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Primary Lead and Zinc Availability—Market Economy Countries

A Minerals Availability Program Appraisal

By G. R. Peterson, K. E. Porter, and A. A. Soja

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

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Robert C. Horton, Director

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PREFACE

The Bureau of Mines is assessing the worldwide availability of nonfuel critical minerals. The Bureau identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits and mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availability.

This report is part of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources. Questions about these reports should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E Street, NW., Washington, DC 20241.

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

g/t	gram per metric ton	pct	percent
kg	kilogram	st	short ton
km	kilometer	t	metric ton
lb	pound	tr oz	troy ounce
lt	long ton	t/yr	metric ton per year
m	meter	yr	year

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PRIMARY LEAD AND ZINC AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Program Appraisal

By G. R. Peterson,[1] K. E. Porter,[2] and A. A. Soja[3]

ABSTRACT

To determine the availability of lead and zinc from demonstrated resources, the Bureau of Mines evaluated 235 mines and deposits in 31 market economy countries. Of the 235 mines and deposits evaluated for this study, 186 were evaluated as zinc operations, 30 as lead operations, and 19 as copper operations.

Demonstrated lead-zinc resources of market economy countries in 1981 were approximately 4.3 billion metric tons (t) of ore containing 221 million t of zinc and 97 million t of lead. Of these amounts, approximately 154 million t of zinc and 70 million t of lead are estimated to be recoverable.

The analyses indicate that demonstrated resources in market economy countries should be sufficient to satisfy projected demand for primary lead and zinc through the balance of the century. The U.S. lead industry will continue to have a comparative advantage over the rest of the world industry, barring any drastic increase in the cost of compliance with pollution control regulations. It appears that the comparative disadvantage faced by the U.S. zinc industry will probably intensify owing to the relative quantity of lower cost zinc resources in other countries, especially Canada, Australia, Mexico, and Peru.

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[1] Mineral economist.
[2] Mining engineer.
[3] Economist.
Minerals Availability Field Office, Bureau of Mines, Denver, CO.

INTRODUCTION

Rising production costs in combination with lagging demand and market prices for both lead and zinc have created serious economic problems for many lead and zinc producers worldwide. The purpose of this Bureau of Mines report is to evaluate the comparative costs of potential lead and zinc production from demonstrated resources of lead and zinc in the market economy countries.[4] This will provide an estimate of the costs (in constant January 1981 dollars) associated with potential supplies of primary lead and zinc, and illustrate the production potential of the United States compared with producers in other market economy countries.

This study evaluates the potential availability of lead and zinc from 235 producing mines and undeveloped deposits, with 186 mines and deposits evaluated as primary zinc operations; 30 mines and deposits evaluated as primary lead operations; and 19 mines and deposits evaluated as primary copper operations. A complete listing of the 235 mines and deposits that were evaluated and their ownership is presented in the "Lead and Zinc Resources" section. The assignment of a particular commodity as the primary product, generally based on that product providing the largest proportion of sales revenue at current (1981) market prices, was a necessary requirement of the evaluation process using a price determination model as described in the "Evaluation Methodology" section.

Resource tonnage estimates for the lead and zinc mines and deposits evaluated for this report were made at the demonstrated resource level according to the mineral resource classification system (fig. 1) developed jointly by the Bureau and the U.S. Geological Survey (*1*).[5] It should be kept in mind that reported demonstrated tonnage estimates for many lead and zinc deposits tend to be somewhat conservative. Many companies, particularly small ones, find it economically prohibitive to define resources beyond a 5- or 10-yr planning horizon.

The procedure of this study was to quantify the recoverable demonstrated resource and the engineering and economic parameters affecting actual or proposed production from the mines and deposits selected for evaluation.

The flow of the Minerals Availability Program (MAP) evaluation process from deposit identification to development of availability information is illustrated in figure 2. This flowchart demonstrates the various evaluation stages required to estimate the potential availability of primary lead and zinc metal from demonstrated geologic resources. The following factors had to be estimated before the total production potential of lead and/or zinc from each mine and deposit could be ascertained:

1. The approximate annual production potential of each mine or deposit over its life.
2. The total mine and mill capital and operating costs.
3. The cost of transporting concentrate from each mine to the appropriate smelter and the subsequent transportation from the smelter to the refinery if the refinery was at a separate location.
4. The estimated smelting and refining charges for each commodity using typical smelter schedules for each major producing country. Smelter schedules for smelting and refining in countries outside of North America, Western Europe, or Japan were estimated using the major regions as models. Although an effort was made to simulate the actual flows from the mines through the smelting and refining stage, the scope of this study prohibits an attempt to exactly match the capacities of existing smelters and refineries.

For currently producing operations, the designed mining and milling capacities and other available production specifics were used in this study. For undeveloped or developing deposits, appropriate mining and processing methods and potential capacities were based on published plans from mining companies or were

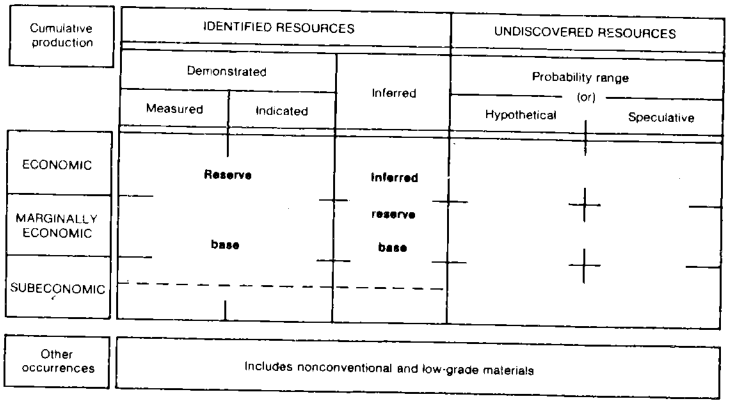

Figure 1.—Classification of mineral resources.

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[4] Market economy countries are defined as all countries that are not considered centrally planned economy countries. Centrally planned economy countries are Albania, Bulgaria, China, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Kampuchea, Laos, Mongolia, North Korea, Poland, Romania, U.S.S.R., and Vietnam.

[5] Italic numbers in parentheses refer to items in the list of references preceding the appendix.

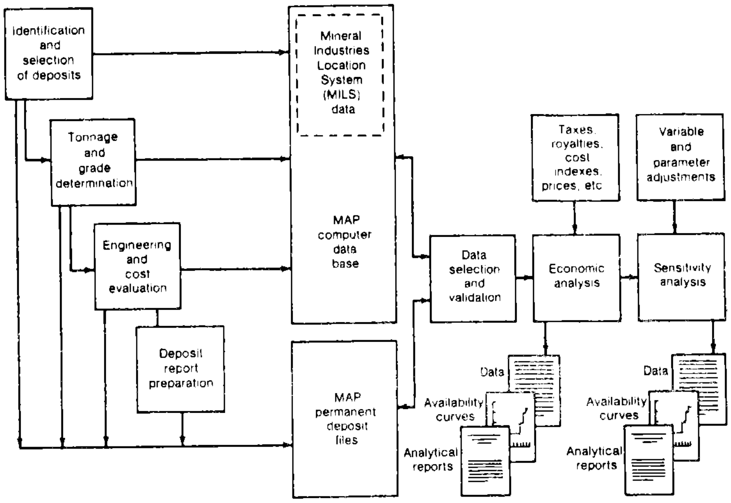

Figure 2.—Flowchart of MAP evaluation procedure.

based on existing mines as models, and on current engineering principles.

When available, actual mining capital and operating costs were used. However, where actual cost data were not available, costs were either estimated using established engineering techniques, or developed using the Bureau's cost estimating system (CES), a computerized version of the Bureau's capital and operating cost estimating manual (*2*). Domestic deposits were evaluated by personnel of the Bureau's Field Operations Centers and foreign data collection and cost estimation were performed under contract by Pincock, Allen & Holt, Inc., Tucson, AZ; personnel of the Bureau's Minerals Availability Field Office, Denver, CO, evaluated the data and performed the economic evaluation analyses.

The following objectives served as guidelines pursuant to the conduct of this study:

1. To determine the demonstrated resources of lead and zinc metal from all known significant deposits in market economy countries. Estimates of identified resources for lead and zinc are also mentioned; however, in the availability analyses, only demonstrated resources are included.
2. To evaluate the quantity and the average total costs of potential primary lead and zinc production from resources in market economy countries in relation to physical, technological, political, and other factors that affect production from each mine or deposit.
3. To aggregate and illustrate graphically total potential production of primary lead and zinc at the average total cost of each mining operation, including a 15-pct discounted-cash-flow rate of return (DCFROR) on all investments.

WORLD LEAD AND ZINC INDUSTRIES

Although lead and zinc exhibit a geologic affinity for each other, their respective industries are distinctly different, each with its unique problems and prospects. The following sections are largely extracted from the 1983 Bureau of Mines Mineral Commodity Profiles for lead (*3*) and zinc (*4*).

LEAD INDUSTRY

Lead was mined in about 50 countries during 1981, but smelted to produce primary metal in only 35. There were 55 countries refining secondary lead. The United States continued to be the leading producer of both primary and secondary lead with production of 498,000 t of primary and 641,000 t of secondary lead in 1981. In primary refined lead production, the U.S.S.R. ranked second with an estimated 410,000 t, followed by Japan with 230,000 t, France with 210,000 t, and Australia with 208,000 t. The U.S.S.R. also ranked second in secondary lead production with an estimated 220,000 t in 1981, followed by the United Kingdom with 198,000 t, the Federal Republic of Germany with 158,000 t, and Italy with 92,000 t. World mine production, by country, for 1961, 1971, and 1981 is shown in table 1, and a comparison of world smelter and refinery production, by region, of primary and secondary lead for 1981 is shown in table 2.

World mine production of contained lead in 1981 amounted to 3.3 million t, which was only 64 pct of the total world demand. The United States had the greatest production, followed by the U.S.S.R., Australia, Canada, and Peru. Eleven countries, producing over 100,000 t each, accounted for 76 pct of the total world mine production. Approximately 350 mines in the world produced lead in 1981, in most cases as a coproduct or byproduct of other metals.

Lead in the United States is produced from about

Table 1.—World lead mine production, 1961, 1971, and 1981, metric tons of contained lead

Area and country	1961	1971	1981[1]
North America:			
Canada	165,616	392,970	332,100
United States	237,615	524,861	445,500
Latin America:			
Argentina	27,760	39,889	32,000
Bolivia	20,301	23,125	16,700
Brazil	13,608	27,837	29,600
Chile	2,043	881	500
Colombia	655	205	100
Ecuador	111	0	200
Guatamala	8,580	500	100
Honduras	6,134	17,967	14,000
Mexico	181,326	156,852	157,400
Nicaragua	0	575	0
Peru	136,400	165,816	186,700
Europe:			
Austria	5,489	7,715	4,200
Bulgaria	79,834	99,792	116,000
Czechoslovakia	6,532	5,806	3,400
Finland	3,120	4,739	1,600
France	18,901	29,771	19,000
German Democratic Rep.	6,895	9,979	0
Germany, Fed. Rep. of	49,577	41,102	21,600
Greece	11,600	10,469	21,000
Greenland	9,166	0	30,000
Hungary	0	1,733	1,000
Ireland	253	51,592	29,900
Italy	47,719	31,600	20,600
Norway	2,290	3,063	3,600
Poland	38,200	62,778	50,400
Portugal	25	1,383	0
Romania	11,975	38,102	33,500
Spain	79,709	70,151	83,000
Europe—Continued			
Sweden	62,143	79,455	84,100
U.S.S.R.	353,808	453,600	410,000
United Kingdom	1,501	1,497	2,400
Yugoslavia	96,682	124,349	120,000
Africa:			
Algeria	9,200	4,717	2,600
Congo (Brazzaville)	875	29	3,500
Egypt	36	0	0
Morocco	88,270	78,001	115,974
Namibia	63,504	71,499	59,100
Nigeria	6	215	1,000
South Africa, Rep. of	93	0	98,900
Tanzania	351	0	0
Tunisia	16,963	18,870	8,000
Zambia	15,382	27,670	14,000
Asia:			
Burma	16,800	8,999	15,600
China	[1]90,000	[1]100,000	155,000
India	4,062	1,556	15,300
Indonesia	0	200	0
Iran	14,969	24,041	10,000
Japan	46,281	70,587	45,900
Korea, North	50,000	80,000	100,000
Korea, Rep. of	920	16,544	11,400
Pakistan	0	6	0
Philippines	101	0	1,100
Thailand	2,211	1,473	17,000
Turkey	1,089	5,967	8,000
Oceania:			
Australia	273,992	403,562	392,300
New Zealand	0	1,246	0
Grand total	2,381,381	3,395,607	3,344,855

[1] Estimated.

NOTE.—Data may not add to totals shown because of independent rounding.

Table 2.—World primary and secondary lead production in 1981, thousand metric tons of contained lead

	Mine	Smelter	Refinery	Secondary (refined)
North America:				
United States	445.5	495.3	495.3	641.1
Canada	332.1	168.5	168.5	69.7
Latin America	437.3	300.7	294.4	99.1
Europe	1,055.3	1,221.7	1,454.6	1,033.2
Africa	312.1	118.5	118.5	30.1
Asia	378.0	487.1	477.2	162.9
Oceania	392.3	367.2	207.7	44.5
Total	3,352.6	3,159.0	3,216.2	2,080.6

40 individual mines in 18 States. Lead concentrates are reduced to lead bullion at five smelters located in Missouri, Montana, and Texas. Three smelters in Missouri also have refineries, and there is one additional refinery in Nebraska that processes crude bullion from smelters in Montana and Texas. The Bunker Hill smelter-refinery in Bradley, ID, shut down indefinitely in 1981 as a result of unfavorable economic conditions.

In 1981, the St. Joe Lead Co. operated six mines and four mills in southeast Missouri and a lead smelter at Herculaneum, MO; AMAX Lead Co. of Missouri operated a mine-mill-smelter complex at Boss, MO, jointly owned by AMAX and Homestake Mining Co. ASARCO Incorporated operated mines in Colorado and New Mexico, smelters in El Paso, TX, East Helena, MT, and Glover, MO, and a lead refinery in Omaha, NE. The three ASARCO smelters and the Bunker Hill smelter treated both domestic and imported concentrates, whereas Missouri facilities normally process domestic concentrates, mostly from Missouri. Other companies operating lead and lead-zinc mines included the Ozark Lead Co., a subsidiary of Kennecott Corp.; Hecla Mining Co.; and Cominco American Inc.

Consumption

Approximately 5.2 million t of lead in all forms was consumed worldwide in 1981, with the United States being the dominant consumer, accounting for 22 pct of total consumption. The U.S. consumption share of refined lead and lead in antimonial lead (excluding other lead alloys and remelt) from 1978 to 1981 averaged 31 pct of the total, compared with 40 pct for Europe and 9 pct for Japan. Actual consumption for individual centrally planned economy countries is not available but, overall, their consumption is estimated to be about 23 pct of the world's total for all types of lead metal; slightly greater than the 1981 percentage for the United States.

Trade Patterns

World trade from 1976 through 1981 averaged 1.9 million t of lead per year contained in the form of ores and concentrates (35 pct), bullion (14 pct), and refined metal (51 pct). The figures exclude internal trade between the centrally planned economy countries, but include estimates of trade between these countries and the market economy countries. During this period, Canada was the leader in exports of concentrates, averaging 144,000 t/yr and Peru was second with 90,000 t/yr. Japan and the Federal Republic of Germany were the leading importers of concentrates during the 1976-81 period. Japan's imports were primarily from Canada and Peru, and concentrate imports for the Federal Republic of Germany were from Sweden, Canada, Ireland, and Morocco. France, the third leading importer of lead concentrates, also depended heavily on Morocco, Ireland, and the Republic of South Africa. In 1981, Canada and Peru supplied 64 pct of the 59,000 t of concentrates imported by the United States.

The leading exporters of refined lead from 1976 through 1981 were Australia with 156,000 t/yr, Canada with 123,600 t/yr, and Mexico with 101,000 t/yr. These three countries exported 40 pct of the world total lead exports over the 6-yr period and, in 1981, provided 94 pct of the U.S. import total of 100,000 t of refined metal. The United States was the largest importer of lead metal during this period, averaging 159,500 t/yr, followed by Italy with an average of 148,000 t/yr. Italy depends primarily on the Federal Republic of Germany, Morocco, Australia, Namibia, and Mexico for refined metal. Although the United States is a significant importer of refined metal, imports do not constitute a major component of U.S. total supply. In 1981, the foreign component of U.S. total supply was about 4 pct in lead concentrates and 7 pct in refined metal. Domestic ores contributed about 31 pct to U.S. supply and recycled old scrap contributed about 40 pct. Industry stocks made up the remaining 18 pct. There have been no shipments of lead from the National Defense Stockpile since 1976. The U.S. import, export, and consumption levels for various forms of lead in 1980 and 1981 are shown in table 3.

