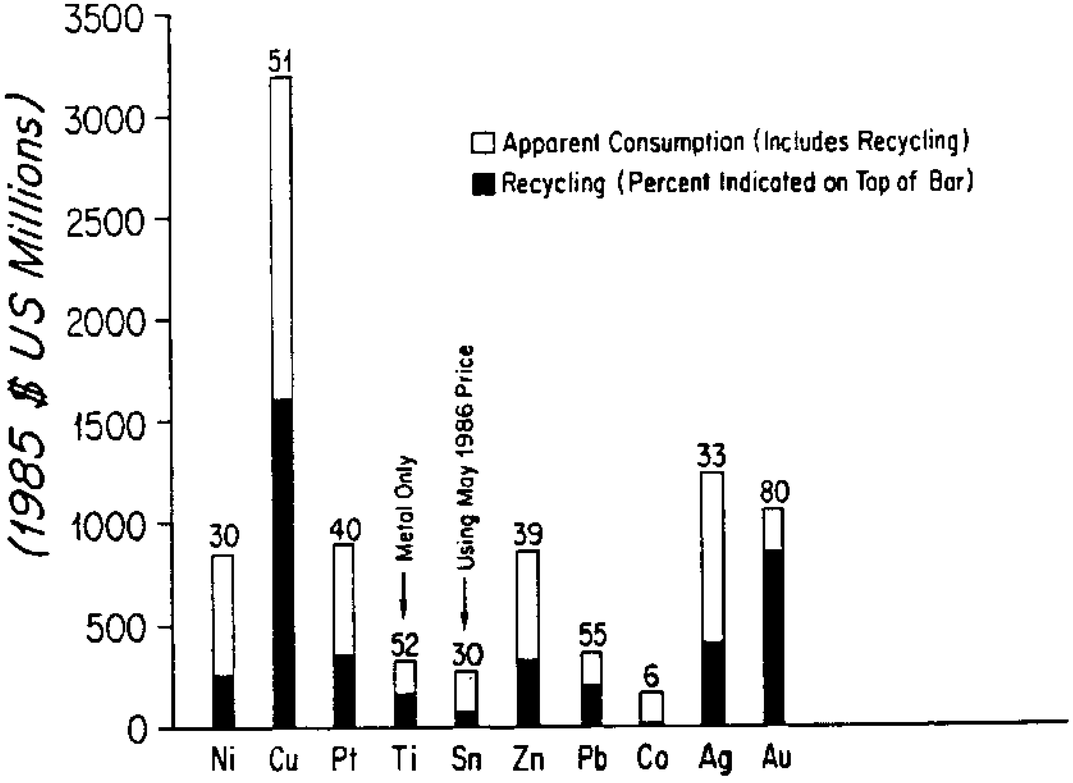


Figure IX-3

Value Of Apparent Consumption And Recycling In U.S.
1985



Section X: Bibliography of Marine Minerals and Public Policy

This section presents a selected bibliography of roughly 1300 references pertaining to marine minerals, oriented toward references in marine policy. Because marine policy is a multidisciplinary field, publications from several academic disciplines are included. More attention was given to selecting references from the social sciences (especially economics, political science, and law) than from the natural sciences. However, there are many marine geological references and general topical sources as well. We believe that no other existing bibliography or database focuses primarily on marine policy publications for marine minerals; this is an attempt to help fill this void. As is the case with most bibliographies, this one cannot claim to be all-encompassing. We expect to update and potentially to index the bibliography in the future. We welcome any additions.

The interested researcher is referred to the following additional bibliographic sources:

Computerized:

NGDC-NOS-MMS Marine Minerals Bibliography. Boulder, Colo.: National Geophysical Data Center, National Oceanic and Atmospheric Administration. Contact: Carla Moore, Geologist, Ph: 303-497-6767.

Ocean Mining Citation Retrieval System. Ottawa, Ontario: Resource Evaluation Branch, Ocean Mining Division, Canada Oil and Gas Lands Administration. Contact: Helen Joseph, Mineral Resources Analyst, Ph: 613-993-3760.

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16. Abstract (Limit: 200 words)

Over the past five years, research on marine minerals conducted by the Marine Policy Center at the Woods Hole Oceanographic Institution has attempted to gain a better understanding of the process by which these minerals are brought into productive use in society. This technical report results from concentrated research conducted by a research team under the primary sponsorship of the National Sea Grant College Program. This report provides background documentation for the recent publication: J.M. Broadus, 1987, "Seabed materials," *Science* 235(4791): 853-860. It is organized to lead the user directly to sources that may provide further information on particular seabed materials. Several presentations of data in the report are of use in understanding the fundamentals of marine mineral markets including: descriptions of the size of the marine mineral resource base and the size of the markets for onshore and offshore sources of marine minerals; price series for minerals with prospective seabed sources; composite prices for four marine mineral types; consumption and price "elasticities" of mineral reserves; trends in mineral exploration inputs and U.S. federal government expenditures for marine nonfuel resources; maps of existing, proposed, or past entitlements for marine hard minerals; a list of known marine polymetallic sulfide (MPS) deposits and reported grades; world trade flows in zinc and copper; the value of apparent consumption in the United States in relation to imports and recycling; and a bibliography.

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20. Security Class (This Page)

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