Table 3.—U.S. lead import, export, and consumption for 1980-81, metric tons of contained lead

	1980	1981
IMPORT		
Ore, flue dust, base bullion, and residues:		
Argentina	61	3,932
Canada	3,232	1,972
Chile	2,236	2,084
Honduras	3,973	11,617
Peru	18,141	6,299
Other	2,268	1,751
Total	29,911	27,655
Metal (pigs and bars):		
Australia	10,844	9,080
Canada	34,929	50,849
Mexico	28,657	33,723
Peru	3,298	2,907
Other	3,532	3,549
Total	81,300	100,108
Reclaimed scrap	2,868	2,661
Sheets, pipe, shot	950	474
Total	3,818	3,135
Total imports	115,029	130,898
EXPORT		
Ore and concentrates	27,615	33,043
Blocks, pig, anodes, etc.:		
Unwrought	147,356	14,484
Unwrought alloys	9,144	2,320
Wrought lead and lead alloys	7,958	6,516
Scrap[1]	71,791	35,651
Total	263,863	92,014
CONSUMPTION		
Apparent consumption	997,000	1,040,000

[1] Lead content at 60 pct.

NOTE.—Data may not add to totals shown because of independent rounding.

Secondary Sources

Secondary lead is recovered from scrap, product and chemical industry wastes, lead refinery drosses, and other metallurgical wastes such as mattes, dust, slag, and residues. Most secondary lead is derived from wornout, damaged, or obsolete fabricated products such as battery plates and oxides, cable covering, pipe, and sheet. Such material is collected, smelted, and refined in secondary smelters to produce soft lead and antimonial lead or other various lead-base alloys. Additional secondary lead is recovered from process scrap, largely drosses and residues generated during the fabrication of lead products and recycled to secondary smelters for production of refined lead. Some secondary lead materials are reused after remelting without refining, but an increasing proportion is processed in refineries because of the need, in most uses, to meet customer product specifications. Secondary materials have been the source for over 35 pct of the total world use of lead and for over 50 pct of U.S. requirements in recent years. The main source of secondary lead is automobile storage batteries that have been scrapped after use. In the United States and other industrialized countries, about 90 pct of the lead used in the manufacture of storage batteries is recycled.

ZINC INDUSTRY

Changes in world mine and smelter production of zinc have led to changes in the zinc supply pattern of the United States, particularly during the last decade. The result has been an increasing reliance on foreign sources of zinc metal to satisfy domestic requirements. World zinc mine production for 1961, 1971, and 1981 are shown in table 4.

The United States, which was the largest zinc metal producer in the world from 1901 through 1971, has been dependent upon imports of concentrates for a substantial portion of smelter feed since the beginning of World War II. Domestic primary production of slab zinc reached a peak of 944,014 t in 1969, with a continuous decline in production since that time as 10 domestic primary zinc smelters have been closed and only 2 new smelters were commissioned, 1 in 1976 and 1 in 1978. Zinc oxide production from zinc fuming plants at the El Paso, East Helena, and Bunker Hill lead smelters has also been curtailed with the fuming furnaces at all three plants on temporary or indefinite closure. Because of this reduction in U.S. smelting capacity, the need for foreign concentrates has declined significantly, with imported refined zinc metal becoming a major factor in U.S. supply.

World zinc metal production increased from about 1 million t/yr in the middle 1930's to 6.1 million t in

Table 4.—World zinc mine production, 1961, 1971, and 1981, metric tons of contained zinc

Area and country	1961	1971	1981[1]
North America:			
Canada	401,979	1,267,582	1,097,200
United States	421,295	455,907	312,400
Latin America:			
Argentina	30,210	43,864	30,000
Bolivia	5,333	45,077	47,000
Brazil	0	16,920	103,000
Chile	162	1,982	1,100
Colombia	726	112	100
Ecuador	0	126	1,600
Guatamala	7,926	506	500
Honduras	6,215	22,894	18,000
Mexico	268,973	264,972	211,600
Nicaragua	0	4,056	0
Peru	173,872	318,078	496,700
Europe:			
Austria	6,034	21,073	18,200
Bulgaria	73,937	79,834	90,000
Czechoslovakia	(2)	8,564	7,200
Finland	46,597	50,888	53,600
France	15,600	15,140	37,400
German Democratic Rep.	6,985	9,979	0
Germany, Fed. Rep. of	87,213	131,986	91,800
Greece	17,547	14,210	26,800
Greenland	7,983	0	86,400
Hungary	0	4,808	2,000
Ireland	167	87,545	120,300
Italy	134,224	105,870	41,500
Norway	9,331	10,717	31,000
Poland	139,579	193,596	146,500
Portugal	0	2,046	0
Romania	(2)	39,826	55,000
Europe—Continued			
Spain	87,983	87,541	180,000
Sweden	75,201	99,044	180,900
U.S.S.R.	399,168	650,462	790,000
United Kingdom	0	0	9,600
Yugoslavia	59,883	98,695	117,900
Africa:			
Algeria	42,638	15,797	6,200
Congo (Brazzaville)	0	633	3,000
Morocco	40,780	12,338	7,900
Namibia	13,522	43,697	29,600
Nigeria	0	0	100
South Africa, Rep. of	0	158	87,172
Tunisia	3,396	11,794	7,500
Zaire	99,634	109,227	63,300
Zambia	45,433	57,067	22,200
Asia:			
Burma	7,348	4,003	4,500
China	[1]100,000	[1]100,000	160,000
India	5,080	8,246	31,600
Iran	13,517	58,061	15,000
Japan	168,262	294,424	242,042
Korea, North	[1]80,000	[1]135,000	140,000
Korea, Rep. of	450	28,161	56,500
Philippines	3,313	3,375	5,289
Thailand	898	0	0
Turkey	2,000	18,933	30,721
Vietnam	0	0	6,000
Oceania:			
Australia	292,840	452,654	508,400
New Zealand	0	1,969	100
Grand total	3,420,144	5,515,200	5,832,424

[1] Estimated. [2] Production data not available; estimates are included in total.
NOTE.—Data may not add to totals shown because of independent rounding.

1981. The leading metal producing countries in 1981 were the U.S.S.R., Japan, Canada, the United States, Federal Republic of Germany, and Australia. Over the past 10 yr, Brazil, Peru, Canada, U.S.S.R., Mexico, Republic of Korea, India, and Netherlands increased metal production considerably, whereas production in the United States, Zambia, and Zaire declined.

About one-half of the world's mine capacity in market economy countries is held by seven companies either through direct ownership, subsidiaries, or equity sharing. These companies are Noranda Mines Ltd., Cominco Ltd., and Kidd Creek Mines Ltd. (Canada); ASARCO Incorporated (United States); The Rio Tinto Zinc Corp. Ltd. (United Kingdom); Centromin (Peru); and Societe Generale de Belgique (Belgium). The largest zinc refining companies are Societe Generale de Belgique, The Rio Tinto Zinc Corp. Ltd., and Mitsui Mining & Smelting Co. Ltd. (Japan).

Several large, vertically integrated firms with mines, smelters, and refineries are prominent in the U.S. primary zinc industry. The principal companies that operated both mines and smelters or refineries in 1981 were Amax Zinc Co. Inc, ASARCO Incorporated, The Bunker Hill Co., Jersey Miniere Zinc Co., and St. Joe Resources Co. In 1981, these companies accounted for 86 pct of the primary slab zinc produced in the United States and 58 pct of the mine output. Cominco American Inc., The New Jersey Zinc Co., Ozark Lead Co., Hecla Mining Co., and United States Steel Corp. were other major mine producers in 1981, accounting for an additional 40 pct. The Bunker Hill complex closed indefinitely in December 1981 and has not reopened. A number of zinc-producing mines closed in late 1981, 1982, and 1983 for economic reasons.

Consumption

World consumption of refined metallic zinc has grown more or less steadily over the past 50 yr. Slab zinc consumption in market economy countries attained its highest level, 4.9 million t in 1973, but has fluctuated below that level since that time. Consumption in 1982 was about 4.2 million t. The anemic state of the world economy, the introduction of thin-wall diecasting, weight-reduction programs in the automobile industry, and substitution by alternate materials, have adversely affected zinc consumption in recent years.

Europe traditionally is the largest zinc-consuming area and, in 1981, accounted for about 36 pct of world consumption, followed by North America, 31 pct, and Asia, 26 pct. The United States has historically been the largest single consumer of zinc; however, its proportion of world consumption has declined. Of the total refined zinc metal consumed by market economy countries in 1981, the United States consumed 16 pct compared with 32 pct in 1960. On the other hand, Japan, because of its rapid industrial growth over the last two decades, was the second largest consumer of zinc in 1981, having increased its proportion of world consumption from 8 pct in 1960 to 12 pct in 1981. In general, the growth of zinc consumption has been more rapid in the newly industrializing countries, especially in Asia, than in the older industrialized countries.

Trade Patterns

Although the trend towards vertical integration in zinc mining countries has continued over the past decade, world trade in zinc concentrates continues to be large and in 1981 was estimated to be 1.9 million t. Concentrates are mainly exported by Canada, Peru, Australia, Sweden, and Ireland; importing countries are mainly Japan, the United States, and countries in Western Europe. Domestic imports of concentrate decreased significantly in the early 1970's owing to numerous smelter closures. Imports of zinc in concentrate by domestic smelters averaged 380,000 t/yr during the 1960-71 period, but have averaged only 160,000 t/yr through 1982.

During 1981, world trade in slab zinc was estimated to be 1.7 million t, or about 30 pct of world refined zinc production. The largest slab zinc exporters were Canada, Australia, Belgium, Netherlands, Finland, and Federal Republic of Germany. Peru and Mexico have opened new smelters since 1980, and slab zinc exports from these countries are expected to increase substantially. The largest importers of slab zinc in 1981 were the United States, Federal Republic of Germany, United Kingdom, India, and France.

The United States imports more than one-half of the zinc it consumes and typically has an import dependence exceeding 60 pct. Approximately 60 pct of the concentrate and metal imports are obtained from Canada and Mexico, and therefore, severe supply disruption is not likely to occur. Canada has the world's largest zinc mine production and has the capacity to meet essentially the whole of U.S. import requirements. A number of other countries, principally Peru, Spain, and Australia, supply the remainder of U.S. zinc imports. The U.S. import, export, and consumption levels for various forms of zinc in 1980 and 1981 are shown in table 5.

Table 5.—U.S. zinc import, export, and consumption for 1980-81, thousand metric tons of contained zinc

	1980	1981
IMPORT		
Ore and concentrates:		
Canada	110	180
Honduras	7	4
Mexico	14	21
Peru	40	29
Other	11	12
Total	182	246
Metal (blocks, pigs and slabs):		
Australia	25	26
Canada	280	309
Finland	18	29
Mexico	24	15
Peru	4	43
Spain	11	29
Zaire	NAp	29
Other	48	132
Total	410	612
Total imports	592	858
EXPORT		
Waste and scrap	30	30
Ore and concentrates	54	54
Total	84	84
CONSUMPTION		
Apparent consumption		
Slab	811	841
Ores	59	61
Zinc scrap	133	149
Other scrap[1]	139	139
Total	1,142	1,189

NAp Not applicable.

[1] Includes zinc contained in copper-, aluminum-, and magnesia-based scrap.

NOTE.—Data may not add to totals shown because of independent rounding.

Secondary Sources

Recovery of zinc from old scrap, mainly in the form of diecastings, engravers plate, and brass and bronze currently represents from 6 to 8 pct of the total world supply. New scrap is principally zinc- and copper-base alloys from manufacturing operations and drosses and skimmings from galvanizing and diecasting operations. New scrap is either sold to smelters or processed as runaround scrap by the company that generates it. The large use of zinc in galvanizing and in compounds in which the zinc is lost limits the potential for any increased recycling of old scrap.

EVALUATION METHODOLOGY

To determine the potential availability of lead and zinc, 235 mines and deposits in market economy countries were evaluated: 186 mines and deposits were evaluated with zinc as the primary commodity; 30 mines and deposits were evaluated with lead as the primary commodity, and 19 mines and deposits were evaluated with copper as the primary commodity. Geologic and operating data were collected for each of the evaluated mines and deposits. These data included demonstrated and identified resource estimates, actual or estimated mine and mill operating capacities including future expansions and development plans when reported, estimated mine life based on production capacity and demonstrated resource, all capital and reinvestment costs, operating costs for mining and milling, mass balances for each concentrate produced in the mill, and estimates of smelting and refining toll charges for each concentrate and the pay-fors (credits and deductions) associated with each commodity treated.

Although an effort was made to simulate the actual flows from the mines through the smelting and refining stage, with the appropriate smelter charges and pay-fors associated with the particular smelter and refinery; the scope of this study does not attempt to exactly match the capacities of existing smelters and refineries. Smelting and refining charges and the pay-for schedules used in the study are for typical smelters and refineries within the particular region or country. For example, one smelter schedule was used for all concentrates sent to the United States, another was used for all concentrates sent to Japan, and so forth. For undeveloped deposits, future materials flows were estimated based on historical patterns, and on estimates of where plants for future smelting and refining capacity is likely to be constructed.

For each mine and deposit included in this evaluation, capital expenditures were estimated for exploration, acquisition, development, mine plant and equipment, and mill plant and equipment. The capital expenditures for mining and processing facilities include the costs of stationary and mobile equipment, construction, engineering fees, infrastructure, and working capital. Infrastructure includes costs for access and haulage facilities, ports, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for current operating expenses such as labor, supplies, insurance, and taxes.

The total operating cost is a combination of direct and indirect costs. Direct operating costs include materials, utilities, direct and maintenance labor, and payroll overhead. Indirect operating costs include technical and clerical labor, administrative costs, facilities maintenance and supplies, and research. Other costs in the analysis are fixed charges, including local taxes, insurance, depreciation, deferred expenses, interest payments (if any), and return on investment.

After production parameters and cost estimates were established for each mine and deposit, all of the operating data were entered into the supply analysis model (SAM). The Bureau developed the SAM (*5*) to perform discounted-cash-flow rate of return (DCFROR) analyses to determine the long-run constant dollar price at which the primary commodity must be sold (f.o.b. the smelter-refinery) to recover all costs of production including a prespecified DCFROR on all investments. The DCFROR is most commonly defined as the rate of return that makes the present worth of cash flow from an investment equal the present worth of all aftertax investments (*6*).

For this study, a 15-pct DCFROR was considered the necessary rate of return to provide the incentive to develop a mineral property or to continue producing over the long run. The determined value for the primary commodity price is equivalent to the average total cost of production for the operation over its producing life under the set of assumptions and conditions (e.g., mine plan, full capacity production, and a market for all output) necessary to make a full economic evaluation. If an operation has more than one product, the prices of the byproducts are assumed to be the market prices for the period of analysis, which for this study was January 1981. An exception was made for the byproduct prices for cobalt, gold, and silver, which were adjusted to reflect more representative prices over the past 3-yr period. The January 1981 prices for these three commodities were anomalously high. Revenues generated by byproducts are credited against the cost of production. The market prices for byproducts used in the analysis are shown in table 6.

Table 6.—Byproduct prices used in the economic evaluations, January 1981 dollars

Commodity and unit		*Price*
Barite	st	$65.00
Cadmium	lb	2.50
Cobalt	lb	[1]7.00
Copper	lb	.89
Fluorspar	t	140.00
Germanium	kg	1,060.00
Gold	tr oz	[1]425.00
Iron (pellets)	lt units	.81
Lead	lb	.34
Manganese	lt units	1.70
Silver	tr oz	[1]10.00
Sulfur	t	117.50
Tin	lb	7.49
Tungsten	lb	14.70
Zinc	lb	.41

[1] Adjusted to reflect representative period average; January 1981 price was anomalously high.

The SAM system contains a separate tax records file for each particular State or nation, which includes all of the relevant tax parameters under which a mining firm would operate, such as corporate income taxes, property taxes, royalties, severance taxes, or other taxes that pertain to the production of lead or zinc. These tax parameters are applied against each mineral deposit under evaluation with the implicit assumption that each deposit represents a separate corporate entity. Other charges considered in the analysis include standard deductibles such as depreciation, depletion, deferred expenses, investment tax credits, and tax-loss carryforwards. The system also contains an additional file of economic indexes to allow for continuous updating of cost estimates to a base date. The recently published Bureau of Mines report on the availability of lead and zinc—domestic (*7*), used 1981 cost estimate data updated to the base study date of January 1982. This study uses the base date of January 1981 since the data were collected for that year and it was felt that the limited cost-index data for certain countries were too unreliable to update to January 1982. For this reason, the U.S. costs presented in this report differ slightly from those presented in the domestic lead and zinc report.

Detailed cash-flow analyses are generated by the SAM system for each preproduction year of an operation beginning with the initial year of the analysis, 1981. Upon completion of the individual analysis for each mine and deposit, all properties were simultaneously analyzed and aggregated onto the availability curves presented in the "Availability of Lead and Zinc" section of this report.

LEAD AND ZINC RESOURCES

Demonstrated lead-zinc resources of the 235 mines and deposits evaluated in market economy countries in 1981 were approximately 4.3 billion t of ore containing 221 million t of zinc and 97 million t of lead. Of these amounts, approximately 153.7 million t of zinc and 70.4 million t of lead are estimated to be recoverable. At the identified resource level, approximately 250 million t of zinc and 111 million t of lead are contained in 5.3 billion t of lead and zinc ores in market economy countries. An additional 24 million t of zinc and 33 million t of lead are contained as identified resources in centrally planned economy countries.

Demonstrated lead-zinc resources, by country, are shown in table 7. Percentage shares of contained lead, by country, are shown in figure 3, and percentage shares of contained zinc are shown in figure 4. Note

Table 7.—Summary of demonstrated lead and zinc resource values in market economy countries, as of January 1981

Country	Mines-deposits	Resources (ore), 10^3 t	Weighted av grade, pct		Contained metal, 10^3 t	
			Zinc	Lead	Zinc	Lead
Algeria	1	3,580	5.56	1.33	199	48
Argentina	1	6,600	7.60	6.20	502	409
Australia	15	468,588	9.01	4.95	42,247	23,207
Austria	1	10,000	4.80	1.40	480	140
Bolivia	2	2,365	9.05	1.34	214	32
Brazil	2	23,237	8.43	1.12	1,960	261
Burma	1	3,100	5.00	6.25	155	194
Canada	42	760,880	6.34	2.27	48,258	17,308
Finland	4	40,950	2.72	.08	1,113	31
France	5	16,816	5.11	2.15	860	362
Germany, Fed. Rep. of	3	24,400	8.97	2.46	2,191	588
Greece	2	20,000	4.50	3.50	900	700
Greenland	1	3,738	13.40	4.40	501	165
Honduras	1	7,200	8.00	4.20	576	302
India	4	110,200	4.99	1.97	5,499	2,168
Ireland	5	59,506	8.97	2.04	5,339	1,216
Italy	5	32,900	4.52	1.44	1,487	475
Japan	9	74,579	4.77	.86	3,561	641
Mexico	18	237,638	3.52	1.83	8,380	4,359
Morocco	6	24,230	.61	6.89	150	1,670
Namibia	3	14,798	2.89	3.20	429	473
Norway	1	12,050	1.20	.00	145	0
Peru	15	254,996	3.44	1.13	8,765	2,881
Portugal	1	140,000	3.24	1.23	4,536	1,722
South Africa, Rep. of	3	282,433	4.51	1.87	12,741	5,287
Spain	6	194,260	2.89	1.24	5,622	2,414
Sweden	5	65,900	3.91	3.36	2.579	2,215
Turkey	3	33,358	4.76	.12	1,588	40
Zaire	1	49,550	13.60	.00	6,739	0
Zambia	1	1,741	22.30	11.30	388	197
Total or average	167	2,979,592	5.64	2.33	168,101	69,515
United States	68	1,354,892	3.91	2.01	52,949	27,254
Grand total or average	235	4,334,484	5.10	2.22	221,050	96,769

NOTE.—Data may not add to totals shown because of independent rounding.

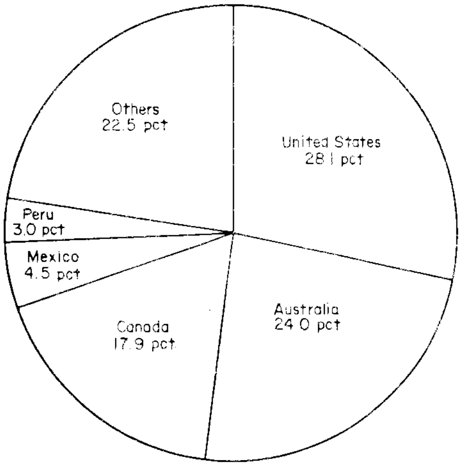

Figure 3.—Percent share of contained lead in market economy countries.

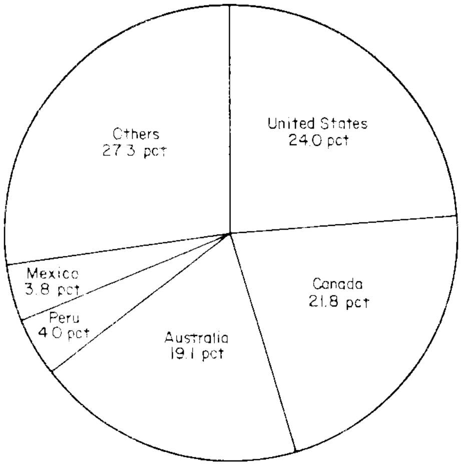

Figure 4.—Percent share of contained zinc in market economy countries.

that the weighted-average ore grades include both primary and byproduct ore grades. Average zinc grades from mines and deposits evaluated as primary zinc operations are higher than the averages shown in table 7, as are the average lead grades from mines and deposits evaluated as primary lead mines. A more meaningful comparison of lead and zinc grades can be shown by presenting minable ore tonnages (recoverable ore) and actual feed grades (including dilution) for mines and deposits evaluated as primary zinc, lead, or copper operations. These data, by country, are presented in tables 8 through 13.

Table 8.—Summary of January 1981 minable resource values for mines and deposits evaluated as lead properties, with minable resources and weighted-average feed grades

Country	Mines-deposits	Resources, 10^3 t	Grade, pct.	Contained lead, 10^3 t
Australia	1	5,950	12.60	750
Canada	1	838	4.76	40
France	1	7,389	2.54	188
Mexico	2	7,914	6.65	447
Morocco	5	22,363	6.87	1,537
Namibia	1	6,300	6.98	440
South Africa, Rep. of	2	121,075	3.71	4,494
Spain	1	1,830	5.00	92
Sweden	2	34,930	4.18	1,459
Total or average	16	208,589	4.53	9,445
United States	14	337,108	5.62	18,931
Grand total or av.	30	545,697	5.19	28,375

NOTE.—Data may not add to totals shown because of independent rounding.

Table 9.—Summary of January 1981 minable resource values for mines and deposits evaluated as lead properties, with minable resources and weighted-average grades for byproduct zinc

Country	Mines-deposits	Resources, 10^3 t	Grade, pct	Contained zinc, 10^3 t
Australia	1	5,950	9.70	577
France	1	7,389	.59	44
Mexico	1	4,701	3.70	174
Morocco	2	3,430	1.46	51
Namibia	1	6,300	1.90	120
South Africa, Rep. of	2	121,075	1.24	1,498
Sweden	1	32,000	.74	237
Total or average	9	180,845	1.49	2,700
United States	12	332,793	1.05	3,504
Grand total or av.	21	513,638	1.21	6,204

NOTE.—Data may not add to totals shown because of independent rounding.

Table 10.—Summary of January 1981 minable resource values for mines and deposits evaluated as zinc properties, with minable resources and weighted-average feed grades

Country	Mines-deposits	Resources 10^3 t	Grade, pct	Contained zinc, 10^3 t
Algeria	1	3,381	5.00	169
Argentina	1	6,967	6.84	477
Australia	12	404,970	9.10	36,858
Austria	1	10,000	3.80	380
Bolivia	2	3,621	5.14	186
Brazil	2	23,237	7.84	1,823
Burma	1	3,100	4.00	124
Canada	33	612,288	6.30	38,609
Finland	2	28,523	2.68	765
France	4	10,060	6.43	647
Germany, Fed. Rep. of	3	24,963	8.45	2,109
Greece	2	20,000	4.05	810
Greenland	1	3,177	13.40	426
Honduras	1	7,200	7.20	518
India	4	111,629	4.30	4,803
Ireland	5	54,503	7.92	4,322
Italy	5	32,900	4.05	1,334
Japan	8	62,560	4.21	2,636
Mexico	16	220,938	3.29	7,263
Morocco	1	1,500	5.85	88
Namibia	1	5,078	6.30	320
Peru	14	100,401	6.78	6,808
Portugal	1	103,451	3.06	3,166
South Africa, Rep. of	1	143,570	6.04	8,672
Spain	5	173,676	2.75	4,775
Sweden	2	25,288	7.50	1,898
Turkey	1	698	24.50	171
Zaire	1	32,550	12.20	3,971
Zambia	1	2,067	17.80	368
Total or average	132	2,232,296	6.02	134,494
United States	54	1,024,463	4.43	45,441
Grand total or av	186	3,256,759	5.52	179,935

NOTE.—Data may not add to totals shown because of independent rounding.

Table 11.—Summary of January 1981 minable resource values for mines and deposits evaluated as zinc properties, with minable resources and weighted-average grades for byproduct lead

Country	Mines-deposits	Resources, 10^3 t	Grade, pct	Contained lead, 10^3 t
Algeria	1	3,381	1.20	41
Argentina	1	6,967	5.58	389
Australia	11	402,405	5.03	20,223
Austria	1	10,000	1.10	110
Bolivia	2	3,621	.66	24
Brazil	1	17,613	1.26	222
Burma	1	3,100	5.00	155
Canada	26	540,894	2.84	15,361
Finland	1	11,180	.26	29
France	4	10,060	.99	100
Germany, Fed. Rep. of	3	24,963	2.27	567
Greece	2	20,000	3.15	630
Greenland	1	3,177	4.40	140
Honduras	1	7,200	3.80	274
India	4	111,629	1.75	1,951
Ireland	5	54,503	1.80	983
Italy	5	32,900	1.31	432
Japan	8	62,560	.74	464
Mexico	15	220,136	1.52	3,352
Morocco	1	1,500	1.35	20
Namibia	1	5,078	1.80	91
Peru	14	100,401	2.77	2,777
Portugal	1	103,451	1.16	1,200
South Africa, Rep. of	1	143,570	.47	675
Spain	5	173,676	1.13	1,959
Sweden	2	25,288	1.58	399
Turkey	1	698	1.20	8
Zambia	1	2,067	9.00	186
Total or average	120	2,102,018	2.51	52,762
United States	20	354,390	1.78	6,295
Grand total or av	140	2,456,409	2.40	59,057

NOTE.—Data may not add to totals shown because of independent rounding.

A detailed breakdown of recoverable metal from lead and zinc resources is presented in the "Availability of Lead and Zinc" section. Mines and deposits evaluated for this study, including ownership, status, and type, are listed in tables 14 through 16.

Table 12.—Summary of January 1981 minable resource values for mines and deposits evaluated as copper properties, with minable resources and weighted-average grades for byproduct lead

Country	Mines-deposits	Resources, 10^3 t	Grade, pct	Contained lead, 10^3 t
Australia	2	30,041	1.18	355
Canada	1	91,240	.18	164
Japan	1	31,787	.86	273
Namibia	1	4,200	2.14	90
Total or average	5	157,268	.56	882

Table 13.—Summary of January 1981 minable resource values for mines and deposits evaluated as copper properties, with minable resources and weighted-average grades for byproduct zinc

Country	Mines-deposits	Resources, 10^3 t	Grade, pct	Contained zinc, 10^3 t
Australia	2	30,041	3.32	997
Canada	7	145,228	3.94	5,727
Finland	2	8,712	1.05	92
Japan	1	31,787	3.22	1,024
Norway	1	10,145	1.10	112
Peru	1	156,695	1.05	1,645
South Africa, Rep. of	1	7,749	2.07	160
Sweden	1	7,600	2.88	219
Turkey	2	31,200	3.11	969
Total or average	18	429,156	2.55	10,944

NOTE.—Data may not add to totals shown because of independent rounding.

Table 14.—Mines and deposits evaluated as lead operations

(Property information as of January 1981)

	Ownership	Status[1]	Type[2]	Est ore capacity, 10^3 t/yr	Mining methods
UNITED STATES					
Colorado: Bulldog	Homestake Mining	P	U	102	Cut and fill.
Idaho: Lucky Friday	Hecla Mining Co.	P	U	168	Do.
Missouri:					
Boss-Bixby	Getty Oil-AZCON-Hanna Mining	E	U	136	Room and pillar.
Brushy Creek Division	St. Joe Minerals Corp.	P	U	1,134	Do.
Buick	AMAX Lead-Homestake Lead	P	U	1,932	Do.
Fletcher Division	St. Joe Minerals Corp.	P	U	1,134	Do.
Frank R. Milliken	Kennecott (Ozark Lead Co.)	P	U	2,058	Do.
Higdon-BonneTerre	Bunker Hill-St. Joe Minerals	PP	U	200	Do.
Indian Creek	St. Joe Minerals Corp.	P	U	590	Do.
Magmont	Cominco American-Dresser	P	U	952	Do.
Viburnum No. 28 and No. 29	St. Joe Minerals Corp.	P	U	1,769	Do.
Viburnum No. 35	do	D	U	867	Do.
West Fork	ASARCO	D	U	454	Do.
Utah: Ontario	United Park City-Noranda	T	U	212	Combined methods.
FOREIGN					
Australia: North Broken Hill	North Broken Hill Ltd.	P	U	500	Do.
Canada: Yava	Barymin Exploration Ltd.	P	U	164	Room and pillar.
France: L'Argentiere	Penarroya	P	U	616	Do.
Mexico:					
La Encantada	La Encantada S.A.	P	U	355	Combined methods.
Rosario	Industria Minera Mexico S.A.	D	U	235	Cut and fill.
Morocco:					
Aouli-Mibladen	Penarroya	P	C	150	Combined methods.
Djebel Aouam	BRPM-Royal Asturienne-Vielle	P	U	200	Do.
Sidi Lachen	BRPM-Armico	D	U	84	Overhand.
Touissit	Royal Asturienne des Mines	P	U	400	Room and pillar.
Zeida	SODIM-ZELLIDJA-BRPM	P	S	1,200	Open pit.
Namibia: Tsumeb	Tsumeb Corp. Ltd.	P	U	450	Cut and fill.
South Africa, Rep. of:					
Black Mountain	Phelps Dodge-GFSA	E	U	3,440	Do.
Broken Hill	do	P	U	1,800	Do.
Spain: Linares (El Cobre)	Cia. Minera la Cruz	P	U	145	Do.
Sweden:					
Laisvall	Boliden Metall AB	P	U	1,500	Room and pillar.
Vassbo-Guttusjo	do	P	U	300	Do.

[1] D—developing deposit, E—explored deposit, P—producing mine, PP—past producer, T—temporarily shut down.

[2] C—surface and underground, S—surface, U—underground.

Table 15.—Mines and deposits evaluated as zinc operations

(Property information as of January 1981)

	Ownership	Status[1]	Type[2]	Est ore capacity, 10^3 t/yr	Mining methods
UNITED STATES					
Alaska:					
Arctic Camp	Kennecott Copper Corp	E	S	2,640	Open pit.
Greens Creek	Noranda-Others	E	U	240	Cut and fill.
Lik	Houston Oil & Minerals-GCO	E	S	900	Open pit.
Red Dog	Cominco	E	S	900	Do.
Colorado:					
Black Cloud	ASARCO-Resurrection	P	U	189	Room and pillar.
Idarado	Newmont Mining	PP	U	381	Sublevel open stope.
Sunnyside	Standard Metals	P	U	272	Shrinkage.
Idaho:					
Bunker Hill	Bunker Hill-Gulf Resources	PP	U	525	Combined methods.
Star Morning	Bunker Hill-Hecla Mining	P	U	250	Cut and fill.
Illinois: Minerva No. 1-Spivey	Inverness Mining	P	U	181	Room and pillar.
Kentucky:					
Burkesville Project	Cominco-ASARCO-Others	E	U	625	Do.
Fountain Run	St. Joe Minerals Corp.	E	U	625	Combined methods.
Maine:					
Bald Mountain	Superior Oil Co.	E	S	1,656	Open pit.
Kerr American-Blue Hill	Kerr American-Black Hawk	PP	U	192	Room and pillar.
Montana: Butte District Zinc	Anaconda Copper Corp.	PP	U	1,797	Block caving.
Nevada:					
Ruby Hill Mine	Ruby Hill-Hecla-Others	E	U	324	Combined methods.
Ward Mountain	Gulf Oil-Silver King Mianes	E	U	725	Room and pillar.
New Jersey: Sterling	New Jersey Zinc Co.	P	U	182	Cut and fill.
New Mexico: Pinos Altos	Boliden-Exxon Minerals	E	U	643	Open stope.
New York:					
Balmat	St. Joe Zinc	P	U	960	Room and pillar.
Pierrepoint	do	D	U	113	Do.
Pennsylvania: Friedensville Mine	New Jersey Zinc Co.	P	U	490	Do.
Tennessee:					
Beaver Creek	do	P	U	544	Do.
Big War Creek	do	E	U	272	Do.
Carthage Property	St. Joe Minerals-Others	E	U	400	Combined methods.
Copperhill:					
Boyd North-South	Cities Services Corp.	P	U	311	Sublevel caving.
Eureka-Calloway	do	P	U	709	Do.
Coy	ASARCO	PP	U	228	Room and pillar.
Cub Creek	New Jersey Zinc-Others	E	U	625	Combined methods.
Cumberland	Jersey Miniere Zinc Co.	E	U	625	Do.
Cumberland Deposit	Exxon Minerals	E	U	625	Do.
Cumberland Property	St. Joe Minerals-Others	E	U	625	Room and pillar.
East Gainsboro	Getty Oil-Tennessee Zinc Dev.	E	U	625	Combined methods.
Gainesboro	New Jersey Zinc-Others	E	U	625	Room and pillar.
Gordonsville-Elmwood	Jersey Miniere Zinc Co.	P	U	2,041	Do.
Hartsville	Marathon Oil-J. F. Landers	E	U	625	Combined methods.
Hartsville Area	Cominco American-NL Ind.	E	U	275	Do
Idol	New Jersey Zinc Co.	P	U	272	Room and pillar.
Immel	ASARCO	PP	U	525	Do.
Jefferson City Mine	New Jersey Zinc Co.	P	U	68	Do.
Lost Creek	do	P	U	136	Shrinkage.
New Market	ASARCO	P	U	568	Combined methods.
Pall Mall	ASARCO-Others	E	U	400	Do.
Right Fork	ASARCO	E	U	625	Room and pillar.
Roaring River	New Jersey Zinc Co.-AMAX Inc.	E	U	625	Do.
Stonewall	Jersey Miniere Zinc Co.	E	U	400	Do.
Young	ASARCO	PP	U	794	Do.
Zinc	US Steel Corp.	P	U	544	Do.
Washington:					
Boundary Dam-Metaline Falls	Metaline-Washington Res.	PP	U	544	Do.
Washington Zinc Unit	Callahan Mining-Others	PP	U	635	Sublevel open stope.
Wisconsin:					
Crandon	Exxon Minerals Corp.	E	U	2,820	Do.
Crawhall-Elmo No. 3	Inspiration Mines	PP	U	114	Room and pillar.
Pelican River	Noranda Corp.	E	U	355	Cut and fill.
Shullsburg-Bearhole	Inspiration Mines	PP	U	340	Room and pillar.
FOREIGN					
Algeria: El Abed	SONAREM	P	U	500	Do.
Argentina: El Aguilar	St. Joe Minerals Corp.	P	U	600	Overhand square set.
Australia:					
Dugald River	CRA Ltd.	E	U	1,000	Open stope.
Elura	EZ Industries Ltd.	D	U	1,100	Do.
Hilton	Mount Isa Mines (MIM) Ltd.	D	U	710	Combined methods.
Lady Loretta	Triako Mines NL-MIM Holdings	E	U	710	Open stope.

See footnotes at end of table.

Table 15.—Mines and deposits evaluated as zinc operations—Continued

	Ownership	Status[1]	Type[2]	Est ore capacity, 10^3 t/yr	Mining methods
FOREIGN—Continued					
Australia—Continued					
McArthur River	MIM Holdings Ltd	E	C	7,000	Combined methods.
Mount Isa	MIM Ltd	P	U	3,600	Do.
New Broken Hill	CRA Ltd	P	U	1,100	Do.
Que River	Aberfoyle Ltd.-Paringa Mining	P	U	200	Open stope.
Roseberry-Hercules	EZ Industries Ltd	P	U	675	Combined methods
Teutonic Bore	Seltrust-MIM Ltd.	D	C	300	Open pit.
Woodlawn	St. Joe-Phelps Dodge-CRA Ltd.	P	S	1,050	Do.
Zinc Corporation	Zinc Corp. Ltd.	P	U	900	Cut and fill.
Austria: Bleiberg-Kreuth	Bleiberger Bergwerks Union	P	U	500	Combined methods.
Bolivia:					
Matilde	COMIBOL	P	U	245	Cut and fill.
Quechisla	do.	P	U	161	Shrinkage.
Brazil:					
Paracatu	Mineracao Morro Agudo	D	U	825	Room and pillar.
Vazante	Companhia Mineria de Metais	P	S	420	Bench (berm).
Burma: Bawdwin	No. 1 Mining Corp.	P	S	310	Do.
Canada:					
Abcourt-Barvue	Abcourt Silver Mines-Noranda	E	U	350	Cut and fill.
Anvil Range	Cyprus Anvil Mining Corp.	P	C	3,400	Open pit.
Brunswick No. 12	Brunswick Mining and Milling	P	U	3,500	Cut and fill.
Buttle Lake	Westmin Res. Ltd.-Brascan Ltd.	P	U	300	Do.
Caribou Mine	Anaconda Canada Ltd.	T	U	2,800	Do.
Chisel Lake	Hudson Bay Mining and Smelting	P	U	181	Sublevel open stope.
Cirque	Cyprus Anvil-Hudson Bay	E	U	1,750	Cut and fill.
Daniels Harbor	Teck Corp.	P	U	529	Room and pillar.
Detour Project	Selco Mining Corp. Ltd.	D	C	450	Combined methods.
F Group	Noranda Mines Ltd.	P	S	222	Open pit.
Gallen	Noranda-MacDonald	D	S	350	Do.
Gays River	Canada Wide Mines Ltd.	T	U	286	Room and pillar.
Goldstream	Noranda Mines Ltd.	D	C	496	Combined methods.
Goz Creek	Barrier Reef Resources Ltd.	E	S	544	Open pit.
Great Slave Reef	Westmin-Dupont-Philipp Bros.	E	U	350	Room and pillar.
Hackett River	Bathurst Norsemines-Cominco	E	U	1,500	Cut and fill.
Half Mile Lake	Texasgulf Inc.	E	U	1,000	Do.
Heath Steele (Little River Joint Venture).	Heath Steele-Noranda-ASARCO	P	U	1,570	Open stope.
Howard's Pass	Placer Dev.-US Steel Corp.	E	U	3,500	Combined methods.
Izok Lake	Texasgulf Inc.	E	S	733	Open pit.
King Fissure	Internat. Standard Resources	E	U	350	Cut and fill.
Lyon Lake	Noranda Mines Ltd.	P	U	350	Do.
Mattabi	Noranda-Abitibi Mines Ltd.	P	U	508	Sublevel open stope.
Mattagami Lake	Noranda Mines Ltd.	P	U	1,476	Cut and fill.
Mel	St. Joseph-Sovereign Metals	E	U	495	Do.
Nanisivik	Mineral Resource Internat.	P	U	562	Room and pillar.
Pine Point	Pine Point Mines Ltd.	P	S	3,290	Open pit.
Polaris	Cominco Ltd.	D	U	749	Cut and fill.
Prairie Creek	Cadillac Procan Explorations	D	U	315	Do.
Restigouche	Placer Development	E	S	350	Open pit.
Robb Lake	Texasgulf-Arrow Inter/Am-Bar	E	U	450	Room and pillar.
Sullivan	Cominco Ltd.	P	U	2,130	Sublevel caving.
Tom	Hudson Bay Mining and Smelting	E	U	700	Cut and fill.
Finland:					
Pyhasalmi	Outokumpu Oy	P	U	1,100	Sublevel open stope.
Vihanti	do.	P	U	1,000	Do.
France:					
Bodennec	BRGM	E	S	260	Open pit.
Malines	Penarroya	P	U	260	Cut and fill.
Porte-Aux-Moines	BRGM	E	U	182	Sublevel open stope.
Saint Salvy	Penarroya	P	U	240	Cut and fill.
Germany, Fed. Rep. of:					
Grund	Preussag AG Metall	P	U	407	Do.
Meggen	Sachtleben Bergbau Gmbh	P	U	850	Sublevel open stope.
Rammelsburg	Preussag AG Metall	P	U	277	Cut and fill.
Greece:					
Mavres Petres-Madem Lakos	Hellenic Chemical Prod. Co.	P	U	550	Sublevel caving.
Olympias	do.	P	U	800	Do.
Greenland: Black Angel	Cominco Ltd.	P	U	640	Room and pillar.
Honduras: El Mochito	Rosario Resources-Amax Inc.	P	U	700	Combined methods.
India:					
Ambaji	Gujarat Mineral Dev.	D	C	350	Open pit.
Mochia-Balaria	Hindustan Zinc, Ltd.	P	U	1,040	Top slicing.
Rajpura-Dariba	do.	D	U	900	Open stope.
Zawarmala-Baroi	do.	E	U	900	Shrinkage.

See footnotes at end of table.

Table 15.—Mines and deposits evaluated as zinc operations—Continued

	Ownership	Status[1]	Type[2]	Est ore capacity, 10^3 t/yr	Mining methods
FOREIGN—Continued					
Ireland:					
Ballinalack	Noranda-Barymin	E	U	350	Sublevel.
Bula	Bula Ltd.-Govt. of Ireland	E	U	700	Cut and fill.
Mogul	Kerr Addison-Silvermines	P	U	600	Combined methods.
Sabina-Tatestown	Sabine-Messina-Irish Base Met.	E	U	350	Room and pillar.
Tara (Navan)	Tara Exp.-Govt. of Ireland	P	U	2,250	Combined methods.
Italy:					
Funtana Raminosa	SAMIM	P	U	350	Sublevel open stope.
Masua	do	P	U	950	Sublevel caving.
Monteponi	do	D	U	300	Combined methods.
Montevecchio	do	E	U	300	Cut and fill.
Raibl	do	P	U	468	Combined methods.
Japan:					
Ezuri	Dowa Mining Co. Ltd.	P	U	120	Top slicing.
Fukazawa	do	P	U	240	Do.
Hosokura	Mitsubishi Metal Corp.	P	U	444	Cut and fill.
Kamioka:					
Mozumi	Mitsui Mining & Smelting	P	U	329	Sublevel open stope.
Tochibora	do	P	U	954	Do.
Kosaka	Dowa Mining Co. Ltd.	P	U	546	Cut and fill.
Nakatatsu	Nippon Zinc Mining Co. Ltd.	P	U	384	Do.
Toyoha	do	P	U	396	Do.
Mexico:					
Charcas	Industrial Minera Mexico	P	U	390	Combined methods.
Cuale	Cia. Fresnillo S.A.	P	S	300	Open pit.
El Monte-El Carrizal	do	P	U	140	Open stope.
El Tecolote	Industrial Minera Mexico	P	U	124	Sublevel caving.
Fresnillo	Cia. Fresnillo S.A.	P	U	241	Combined methods.
La Negra	Industrias Penoles S.A.	P	U	240	Sublevel open stope.
Naica	Cia. Fresnillo S.A.	P	U	756	Cut and fill.
Parral	Industrial Minera Mexico	P	U	218	Combined methods.
Real De Angeles	Minera Real de Angeles	D	S	3,500	Open pit.
San Francisco Del Oro	Frisco S.A. de C.V.	P	U	852	Shrinkage.
San Martin	Industrial Minera Mexico	P	U	770	Cut and fill.
Santa Barbara	do	P	U	1,622	Combined methods.
Santa Eulalia	do	P	U	312	Cut and fill.
Santa Maria de la Paz	Min. Santa Maria de la Paz	P	U	1,026	Shrinkage.
Taxco	Industrial Minera Mexico	P	U	1,034	Combined methods.
Velardena	do	P	U	281	Shrinkage.
Morocco: Bou Madine	Government of Morocco	E	U	60	Overhand.
Namibia: Rosh Pinah	Imcor Zinc (Pty.) Ltd.	P	U	420	Sublevel open stope.
Peru:					
Atacocha	Cia. Minera Atacocha S.A.	P	U	460	Combined methods.
Carahuacra	Volcan Mines Co.	P	C	320	Do.
Casapalca	CENTROMIN	P	U	892	Do.
Cerro de Pasco	do	P	C	2,113	Do.
Hercules	Cia. Minera Alianza S.A.	P	U	432	Room and pillar.
Huanzala	Cia. Minera Santa Luisa S.A.	P	U	273	Cut and fill.
Huaron	Cia. Minera Huaron S.A.	P	U	600	Combined methods.
Milpo	Cia. Minera Milpo S.A.	P	U	540	Cut and fill.
Morococha	CENTROMIN	P	U	513	Combined methods.
Raura	Cia. Minera Raura S.A.	P	U	350	Do.
San Cristobal	CENTROMIN	P	C	636	Do.
San Vicente	San Ignacio de Morococha	P	U	406	Cut and fill.
Santander	St. Joe Minerals	P	U	300	Sublevel open stope.
Yauricocha	CENTROMIN	P	U	497	Combined methods.
Portugal: Aljustrel	Empresa Minera D'Aljustrel	P	U	429	Cut and fill.
South Africa, Rep. of: Gamsberg	Gamsberg Zinc Corp.	E	U	3,000	Sublevel open stope.
Spain:					
Aznalcollar	Soc. Andalusa de Piritas S.A.	P	S	4,000	Open pit.
Cartagena	Penarroya	P	S	1,907	Do.
Reocin	Asturiana De Zinc S.A.	P	U	400	Room and pillar.
Rubiales	Exminesa	P	U	885	Cut and fill.
Sotiel	Minas de Almagresa S.A.	D	U	600	Room and pillar.
Sweden:					
Garpenberg	Boliden	P	U	475	Cut and fill.
Zinkgruven	Soc. des Mines et Fonderies	P	U	599	Do.
Turkey: Aladag	Cinko-Kursan Metal Sanayii	P	S	90	Open pit.
Zaire: Kipushi	Gecamines	P	U	1,450	Combined methods.
Zambia: Broken Hill	Nchanga Consolidated	P	U	240	Sublevel open stope.

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[1] D—developing deposit, E—explored deposit, P—producing mine, PP—past producer, T—temporarily shut down.

[2] C—surface and underground, S—surface, U—underground.

Table 16.—Mines and deposits evaluated as copper operations with lead and zinc as major byproducts

(Property information as of January 1981)

	Ownership	Status[1]	Type[2]	Est ore capacity, 10^3 t/yr	Mining methods
Australia:					
Benambra	Western Mining-British Petrol	E	S	520	Open pit.
C.S.A.	Conzinc Riotinto of Australia	P	U	875	Open stope.
Canada:					
Flin Flon	Hudson Bay Mining and Smelting	P	U	702	Shrinkage.
Fox	Sherritt Gordon Mines Ltd	P	U	702	Cut and fill.
Geco	Noranda Mines Ltd	P	U	1,588	Do.
High Lake	Kennarctic Explorations	E	U	312	Shrinkage.
Kidd Creek	Texasgulf, Inc.	P	U	4,393	Open stope.
Lake Dufault Division	Falconbridge Copper Ltd	P	U	420	Do.
Ruttan	Sherritt Gordon Mines Ltd	P	U	3,175	Do.
Finland:					
Keretti	Outokumpo Oy	P	U	500	Cut and fill.
Vuonos	do	P	U	550	Room and pillar.
Japan: Hanaoka	Dowa Mining Co. Ltd	P	U	876	Do.
Norway: Tverrejellet	Folldal Verk A/S	P	U	650	Sublevel open stope.
Peru: Antamina	Minero Peru	E	S	10,500	Open pit.
Namibia: Kombat-Asis West	Tsumeb Corp. Ltd	P	U	350	Combined methods.
South Africa, Rep. of: Prieska	Prieska Copper Mines Ltd	P	U	520	Open stope.
Sweden: Stekenjokk	Boliden Metall AB	P	C	600	Combined methods.
Turkey:					
Cayeli	Etibank	D	U	600	Cut and fill.
Siirt	do	E	U	705	Shrinkage.

[1] D—developing deposit, E—explored deposit, P—producing mine, PP—past producer, T—temporarily shut down.

[2] C—surface and underground, S—surface, U—underground.

GEOLOGY OF LEAD AND ZINC DEPOSITS

The mineralogy of lead and zinc ores is relatively simple, with the sulfides galena (PbS) and sphalerite (ZnS) occurring as the major lead and zinc minerals, respectively. Most lead deposits contain galena associated with sphalerite, pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and other base metal sulfides or sulfosalts, some of which are recovered to yield byproducts or coproducts. Galena is usually associated with variable amounts of contained silver (argentiferous galena); galena low in silver is referred to as soft lead (*8*). Some galena ore bodies may be altered to cerussite ($PbCO_3$), anglesite ($PbSO_4$), or other oxidized lead minerals, but generally galena is resistant to weathering. Lead is a major constituent in several important deposit types, including stratabound, volcanic-sedimentary, replacement, veins, and contact metamorphic deposits.

The major zinc deposits contain the zinc sulfide mineral, sphalerite. Most sphalerite has associated cadmium in quantities from traces to 2 pct, and small quantities of germanium, gallium, indium, and thallium. A few important zinc deposits contain oxide, carbonate, or silicate zinc minerals such as zincite (ZnO), smithsonite ($ZnCO_3$), willemite (Zn_2SiO_4), or hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$); commonly derived from the altered sulfide minerals. The two principal types of sulfide deposits are massive mixed sulfide ores in metamorphic rocks and irregular breccia or replacement stratabound deposits in carbonate rocks. A lesser number of sulfide deposits are classified as contact metamorphic, replacement, or vein deposits.

The most common host rocks of stratabound lead and zinc deposits are limestones or dolomites. Sedimentary-structural features, such as reefs, facies changes, zones of minor jointing, or collapse breccias associated with ancient karst drainage, serve as loci for ore bodies within the favorable formations. Examples of such stratabound deposits are in the Southeast Missouri lead district; the Missouri-Oklahoma-Kansas district; the Upper Mississippi Valley district; the Pine Point deposit, Northwest Territory, Canada; the Laisvall deposit, Sweden; and the eastern Tennessee zinc deposits.

Volcanic-sedimentary type deposits contain massive sulfide bodies commonly interlayered with volcanic or sedimentary rocks. Most such deposits are found in older folded and disturbed belts that have been severely metamorphosed. Their size can range from small lenses to enormous masses. The ore is commonly a fine-grained mixture of pyrite or pyrrhotite, sphalerite, galena, and chalcopyrite, with minor amounts of nonmetallic and carbonate minerals. Examples of massive sulfide deposits are those near Bathurst, New Brunswick, Kidd Creek, and Sullivan in Canada; Broken Hill and Mount Isa, Australia; and Kuroko, Japan.

Replacement deposits of lead and zinc are commonly irregular hydrothermal type deposits in carbonate rocks, but some also occur in quartzites or metamorphic rocks. The form and extent of the ore bodies are determined by the structural and stratigraphic elements that localized the replacement activity of the ore-bearing solutions. They include tabular or cylindrical flat-lying bodies called mantos, pipelike structures that cross the bedding, and irregular branching bedded deposits associated with veins. Some of the well-known replacement deposits include Cerro de Pasco, Peru; the silver-lead district of Central Mexico; Tsumeb, Namibia; Tintic, Utah; and Leadville and Gilman districts, Colorado.

Veins are the best known type of ore deposits. They are the most obvious and consequently were the first deposits to be exploited by ancient miners. The vein deposits are commonly situated in faults, joints, or at formational contacts. They contain ore minerals and gangue in varying amounts. Veins can be 1 to 10 m long horizontally, and extend downwards hundreds of meters. Some of the better known vein systems occur in the Coeur d'Alene district in Idaho; the Silverton area of Colorado; Santa Barbara, Fresnillo, and Taxco Mines in Mexico; and the Harz Mountains, Clausthal, and Freiberg deposits in Germany.

Contact metamorphic deposits are associated with igneous intrusions, which have either provided the solutions or emanations creating the deposit, or have altered and recrystallized (or replaced) a mineral deposit already present prior to the intrusion. Deposits range in size from small vein systems to massive pods hundreds of meters long. Although many deposits of this type are mined for other metals in the United States, only a few have produced significant amounts of lead, usually as a byproduct. The Kamioka, Obori, Chichibu, and Nakatatsu deposits in Japan are examples of this type of deposit.

A description of geological characteristics related to major important lead-zinc occurrences throughout the world is presented in the appendix for countries of six continents. Countries having a small percentage of the total world lead-zinc resource are not discussed.

MINING METHODS AND OPERATING COSTS

Lead and zinc ores are primarily exploited by underground mining methods. Of the 235 market economy deposits investigated, 211 were analyzed as underground operations, 134 of which were producing mines. Producing mines account for approximately 46 pct of the zinc and 66 pct of the lead and silver potentially available from all deposits evaluated.

The deposits were divided into six general mining method categories for analysis. These categories are surface, open stope, filled stope, caving, shrinkage stope, and combinations of underground categories. Figure 5 and table 17 show annual ore capacity information by specific mining method for producing mines and undeveloped deposits. The 145 producing mines have a total ore capacity of 113 million t/yr with an average capacity of 780,000 t/yr. About 45 pct of this annual capacity is from small mines producing less than 1 million t of ore per year, and approximately 85 pct of the small mine capacity is from underground operations. Open stope is the most common mining method, accounting for nearly 31 pct of the annual production capacity of producing mines.

Undeveloped deposits have a potential production capacity of 84 million t of ore per year, 73 pct of which would likely be produced by underground methods. As shown, production using underground methods would be spread nearly equally between combined, filled stope, and open stope methods with the remainder using caving and shrinkage methods. About 42 pct of the potential capacity would be from small mines having capacities of less than 1 million t of ore per year.

The selection of a mining method for the exploitation of a mineralized body depends on a number of factors. A few of the most important are depth, geometry, structure, and attitude of the deposit. Additional factors are strength of the mineralized body and surrounding wall rock. Climate and location may influence the decision to go with an underground rather than surface method because of severe weather

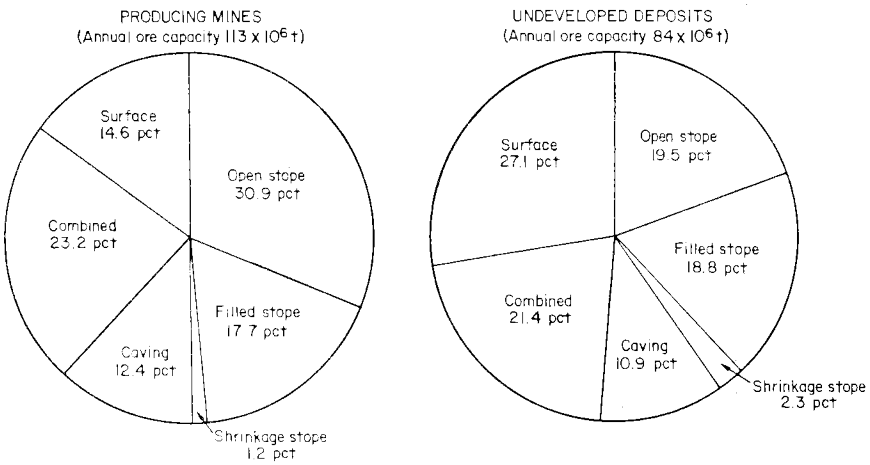

Figure 5.—Share of annual ore capacity, by mining method, for producing and undeveloped lead and zinc mines and deposits.

Table 17.—Mining methods and costs for producing and undeveloped lead and zinc mines and deposits

	Producing				Undeveloped			
	Mines-deposits	Annual ore capacity, 10^3 t		Cost per metric ton of ore	Mines-deposits	Annual ore capacity, 10^3 t		Cost per metric ton of ore
		Average	Total			Average	Total	
Surface[1]	11	1,500	16,500	$7.40	13	1,760	22,860	$9.30
Open stope	39	900	35,000	12.70	33	500	16,390	15.20
Filled stope	34	590	20,070	21.70	17	930	15,880	24.70
Caving	23	610	14,090	17.40	7	1,310	9,160	18.10
Shrinkage	4	360	1,420	26.60	3	640	1,920	20.20
Combined underground	34	770	26,260	23.70	17	1,060	18,040	13.90
Total or average	145	780	113,360	18.40	90	940	84,250	17.90

[1] Average stripping ratios — producing mines, 4.4:1; undeveloped deposits, 3.3:1. Average operating cost per metric ton of material moved — producing mines, $1.40; undeveloped deposits, $2.20.

conditions or proximity to populated areas or bodies of water (lakes, rivers, oceans, etc.).

SURFACE MINING

Surface mining requires a relatively shallow deposit with the stripping ratio (tons of waste rock to tons of ore) normally under 5:1. A typical surface lead-zinc mine uses rotary blasthole drilling machines to drill the blasting rounds, which are charged with ANFO. The blasted ore is loaded with either diesel-electric shovels or front-end loaders into trucks for haulage to the mill. (At Pine Point in the Northwest Territories, Canada, a dragline is used to remove and dispose of blasted overburden prior to mining ore.) For surface operations, average mine recovery is 90 pct with a 4-pct dilution factor.

Eleven producing surface mines were evaluated for this study, five of which were small operations averaging 340,000 t/yr ore capacity while the six larger operations averaged nearly 2.5 million t/yr. Thirteen undeveloped deposits were evaluated as potential surface operations. Nine of these deposits averaged 510,000 t/yr ore capacity while the remaining four deposits averaged nearly 4.6 million t/yr.

Surface mine operating costs are dependent on a wide range of variables, such as location and physical characteristics of the deposit and degree of mechanization. High mining costs per ton of ore for some mines are due to their remote location where costs of labor, supplies, and power are high. Large-capacity mines tend to be highly mechanized, efficient operations. Smaller capacity mines, on the other hand, tend to be more labor intensive and require higher ore grades to operate profitably. An important cost factor for surface mines is the stripping ratio, which measures the tons of waste which must be mined to recover each ton of ore.

The 11 producing mines have an average mining cost of $7.40 per metric ton of ore ($1.40 per metric ton of material) with an average stripping ratio of 4.4:1 (table 17). Costs for the undeveloped deposits average $9.30 per metric ton of ore ($2.20 per metric ton of material) with an average stripping ratio of 3.3:1. Estimated undeveloped mining costs per metric ton of ore average 25 pct greater than producing mines.

UNDERGROUND MINING

Underground mining method selection depends primarily on the attitude, depth, and dimensions of the mineralized body as well as the strength of the wall rock and mineralized body. The mining cycle for underground mining is similar from one mining method to another with type of equipment and degree of mechanization being the major variables. Drilling is performed by jackleg drills in smaller mines while jumbo drills are used in the larger, more mechanized mines. Dynamite, in the form of cartridges, is normally used as the blasting agent, and it is initiated by electric blasting caps. Loading of broken ore and waste is performed by diesel or electric load-haul-dump (LHD) machines in the more mechanized mines while the smaller mines use overshot mucking machines and manual shovel loading of ore carts. Transportation of ore and waste within the mine is primarily by truck or train with ore passes used to transfer material to the main haulage levels. In some cases, when the haul distance is relatively short, LHD machines perform both the loading and transportation functions.

Access to underground mines is either by adit, incline, vertical shaft, or a combination of the three. Mode of access depends on the local topography and depth to the working areas. Shallow deposits or deposits in mountainous terrain may be accessed by adits or inclines while deeper deposits invariably are accessed by shafts.

Open stope mining is characterized by strong and competent ore and country rock requiring a minimum of artificial support during the mining cycle. A horizontal to shallow dipping tabular ore body is developed by a series of interconnected rooms excavated in a regular or irregular pattern with pillars left for support. This mining method is well suited for a high degree of mechanization because of large openings that make the access of large capacity equipment possible.

Room-and-pillar and breast stoping are the principal types of open stope mining used in lead and zinc mining. All of the Missouri lead-zinc mines and a majority of the Tennessee zinc mines use the room-and-pillar mining method. Open stope mining accounts for 31 pct of producing and 19 pct of potential undeveloped annual ore capacity in market economy countries.

Filled stope methods are used when the country rock or the mineralized body or both are too weak to allow excavated openings to remain open during the mining cycle. Some form of cut-and-fill operation is employed to provide the necessary support for the stope walls and back. Following the drilling, blasting, and loading operations in the mining cycle, the stope is backfilled with either waste rock or the sand portion of classified mill tailings. Both horizontal and inclined cut-and-fill stope methods and one square-set operation are included in the filled stope category. Approximately 18 pct of producing and 19 pct of potential undeveloped annual ore capacity from underground mines in market economy countries is from filled stope methods.

Caving methods require the mineralized body to be weak enough to cave because of gravity once support is removed. Drilling and blasting is restricted to development work. The loading and hauling operations are essentially the same as other underground methods with similar degrees of mechanization. Caving methods provide 12 pct of the producing and 11 pct of the potential undeveloped annual ore capacity.

Shrinkage stoping is similar to cut-and-fill stoping except that the broken rock filling the stope during the mining cycle is ore instead of waste or mill tailings. The ore is drilled and blasted in horizontal slices on a steeply dipping tabular ore body. The broken ore becomes the working floor for subsequent drilling. Sufficient ore is removed from the bottom of the stope to maintain an adequate working space from which to drill the next slice. One of the drawbacks to using this method for lead and zinc ores is that the high pyrite and other sulfide content of many deposits tends to oxidize in the stope causing poor flotation recovery in the mill. Only 1 pct of the producing and 2 pct of the proposed undeveloped annual ore capacity is from shrinkage method operations.

Some mines use a combination of mining methods because of the difference in physical conditions from one part of the deposit to another. Mining methods may change through time because of economic considerations to maintain or improve the competitiveness of an operation. Approximately 23 pct of the producing and 21 pct of the proposed undeveloped annual ore capacity is from mines that use or may use a combination of mining methods.

Operating costs were also estimated for the 211 underground lead and zinc mines and deposits, 134 of which were producing as of January 1981. Individual deposit characteristics, such as location, stope width, depth, rock support requirements, and degree of mechanization all contribute to creating a wide range of operating costs.

Among producing mines, open stope is the most common underground method with an average capacity of 900,000 t/yr and the lowest underground mine operating cost at $12.70 per metric ton. The shrinkage method, with an average mine operating cost of $26.60 per metric ton of ore, is the highest cost method and has the lowest average capacity, 360,000 t/yr.

BENEFICIATION METHODS AND OPERATING COSTS

With the exception of the high-grade Sterling Mine in New Jersey and the Aladag Mine in Turkey, which produce direct shipping ore, all of the properties evaluated for this investigation use conventional crushing, grinding, and differential flotation as the primary beneficiation method. Individual flowsheets will differ in detail because of characteristics of the ore and number of concentrates recovered but all will have the same basic steps. Figure 6 is a simplified basic flowsheet for a typical lead-zinc-copper flotation mill. The ore is crushed, ground, and classified prior to flotation. Sometimes a heavy media separation circuit follows the crushing circuit to remove waste prior to grinding. After flotation, the concentrates are thickened, filtered, dried, and stored for shipment.

As many as three concentrates (lead, zinc, and copper), are generally produced in the flotation circuit. Zinc in the form of sphalerite is depressed, while copper in the form of chalcopyrite, and lead in the form of galena, are floated. The copper and lead concentrates are then separated by floating copper followed by cleaning the copper and lead concentrates. Tails from the first stage of flotation become the feed to the zinc flotation circuit. The zinc concentrate is cleaned and all three concentrates are subsequently thickened, filtered, and dried.

When the grind sizes are very small (minus 200

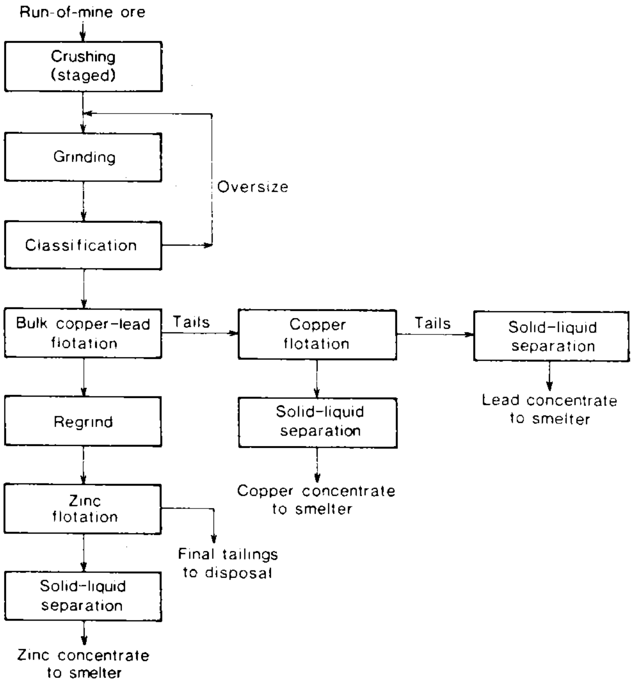

Figure 6.—Basic flowsheet for a typical copper-lead-zinc flotation mill.

mesh) because of fine sulfide grain sizes or intimate ore mineral associations, it is not practical to produce separate concentrates owing to poor liberation of the lead and zinc minerals. This situation would result in very poor recoveries and/or very low quality concentrates if separate concentrate production were attempted. In such cases, a bulk lead-zinc or lead-zinc-copper concentrate is produced. Further treatment would most likely be in an Imperial Smelting Corporation blast furnace (Imperial smelting furnace), which is designed for handling bulk lead-zinc concentrates.

Table 18 shows average estimated milling costs by ore capacity range. The number of concentrates produced, grinding size, and power and labor rates are a few of the more important factors affecting these costs.

Average mill operating costs range from $6 per metric ton of ore for operations with annual ore capacities greater than 2 million t to $8.60 per metric ton of ore for operations with annual ore capacities less than 500,000 t.

Table 18.—Estimated average mill capacity and operating cost

Mine ore capacity, 10^6 t/yr	Mines-deposits	Mill ore capacity, 10^3 t/yr	Cost per metric ton of ore
<0.5	107	290	$8.60
0.5 to 1.0	79	680	6.70
1.0 to 2.0	27	1,370	6.10
>2.0	21	3,580	6.00
Total or av.	234	840	6.60

Most lead and zinc deposits in the United States are metallurgically simple and tend to be at the lower end of milling operating costs. With the exception of Ducktown, the Tennessee zinc deposits are essentially single mineral deposits and the Missouri lead-zinc deposits are primarily coarse-grained galena with low sphalerite content. The higher cost operations are primarily due to complex ores that require extensive grinding and separate flotation circuits to recover separate, clean, marketable concentrates of lead, zinc, and copper.

SMELTING AND REFINING

As of 1981, world lead smelter capacity was 4,765,000 t and lead refinery capacity was 4,699,000 t (*3*, p. 7). The market economy countries had an estimated 3,257,000 t of lead smelting and 3,228,000 t of lead refining capacity in 1981. Lead smelting technologies include the conventional blast furnace, Imperial smelting furnace, and electric furnace processes. Lead refining technologies use both pyrometallurgical and electrolytic processes.

World zinc refining[6] capacity in 1981 was 7,477,000 t (*4*) of zinc, of which 5,839,000 t was from market economy countries. Zinc refining technologies utilize electrolytic, Imperial smelting furnace, electrothermic, and horizontal and vertical retort techniques for the recovery of zinc from concentrates. Table 19 shows a breakdown of capacities by smelting and refining methods by region.

The relative importance of the various extractive metallurgical techniques used in the lead and zinc industry has changed significantly in the past two decades. Lead smelting by conventional blast furnace technology has increased from 80 to 89 pct from 1968 to 1981 while electric furnace processes have decreased in relative importance by the same amount (table 20). The Imperial smelter furnace has remained unchanged in overall importance, accounting for about 8 pct of capacity. The trend in lead refining is to pyrometallurgical versus electrolytic, with an increase of 8 pct from 1968 to 1981 for the pyrometallurgical process production capacity. An estimated 78 pct of lead refining capacity utilizes pyrometallurgical methods.

Zinc extraction technology has undergone a major shift towards electrolytic refining away from horizontal and vertical retort technology (table 21). The technological reasons for this shift are reduced recovery, low energy efficiencies, and high levels of pollution effluents and emissions from the horizontal and vertical retorting plants. Electrolytic methods

Table 19.—Market economy country 1981 lead and zinc smelting and refining capacity, by region, thousand metric tons metal

	North America	South America	Europe	Africa	Asia	Oceania	Total
Lead smelting (furnace):							
Conventional blast	1,212	207	717	150	235	380	2,901
Imperial smelting	0	0	144	30	49	30	253
Electric	0	0	55	0	48	0	103
Total	1,212	207	916	180	332	410	3,257
Lead refining:							
Pyrometallurgical	934	141	944	180	80	230	2,509
Electrolytic	309	90	50	0	270	0	719
Total	1,243	231	994	180	350	230	3,228
Zinc refining:							
Electrolytic	[1]1,280	294	1,804	213	848	260	4,699
Imperial smelting furnace	0	0	389	34	136	70	629
Electrothermic	77	25	18	0	125	0	245
Horizontal retort	100	0	25	0	0	0	125
Vertical retort	0	0	25	0	116	0	141
Total	1,457	319	2,261	247	1,225	330	5,839

[1] Includes capacity of Luis Potosi, Mexico, zinc refinery that started production in 1982.

Sources: Bureau of Mines data and reference 9.

Table 20.—Comparison of 1968 and 1981 lead smelting and refining methods, share of production, percent

Process	1968	1981
Smelting (furnace):		
Conventional blast	80	89
Imperial smelting	8	8
Electric	12	3
Refining:		
Pyrometallurgical	70	78
Electrolytic	30	22

Sources: Bureau of Mines data and reference 10.

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[6] Zinc refining, as used in this investigation, refers primarily to electrolytic zinc refining but does include some zinc recovered through pyrometallurgical smelting technology.

Table 21.—Comparison of 1958, 1968, and 1981 zinc refining methods, share of production, percent

Process	1958	1968	1981
Electrolytic	50	56	81
Imperial smelting furnace	8	11	11
Electrothermic	3	4	4
Horizontal retort	32	15	2
Vertical retort	7	14	2

Sources: Bureau of Mines data and reference 10.

Table 22.—Typical smelter and refinery recoveries and product grades, percent

Concentrate and commodity	Smelter		Refinery	
	Recovery	Grade	Recovery	Grade
Zinc:				
Zinc	NAp	NAp	95	99.9
Cadmium	NAp	NAp	90	99.95
Gold	NAp	NAp	97	99.99
Silver	NAp	NAp	97	99.99
Lead	NAp	NAp	97	99.9
Lead:				
Lead	97	98.5	99	99.9
Gold	99	NAp	99.9	99.99
Silver	99	NAp	99.9	99.99
Copper:				
Copper	97	98.5	99	99.9
Gold	99	NAp	99.9	99.99
Silver	99	NAp	99.9	99.99
Bulk lead-zinc:[1]				
Lead	95	98.5	99	99.9
Zinc	78–91	98.5	99	99.9
Silver	99	NAp	99.9	99.99
Gold	99	NAp	99.9	99.99

NAp Not applicable. [1] Imperial smelting furnace.

presently account for about 81 pct of market economy and 84 pct of U.S. zinc refining capacity.

Typical smelter and refinery recoveries and product grades that can be expected for zinc, lead, copper, and bulk lead-zinc concentrates are listed in table 22. These are averages of values used in the evaluation of individual operations. Zinc recovery from zinc concentrates ranged from 90 to 97 pct and lead recovery from lead concentrates ranged from 92 to 98 pct. The range in lead recoveries from a bulk lead-zinc or lead-zinc-copper concentrate processed by the Imperial smelting furnace did not differ significantly from that experienced with a simple lead concentrate, but zinc recovery from a bulk lead-zinc concentrate ranged considerably lower at 75 to 85 pct. This recovery could be increased by fuming the furnace slag for additional zinc, lead, and cadmium recovery. Copper recoveries generally range from 95 to 98 pct.

LEAD SMELTING

Conventional Blast Furnace

The most widely used method for producing metallic lead is the blast furnace, which accounts for 89 pct of market economy country lead production capacity (table 20). Figure 7 shows a simplified schematic of a conventional blast furnace operation. Lead sulfide concentrate feed is first sent through a

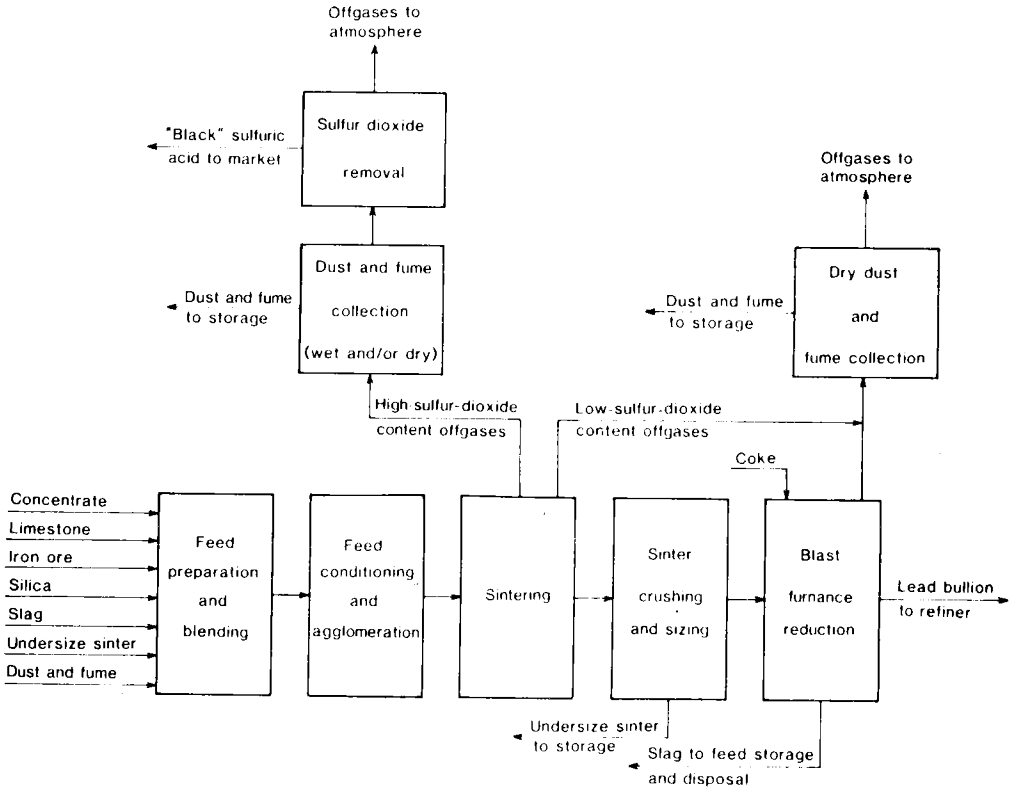

Figure 7.—Simplified schematic of a typical lead smelter using conventional blast furnace technology.

sintering plant to form sinter, a hard porous material suitable for charging to the blast furnace, and to remove most of the sulfur primarily as SO_2 gas. Generally, dust and fume containing lead, zinc, and cadmium oxide are collected in a baghouse and returned to the sinter plant. The sulfur dioxide in the offgas may report to a contact-type sulfuric acid plant or may be dispersed to the atmosphere through a tall smelter stack.

The sinter is charged with coke and fed to the blast furnace where it is reduced to lead and collected at the hearth off of the furnace. Molten slag is tapped above the lead and is normally granulated for return to the sintering plant or to slag dumps. Crude lead is either tapped from the bottom of the settler or recovered via a leadwell to a drossing ladle for delivery to the drossing section of the refinery. The locations of currently operating conventional lead blast furnace smelters in the United States are Boss, MO (AMAX-Homestake), Glover, MO (ASARCO), Herculaneum, MO (St. Joe), East Helena, MT (ASARCO), and El Paso, TX (ASARCO).

Imperial Smelting Furnace

Imperial smelting furnace technology was developed in the 1950's to treat combined lead and zinc concentrates, bulk lead-zinc concentrates, and concentrates of oxidized lead and zinc minerals. Products are standard zinc grade metal, silver-lead bullion, and cadmium-bearing sludge. Approximately 8 pct of the lead production capacity in market economy countries is treated by this method (table 20).

The Imperial smelting furnace is basically a conventional lead blast furnace with a zinc recovery section added (fig. 8). The concentrate feed is first sent through a sintering plant to form lead- and zinc-bearing sinter and partially remove the sulfur and cadmium in the offgases. The cadmium is contained in a sludge collected in the gas scrubbing system and recovered in a separate refinery. Sulfur dioxide is primarily converted to sulfuric acid with some loss through the stack. The lead-zinc sinter is treated in an Imperial smelting blast furnace where the lead and zinc are reduced to metal. Zinc is volatilized and collected in the condenser section while the lead is tapped from the bottom of the furnace as crude lead for further refining. Zinc recovery in the condenser is discussed in more detail in the "Zinc Refining" section of this report.

There are currently eight Imperial smelting furnaces operating in market economy countries. These are located in Australia, France, Federal Republic of Germany, Italy, Japan (2), United Kingdom, and Zambia. Brunswick Mining and Smelting Co. converted Canada's only Imperial smelting furnace, in New Brunswick, to a conventional lead blast furnace in 1972.

LEAD REFINING

The purpose of lead refining is to produce refined lead (99.99 pct Pb) and to recover metal byproducts. Two methods of lead refining, pyrometallurgical and electrolytic, are in use in the lead industry. The pyrometallurgical method accounts for approximately 78 pct of market economy country primary lead refining capacity (table 20). The electrolytic refining method, used in Canada, Italy, Japan, and Peru makes up the remaining 22 pct capacity. A brief description of these two processes follows.

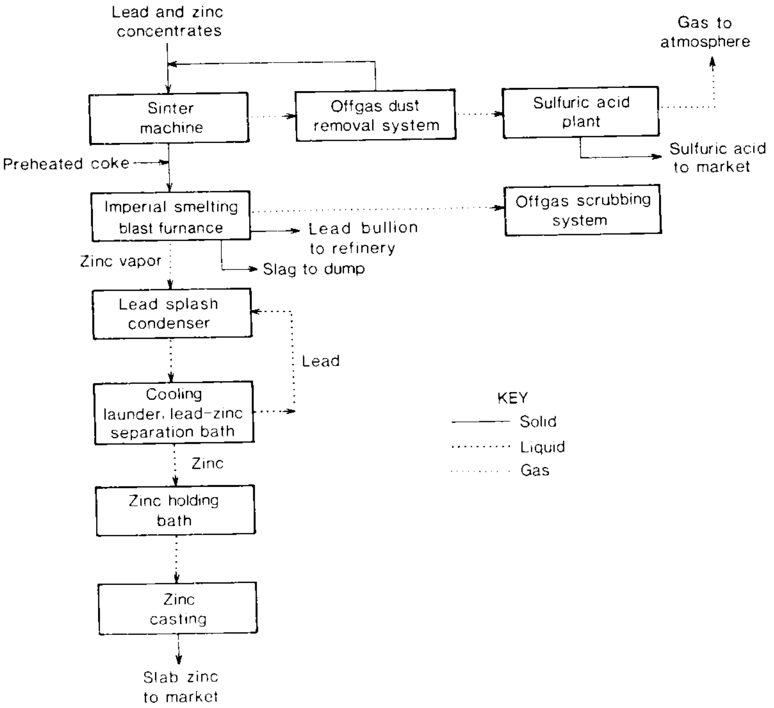

Figure 8.—Simplified schematic of an Imperial smelting furnace plant.

Pyrometallurgical

Pyrometallurgical refining starts with the copper drossing of molten crude lead to remove copper as a result of cooling and treatment with elemental sulfur. The next step is the softening step, which removes any impurities of antimony, arsenic, and tin. Oxygen-enriched air is bubbled through the molten bullion to form a dross comprising lead oxide with the oxides of these elements. The dross is treated at the refinery in a barrel furnace with coke to recover the lead and to produce an antimony-rich slag. These first two steps are normally performed as part of the blast furnace operation at the smelter for convenience even though they are the first steps in the lead refining process.

Next, the molten bullion is desilverized by adding zinc. Silver and gold form an alloy with the zinc, which floats to the top of the melt as a crust where it is skimmed off. The zinc crusts are retorted to recover the zinc by volatilization. The remaining material, which comprises lead, silver, and gold, is roasted in a cupeling furnace and the lead is oxidized to litharge. The litharge is returned to the blast furnace and the remaining gold-silver dore is sent elsewhere for parting.

The zinc remaining in the bullion after desilverization is normally removed by vacuum distillation for reuse in the desilverization process. The final refining step is accomplished by adding caustic soda to remove any remaining antimony and zinc; the dross thus formed is recycled to the sinter plant. The final lead product is 99.99+ pct lead and is cast into ingots or pigs for shipment to market. A simplified flowsheet for pyrometallurgical refining is shown in figure 9.

Electrolytic

Electrolytic lead refining starts with the decopperized molten bullion from the blast furnace being cast into anodes. Refined lead, usually in the form of rejected bars or blocks, is cast into the cathode starter sheets (although other metals, such as aluminum can also be used for the cathode starter sheets). The anodes and cathodes are placed in the electrolytic cells, and the cells are filled with electrolyte, normally hydrofluosilicic acid and lead fluosilicate. Electric current is applied and it passes from the anodes through the electrolyte to the cathodes. Lead is transferred from the anodes to the cathodes during this process. Finished cathodes grading 99.99+ pct lead are melted and cast into shapes for market. Slimes with high values of antimony, bismuth, silver, gold, and some residual lead adhere to the scrap anodes. The slimes are removed from the anodes and sent elsewhere for further treatment, and the scrap anodes are returned to the smelter.

ZINC REFINING

Electrolytic

Electrolytic refining accounts for over 80 pct (table 21) of the current zinc production capacity in market economy countries. Zinc sulfides, primarily in the form of sphalerite, are roasted (usually in fluidized bed roasters) to convert the sulfides to an acid-soluble sulfate and convert the sulfur to sulfur dioxide. This sulfur dioxide is removed with the roaster offgases

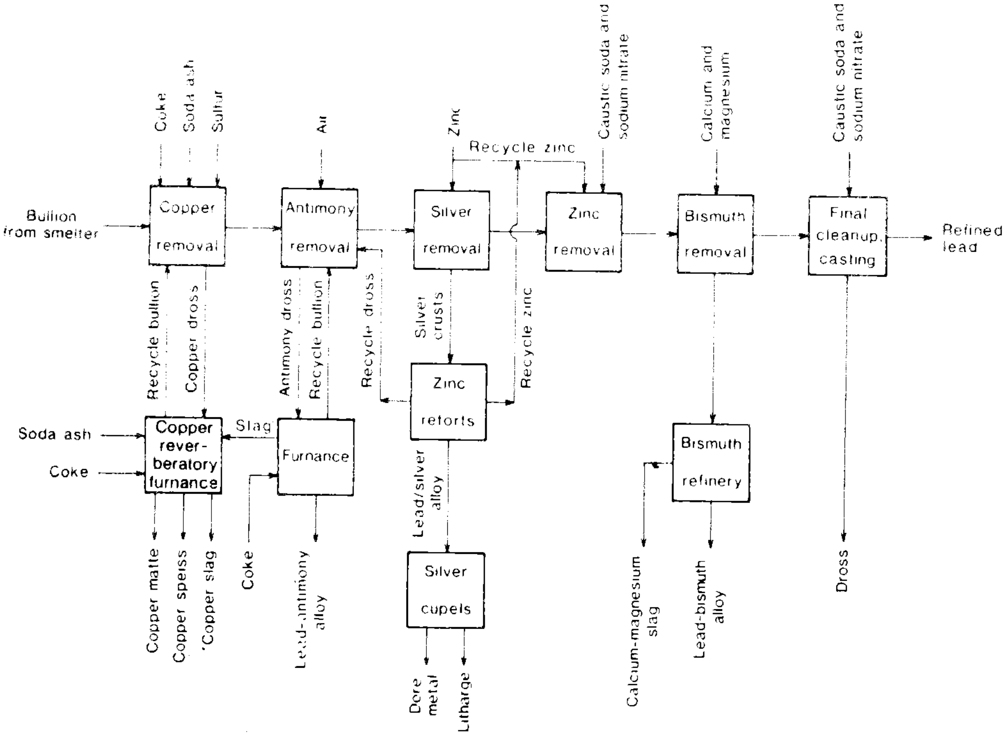

Figure 9.—Simplified schematic of pyrometallurgical lead refining.

and treated in a contact-type acid plant to produce sulfuric acid. Calcine formed by roasting is treated in a sulfuric acid leach plant. Residues that settle out as a sludge in the leach plant are treated separately for the recovery of copper, cadmium, lead, silver, cobalt, and tin. The solution containing dissolved zinc is purified through several stages to remove residual copper and cadmium prior to electrowinning. The purified leach solution is mixed with electrolyte and undergoes the electrolysis process in electrolytic cells in similar fashion as described in the "Lead Refining" section. The electrolytic zinc process differs from the lead process in that the transfer of zinc to the cathode is effected from the electrolytic solution rather than the anode. The anodes in an electrolytic zinc plant are fabricated from sheets containing 99 pct lead and 1 pct silver. The cathode starter sheets are normally fabricated from aluminum sheet. The cathodes (which grade 99.99+ pct zinc) are stripped, melted, and cast into shapes for market. A simplified flowsheet of the refining process is shown in **figure 10.**

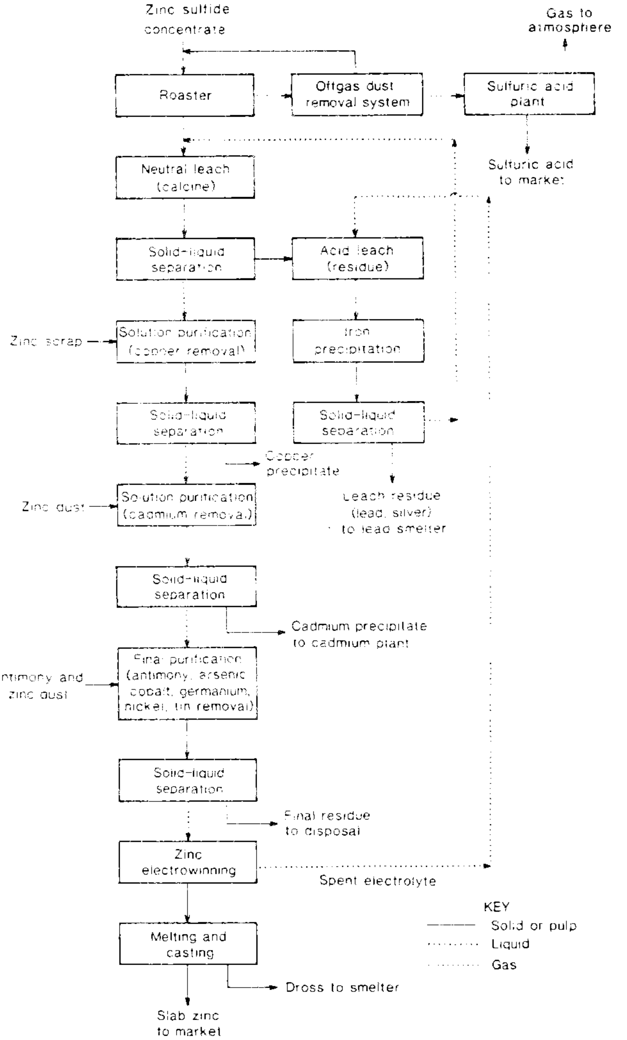

Figure 10.—Simplified schematic of an electrolytic zinc refinery.

Imperial Smelting Furnace

The Imperial smelting furnace process provides 11 pct of market economy country zinc capacity (table 21). The lead recovery portion of this extraction was discussed previously. In this process, the zinc vapor is removed from the top of the lead blast furnace and passed through a condenser where the zinc is mixed into a molten lead spray. The molten lead-zinc mixture is cooled until the zinc separates from the lead and rises to the top of the holding tank. Zinc is recovered as prime western grade (98.0 to 98.5 pct zinc) which can be further refined by distillation to special high-grade specifications equal to electrolytic zinc (99.99 pct zinc). The molten lead is recycled to the condenser. This method of zinc extraction provides a lower zinc recovery (approximately 96 pct) than the electrolytic process but provides the advantage of being able to treat lead-zinc ores that do not respond well to differential flotation and the ability to recover the lead and silver values in zinc concentrates in a single process, whereas the electrolytic process must rely on retreatment of lead and silver residues in a blast furnace.

Electrothermic

The electrothermic process for zinc extraction was first developed by St. Joe Minerals Corp. and put into commercial operation during 1930 at Monaca, PA. The relative importance of this method has remained the same over the last two decades at 4 pct of world market economy country zinc extraction capacity (table 21). The zinc sulfide concentrate is first roasted then sintered in preparation for the charging of the resistance-type electric furnaces; lead and cadmium are removed during roasting and sintering. The flow of current through the sintered ore and coke charge develops the energy required for smelting at the reaction sites. To produce zinc oxide, the furnace vapors are oxidized with air, or to produce zinc metal the furnace vapors are bubbled through a zinc bath where the zinc is condensed. A simplified flowsheet for the electrothermic process is presented in **figure 11.**

Horizontal Retort

The horizontal retort process is one of the oldest methods used for zinc metal recovery with commercial adaptation as early as 1800. This process represented only 2 pct of market economy country zinc production capacity in 1981 as compared to 32 pct in 1958 (table 21). The decline in use is primarily the result of increased labor and energy costs, and the control of particulate emissions.

Zinc sulfide concentrates are first calcined in multiple hearth roasters. Roaster gases are cleaned in electrostatic precipitators and sent to an acid plant to produce sulfuric acid or are discharged to the atmosphere through the stack. The calcine is sintered to produce a sinter product suitable for feed to the horizontal retorts. Cadmium is volatilized in both the roasting and sintering operations and is collected as residue (from roasting) and fume (from sintering)

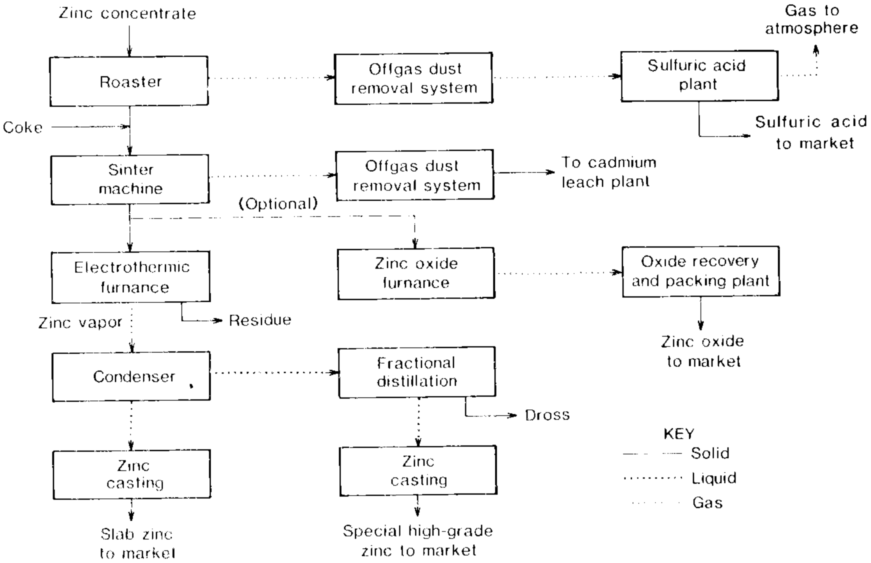

Figure 11.—Simplified schematic of an electrothermic zinc plant.

for further processing and recovery. The retorts are manually filled with sinter mixed with pulverized coal and charged in a batch process to volatilize the zinc. The zinc in the charge is reduced and distilled in the gas-fired furnaces, and the distilled zinc is collected in condensers and cast into slabs of prime western zinc, which can be further refined in a distillation process to produce a special high-grade product (99.99 pct zinc) for market. Only two horizontal retort plants are still in operation in market economy countries, both of them in Mexico.

Vertical Retort

Vertical retort plants have faced a decline in use similar to the horizontal retort plants and for similar reasons. Production capacity as a percentage of total market economy country capacity has dropped from 14 pct to 2 pct between 1968 and 1981 (table 21). Initial development of both the horizontal and vertical retort processes revolved around the availability of a cheap supply of natural gas.

Modern vertical retorts were developed as a modification of horizontal retorts with the vertical retort configuration having the advantages of continuous, mechanized operation giving higher production capacity at a lower unit cost than the batch-type process of the horizontal retort. The feed preparation for the vertical retort is similar to that of the horizontal retort except that the smelting charge is supplied in the form of briquettes. The briquettes, made from a sinter, bituminous coal, anthracite fines, and clay mixture, are first processed in a coking furnace for strengthening. They can then withstand handling and introduction into the vertical retort without disintegrating. The vertical retort operates on a continuous basis with the introduction of new briquettes into the charge column to replace the reduced briquettes that are continuously withdrawn from the bottom of the retort. The zinc vapor and reaction gases produced flow upward through the retort and escape via a duct leading from an upper extension of the retort and are drawn into a zinc vapor condenser from which the liquid zinc is withdrawn for casting as prime western zinc or further refined to 99.99+ pct purity. A simplified flowsheet for the process is illustrated in figure 12.

The United States has one vertical retort plant at Palmerton, PA, that is currently closed and not expected to reopen. Two other plants are still operating in market economy countries, one at Anby, France, and the other at Miike, Japan.

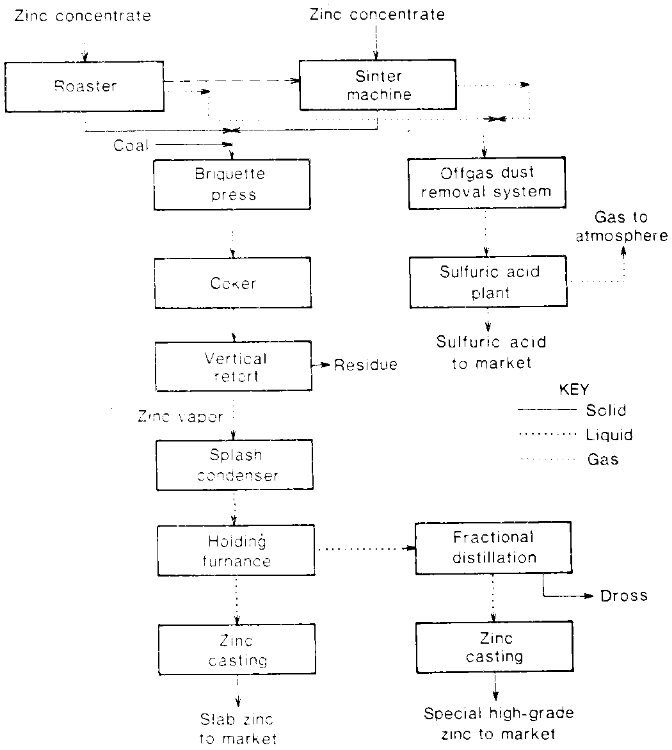

Figure 12.—Simplified schematic of a vertical retort zinc plant.

OPERATING COSTS

Operating costs for mining, beneficiating, transportation, and smelting-refining were estimated for each mine or deposit. Where possible, actual operating costs were collected from published sources or contacts with company personnel. When actual costs were not available, costs were either estimated using standardized costing techniques or derived from the Bureau's cost estimating system (CES) (*2*).

The average total cost calculated for each of the mines and deposits investigated covers mining, beneficiation, transportation, smelting-refining, capital recovery, taxes, and profit. These costs often vary greatly depending on such factors as size of the operation, mining method, deposit location, stripping ratio, depth of the ore body, mill feed grades, complexity of mill feed, processing losses, energy and labor rates, productivity, and country and local tax structures.

The operating costs presented in this section are weighted averages on a per-metric-ton-of-ore basis for mine and mill operating costs and per-metric-ton-of-concentrate basis for transportation costs and smelting-refining treatment charges.

MINE AND MILL

Weighted-average surface and underground operating costs, by country, for producing and undeveloped lead and zinc deposits are presented in this section. Costs for some countries have been aggregated to avoid disclosing individual deposit data. Costs are shown in dollars per metric ton of ore for mining and milling, and per pound of recoverable metal for each stage of production.

Lead Mines and Deposits

The operating costs for the 22 producing lead mines included in table 23 averaged $12.00 per metric ton of ore for mining and $5.40 for milling. Mine operating costs in the United States averaged about one-half the cost of mining in foreign countries, primarily because the Missouri room-and-pillar mines are highly mechanized, low-cost producers. Mill operating costs for U.S. lead mines are lower than foreign costs (averaging $5.20 per metric ton of ore compared with $6.30), because of the simple nature of domestic ores which require less processing. For the same reasons mentioned for producing mines, the five undeveloped deposits in the United States have an average mine operating cost approximately one-half that of the three undeveloped foreign deposits. Mill operating costs would average almost the same for foreign and domestic undeveloped deposits. Average lead ore grades for producing domestic and foreign mines are nearly equal, but grades for undeveloped domestic deposits average 70 pct higher than those of foreign deposits.

Zinc Mines and Deposits

The operating costs for the 109 producing zinc mines included in table 24 averaged $17.10 for mining and $8.20 for milling. Mine operating costs in the United States averaged about 80 pct of the cost of mining in foreign countries (although Spain averaged only 40 pct of the U.S. mining cost because most of the capacity was from low-cost surface mines), primarily because of the Tennessee room-and-pillar mines, which are highly mechanized, low-cost producers. The average United States mill operating cost is 35 pct lower than that for foreign producers ($5.50 versus $8.50), because of the simple mineralogy of the Tennessee mine ores, which require less processing.

The 77 undeveloped zinc deposits have an estimated average mine operating cost of $13.80 and a mill operating cost of $6.00 per metric ton of ore. U.S. undeveloped deposit mining operating costs are estimated to be 30 pct less than foreign costs (averaging $11.20 compared with $16.20 per metric ton ore), because of the high degree of mechanization and productivity inherent in the Tennessee room-and-pillar operations. Mill operating costs do not vary significantly between U.S. and foreign deposits.

Table 23.—Estimated mine and mill operating costs for producing and undeveloped lead mines and deposits

	Mines-deposits	Recoverable ore,[1] 10^3 t	Average ore grade			Production potential[3]			Operating cost per metric ton		
			Zinc, pct	Lead, pct	Silver, [2]g/t	Zinc, 10^3 t	Lead, 10^3 t	Silver, 10^3 tr oz	Mine	Mill	Total
Producing mines:											
Foreign countries	13	116,288	1.75	5.86	64.0	1,375	6,005	203,970	$18.30	$6.30	$24.60
United States	9	295,690	1.06	5.72	[4]23.4	2,208	16,105	191,384	9.80	5.20	15.00
Total or average	22	411,978	1.26	5.76	34.8	3,583	22,110	395,354	12.00	5.40	17.40
Undeveloped deposits:											
Foreign countries	3	92,301	.73	2.85	29.2	438	2,168	64,834	18.20	6.40	24.60
United States	5	41,418	.87	4.87	[5]6.1	247	1,928	7,282	9.70	6.30	16.00
Total or average	8	133,719	.77	3.48	22.1	[6]684	4,096	72,116	15.50	6.30	21.80

[1] Includes mining recovery and dilution.

[2] To convert from grams per metric ton to—troy ounces per short ton, multiply by 0.0291667; troy ounces per metric ton, multiply by 0.0321507.

[3] Includes all mill, smelter, and refinery recoveries over the life of the property.

[4] Silver grades for Missouri mines average 11.0 g/t.

[5] 3 of the 4 Missouri lead-zinc properties have no reported recoverable silver.

[6] Data do not add to total shown because of independent rounding.

Table 24.—Estimated mine and mill operating costs for producing and undeveloped zinc mines and deposits

	Mines-deposits	Recoverable ore,[1] 10^3 t	Average ore grade			Production potential[3]			Operating cost per metric ton		
			Zinc, pct	Lead, pct	Silver, [2]g/t	Zinc, 10^3 t	Lead, 10^3 t	Silver, 10^3 tr oz	Mine	Mill	Total
Producing mines:											
Australia	7	111,200	8.56	6.23	116.6	7,417	5,879	360,192	$23.20	$6.10	$29.30
Canada	13	350,500	6.29	2.90	54.7	17,129	7,746	476,626	15.80	9.90	25.70
Germany, Fed. Rep. of	3	25,000	8.45	2.27	29.0	1,862	405	17,750	25.40	12.10	37.50
Italy	4	30,200	4.16	1.31	13.7	927	312	11,203	15.00	5.60	20.60
Japan	8	62,600	4.21	.74	38.3	2,313	361	55,945	21.20	7.80	29.00
Mexico	15	140,200	4.63	1.82	139.1	4,947	2,132	508,117	20.90	7.00	27.90
Peru	14	100,400	6.78	2.77	108.1	5,347	1,971	252,150	23.20	10.80	34.00
Spain	4	119,400	2.46	.99	27.9	2,204	787	20,250	5.60	9.00	14.60
Other	25	335,600	5.88	1.28	30.0	15,558	4,072	336,015	17.20	7.80	25.00
Total or average	93	1,275,100	5.77	2.35	64.8	[4]57,703	23,665	2,038,255	17.40	8.50	25.90
United States	16	144,300	3.28	.14	2.7	4,140	169	10,210	14.40	5.50	19.90
Total or average	109	1,419,300	5.52	2.12	58.5	[4]61,842	23,834	2,048,465	17.10	8.20	25.30
Undeveloped deposits:											
Australia	5	293,700	9.31	4.53	65.7	15,772	7,585	373,928	13.90	4.60	18.50
Canada	20	261,800	6.32	1.99	44.0	13,118	4,108	268,520	21.40	7.60	29.00
India	3	71,500	4.51	2.07	16.7	2,171	1,001	28,282	24.50	7.10	31.60
Ireland	3	25,000	5.63	1.16	0	1,179	226	0	23.60	9.30	32.90
Other	8	305,200	4.08	.86	35.7	10,876	1,587	240,222	11.50	6.50	18.00
Total or average	39	957,200	6.37	2.39	44.8	[4]43,117	14,507	910,952	16.20	6.30	22.50
United States	38	880,200	4.63	.69	16.9	36,139	5,441	328,658	11.20	5.70	16.90
Total or average	77	1,837,400	5.53	1.58	31.1	[4]79,255	19,947	1,239,610	13.80	6.00	19.80

[1] Includes mining recovery and dilution.

[2] To convert from grams per metric ton to—troy ounces per short ton, multiply by 0.0291667; troy ounces per metric ton, multiply by 0.0321507.

[3] Includes all mill, smelter, and refinery recoveries over the life of the property.

[4] Data do not add to total shown because of independent rounding.

SMELTING AND REFINING

For the purpose of this investigation, all mineral concentrates were treated as if they were shipped to custom smelters-refineries. The cost of smelting and refining includes the treatment charge for processing the concentrates and various deductions and pay-fors on the metal content of the concentrates. Typical treatment charges, deductions, and pay-fors are listed in table 25 for various concentrates processed by the operations evaluated in this investigation.

To determine typical revenues resulting from a concentrate, the grade deduction is first subtracted from the concentrate grade and the result is multiplied by the pay-for percent in decimal form. The resulting quantity is what the smelter will pay for at the current market price minus the price deduction. The price deduction covers any further cost to refine the commodity to a finished product. In the case of lead and copper, the price deduction (normally $0.07 to $0.10 per pound), is incorporated as part of the treatment charge.

Treatment charges and smelter schedules vary significantly from region to region and sometimes from country to country. For example, $150 per metric ton was used as the charge for treating lead and zinc concentrates in Japan while in Europe, charges as high as $200 to $220 per metric ton were used for treating lead concentrate and $180 to $200 for zinc concentrate.

Table 25.—Typical smelter schedules

Commodity	Grade deduction	Percent paid for	Price deduction
ZINC, AV TREATMENT CHARGE—$184/t CONCENTRATE			
Zinc	None	85	None.
Cadmium	0.2 units [1]	60	$1.00/lb
Gold	0.02 oz	75	$5.00/oz.
Silver	3 oz	70	$0.20/oz.
Lead	3 units	50	None.
LEAD, AV TREATMENT CHARGE—$176/t CONCENTRATE[2]			
Lead	1.5 units	95	None
Gold	0.02 oz.	95	$5.00/oz.
Silver	1 oz.	95	$0.20/oz.
Copper	1.5 units	60	$0.40/lb.

Commodity	Grade deduction	Percent paid for	Price deduction
COPPER, AV TREATMENT CHARGE—$130/t CONCENTRATE[2]			
Copper	1 unit	100	None.
Gold	0.02 oz	95	$5.00/oz.
Silver	1 oz.	95	$0.20/oz.
BULK LEAD-ZINC,[3] AV TREATMENT CHARGE. $210/t CONCENTRATE			
Lead	None	85	None.
Zinc	do.	75	Do.
Silver	1 oz	85	Do.
Gold	0.02 oz.	85	Do.
TIN (75 pct), AV TREATMENT CHARGE, $635/t CONCENTRATE			
Tin	1 unit[4]	100	None.

[1] A unit equals 1.0 pct or 22.05 lb.

[2] Treatment charge includes refining charge.

[3] Imperial smelting furnace feed.

[4] For every 0.1 pct tin above or below 75 pct, the unit deduction shall be decreased or increased by 0.01 unit, respectively.

TOTAL PRODUCTION COSTS

Total production costs were determined for the 216 lead and zinc mines in market economy countries and are presented in tables in this section. Mines and deposits having combined surface and underground operations and primary copper operations containing lead and zinc as coproduct or byproduct commodities were not included. Costs are presented on a dollar-per-pound-metal basis and include mine, mill, smelting-refining, other, transportation, and total operating costs as well as taxes, byproduct credits, net cost, and total cost.

Smelting-refining includes processing costs for the primary commodity while other costs include smelting-refining for coproduct and byproduct commodities. Transportation includes transportation costs of all concentrates to the smelter-refinery. Total operating cost is the total of all direct costs before taxes and byproduct credits. The taxes category includes all property, severance, State, and Federal taxes. Revenues from coproduct and byproduct commodities have also been computed and subtracted from total operating cost to arrive at net cost.

Net cost is the average out-of-pocket cost including all operating charges required to produce refined lead or zinc and any credit for byproduct production, but does not include recovery of capital or profit. It reflects the average lead or zinc price at which the mines in the country could break even by covering all production costs. A company may be willing to operate at this price temporarily if it believes the situation will improve in the near future. However, if the company's outlook is bleak, it may temporarily shut down or permanently close the mine and shift its investment to a more profitable venture. An exception is State-owned or State-controlled mines, which may continue to produce at or below this price if the resulting losses are less than those incurred if the mine were closed. (If the mine were closed, the government may have to pay unemployment and other welfare benefits.) Governments also may need the foreign exchange revenues generated by the mine to import other materials needed in their country.

The difference between the net cost and the total cost is that total cost includes recovery of capital and a profit on all investments at a 15-pct DCFROR. For some countries, only a small difference exists since most of the mines have been producing for many years and a large portion of the capital has been written off. For other countries, the difference is significant since new mines have recently begun production and large amounts of capital have yet to be written off.

LEAD

Table 26 compares weighted-average production costs per pound lead for producing and undeveloped deposits in the United States and foreign countries. Costs for producing mines in the United States are comparable to foreign costs except that mining costs and byproduct credits are lower. Mine operating costs average $0.10 per pound lead in the United States compared with $0.17 for foreign countries because of the low cost, highly productive room-and-pillar mining methods used in the Missouri lead mines. However, foreign mines recover this U.S. cost advantage in byproduct credits, which average twice those of domestic mines. As a result, net and total costs for U.S. and foreign mines are nearly equal.

Operating costs for undeveloped deposits in the United States would average slightly higher than producing mines, with a total operating cost before taxes and byproduct credit only $0.04 higher per pound of lead. However, higher capital investments and lower byproduct credits result in a much higher total cost of $0.50 per pound versus $0.27 for producing mines. Taxes for undeveloped domestic deposits are higher than those for producing mines ($0.08 per pound compared with $0.03) because higher incomes are required to provide the stipulated 15 pct DCFROR; thus, aggregate tax payments are generally higher than for producing operations.

Foreign undeveloped lead deposits have high operating costs mainly because of the high costs of

Table 26.—Estimated total production costs for producing and undeveloped lead mines and deposits, January 1981 dollars per pound of lead recovered

	Mines-deposits	Operating costs						Taxes[4]	Byproduct credit	Net cost	Total cost
		Mine	Mill	Smelting-refining[1]	Other[2]	Transport[3]	Total				
Producing mines:											
Foreign	13	$0.17	$0.06	$0.14	$0.05	$0.04	[5]$0.45	$0.04	$0.26	$0.23	$0.30
United States	9	.10	.06	.11	.03	.03	[5].34	.03	.13	.24	.27
Total or average	22	.12	.06	.12	.04	.04	.38	.03	.17	.24	.28
Undeveloped deposits:											
Foreign	3	.36	.13	.15	.08	.11	[5].82	.28	.39	[5].72	1.20
United States	5	.12	.08	.11	.04	.03	.38	08	.12	.34	.50
Total or average	8	.26	.11	.13	.06	.08	.64	.20	28	.56	.87

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[1] Smelting and refining of lead only.

[2] Smelting and refining of all byproduct commodities.

[3] Total transportation cost for all concentrates from mill to smelter and refinery.

[4] Includes all property, State, Federal, and severance taxes, plus any royalty. Undeveloped deposits would require higher income in order to provide the stipulated 15 pct DCFROR; thus, estimated aggregate tax payments are generally higher for undeveloped deposits.

[5] Data do not equal total shown because of independent rounding.

the Black Mountain lead-zinc-silver deposit in the Republic of South Africa. The deposit is a large-tonnage, low-grade deposit proposed for sequential development following depletion of reserves at the Broken Hill Mine. High operating costs, taxes, and a high capital investment (approximately $500 million) result in an average total cost of $1.20 per pound of lead for the three foreign deposits (average total costs without the Black Mountain deposit would drop to $0.55). It should be kept in mind that in many countries, special tax incentives and tax holidays can effectively reduce the tax burden and, consequently, lower the total costs determined for this study.

ZINC

Table 27 shows estimated total production costs per pound of zinc for producing and undeveloped zinc deposits. Mine operating costs for producing mines range from a low of $0.15 per pound in Spanish mines to a high of $0.31 in Mexican mines. The higher cost of underground mining in Mexico and Japan is due to the complex nature of the deposits and small capacity of many of the mines. As discussed earlier, the mining cost per metric ton of ore is lower in the United States than in foreign countries. However, owing to the lower grade of domestic deposits (3.28 pct zinc, compared with 5.77 pct in foreign countries) costs on a per-pound basis are higher.

Mill operating costs range from a high of $0.25 per pound in Spain to a low of $0.05 per pound in Australia. Although U.S. mines had a $3 advantage over foreign mines on a per-metric-ton-ore basis (table 24), this advantage is offset by the lower grade of domestic mines. On a per-pound basis, U.S. and foreign mines are equal, at $0.10.

The average cost to refine zinc ranges from $0.15 to $0.21 per pound of zinc. Japan is represented at the low end of this range as a result of a price support system whereby smelters can offer low terms on custom concentrate contracts because they are guaranteed a price that is higher than the London Metal Exchange (LME) price for product sold to domestic manufacturers. U.S. refining costs average $0.20 per pound, $0.02 greater than foreign zinc refining costs.

Other costs, including smelting and refining of lead and other byproduct commodities, range from $0.04 to $0.16 per pound of zinc. This wide range is due mainly to differences in byproduct grades, which result in additional smelting and refining charges. The mines with high costs in this category usually recover the added cost in the form of byproduct credits.

Total operating costs before taxes and byproduct credits average $0.61 for producing mines. Mexico has the highest operating cost primarily due to high mining costs. However, this high cost is more than compensated for by high byproduct revenues ($0.77 per pound of zinc, principally from silver), which provide Mexico with the lowest net and total cost of any country. High operating costs in Australia and Peru are also offset by high byproduct credits. Byproduct credits for foreign mines average $0.14 per pound greater than for U.S. mines. Net cost for producing mines averages $0.29 per pound, $0.46 in the United States and $0.28 in foreign countries, a difference of $0.18 per pound. As a result, U.S. mines have a long-run weighted-average total cost estimated at $0.58 per

Table 27.—Estimated total production costs for producing and undeveloped zinc mines and deposits, January 1981 dollars per pound of zinc recovered

	Mines-deposits	Operating costs						Taxes[4]	Byproduct credit	Net cost	Total cost
		Mine	Mill	Smelting-refining[1]	Other[2]	Transport[3]	Total				
Producing mines:											
Australia	7	$0.18	$0.05	$0.19	$0.16	$0.03	$0.61	$0.08	$0.56	$0.13	$0.20
Canada	13	.16	.10	.18	.11	.06	.61	.02	.32	.31	.36
Germany, Fed. Rep. of	3	.17	.08	.15	.04	.01	[5].46	.02	.26	.22	.24
Italy	4	.26	.10	.21	.05	.01	.63	.02	.21	.44	.50
Japan	8	.29	.11	.15	.04	.01	[5].59	.01	.20	[5].41	.44
Mexico	15	.31	.10	.20	.11	.04	[5].75	10	.77	[5].09	.16
Peru	14	.22	.10	.17	.06	.05	[5].59	.06	.36	[5].30	.35
Spain	4	.15	.25	.17	.09	.03	.69	.01	.30	.40	.51
Other	25	.20	.09	.19	.07	.02	[5].56	.05	.29	.32	.37
Total or average	93	.20	.10	.18	.10	.04	[5].61	.05	.37	[5].28	.33
United States	16	.26	.10	.20	.07	.02	.65	.04	23	.46	.58
Total or average	109	.20	.10	.18	.09	.04	.61	.04	.36	.29	.35
Undeveloped deposits:											
Australia	5	.13	.04	.19	.12	.05	.53	.15	.26	[5].41	.61
Canada	20	.21	.08	.17	.07	.11	.64	.13	.27	.50	.72
India	3	.40	.12	.19	.08	.03	[5].81	.10	.26	[5].66	.82
Ireland	3	.25	.10	.20	.04	.03	.62	.19	.07	.74	1.02
Other	8	.17	.09	.18	.03	.05	.52	.08	.18	[5].43	.59
Total or average	39	.18	.07	.18	.08	.07	.58	.13	.24	[5].46	.66
United States	38	.16	.08	.18	.03	.06	[5].50	.18	.16	[5].53	.86
Total or average	77	.17	.07	.18	.06	.06	[5].55	.15	.20	[5].49	.74

[1] Refining of zinc only.

[2] Smelting and refining of all byproduct commodities.

[3] Total transportation cost for all concentrates from mill to smelter and refinery.

[4] Includes all property, State, Federal, and severance taxes, plus any royalty. Undeveloped deposits would require higher income in order to provide the stipulated 15 pct DCFROR; thus, estimated aggregate tax payments are generally higher for undeveloped deposits.

[5] Data do not equal total shown because of independent rounding.

pound, $0.17 above the January 1981 LME price of zinc. Italy, Spain, and Japan also have average total costs higher than the January 1981 price.

For most undeveloped deposits zinc could not be produced at a low enough cost to earn a 15-pct DCFROR. The total costs for these deposits average $0.74 per pound of zinc, more than double those of producing mines. Although mining and milling costs for undeveloped deposits would be slightly less than for producing mines, this advantage would be lost in much lower byproduct credits (averaging $0.16 per pound less) and much higher capital costs. U.S. deposits, owing to lower ore grades, would average $0.86 per pound, $0.20 greater than foreign deposits. Taxes for undeveloped deposits would be greater than those for producing mines because higher incomes would be required to provide a 15-pct DCFROR; thus, aggregate tax payments are generally higher than for producing operations.

CAPITAL COSTS

Capital costs reflect the total investment required for those deposits not producing at the time of the study to develop the mine, construct all facilities, and begin production. Capital costs for producing mines are not shown because some of the mines have been producing for many years and a large portion of the initial investment has been depreciated.

Capital costs for exploration, acquisition, development, mine and mill plant and equipment, and infrastructure have been calculated for all deposits. For most deposits, capital costs for smelting and refining are included in the custom operating cost; these costs are not discussed in this section. Capital costs for developing and explored deposits, by type and size of operation, are shown in table 28. All costs are adjusted to January 1981 dollars and converted to dollars per annual metric ton of ore. The costs shown are averages for the deposits by size of operation; actual deposit costs may vary greatly depending on deposit location, characteristics of the ore body, and other factors.

Capital costs were analyzed for 12 undeveloped surface deposits which have a weighted-average annual capacity of 1.9 million t of ore. The four deposits analyzed with annual ore capacities between 500,000 and 1 million t have a very high cost of $221 per annual metric ton of ore capacity because of the large capital requirements for developing three of the properties, which are in Alaska. A more reasonable total cost for less remote deposits of this capacity range would be $85 per annual metric ton of ore.

Capital costs for surface operations with less than 500,000 t annual ore capacity would average $35 million; 500,000- to 1-million-t/yr capacity—$67 million (revised down from the high of $177 million in Alaska); 1 to 2 million—$134 million; and $275 million for deposits with annual capacity greater than 2 million t.

Table 28.—Capital costs of undeveloped lead and zinc deposits, January 1981 dollars per annual metric ton of ore

Ore capacity, 10^6 t/yr	Deposits	Av ore capacity, 10^6 t/yr	Exploration, acquisition, development	Plant and equipment		Infrastructure	Total
				Mine	Mill		
Surface:							
<0.5	4	0.3	$56	$21	$29	$11	$117
0.5 to 1.0	4	0.8	50	42	61	68	221
1.0 to 2.0	1	1.7	28	11	29	11	79
>2.0	3	5.5	4	16	19	11	50
Total or av.	12	1.9	14	19	25	18	76
Underground:							
<0.5	35	.3	35	34	35	13	117
0.5 to 1.0	31	.7	29	30	30	9	98
1.0 to 2.0	6	1.4	35	27	27	83	172
>2.0	6	3.1	24	20	42	11	97
Total or av.	78	.8	30	27	35	21	113

Capital costs were also estimated for 78 undeveloped underground deposits. High total capital cost per annual metric ton of ore for the 1- to 2-million-t/yr capacity range is a result of the remote location of many of the deposits, which would result in very high infrastructure costs. A more reasonable estimate of capital cost per annual metric ton ore capacity for this range would be $95 as opposed to $172. Average capital cost for underground operations with less than 500,000 t/yr ore capacity is $35 million; 500,000 to 1 million—$69 million; 1 to 2 million—$133 million; and for annual capacity greater than 2 million t, $300 million.

AVAILABILITY OF LEAD AND ZINC

An economic evaluation was performed on each of the studied mines and deposits to determine the average total cost of production over its entire producing life. The evaluation uses DCFROR techniques to determine the constant dollar long-run price of the operation's primary commodity so that total revenues (from the primary commodity and byproducts) are sufficient to cover all costs of production, discounted at a prespecified rate of return on all investments. An implicit assumption in each evaluation is that each deposit represents a separate corporate entity. The life of each property was determined by assuming that the property would operate at 100 pct of mine capacity. The mine life covers only the demonstrated resource level.

All capital investments incurred 15 or more years before the cost date of the analysis (January 1981) are treated as sunk costs. Investments incurred during the prior 15 yr have the undepreciated balances entered as a capital investment in 1981. All subsequent investments, reinvestments, operating costs, and transportation costs are expressed in constant January 1981 dollars. Investment and operating schedules are determined as much as possible from published data or plans announced by the companies involved. For those deposits that have been explored, but where no plans to initiate production have been announced, a development plan was assumed. The preproduction period for these explored deposits allows for only the minimum engineering and development time necessary to initiate production. Additional time lags and potential costs involved in filing environmental impact statements, receiving required permits, arranging financing, etc., are not accounted for in the analysis, but may be significant in the developed countries.

The potential tonnage and the average total cost determined over the life of the operation for each of the mines and deposits evaluated in this study have been aggregated onto availability curves that illustrate the potential availability of the studied commodity at different cost levels. Availability curves are constructed as aggregations of the total amount of the studied commodity potentially available from each of the evaluated mines and deposits, ordered from those having the lowest average total cost to those having the highest. The total potential availability of the commodity can be seen by comparing a projected constant-dollar long-run market price to the average total cost values shown on the availability curves.

Availability curves were developed for 186 mines and deposits that were evaluated as operations with zinc as the primary commodity, 30 mines and deposits that were evaluated as operations with lead as the primary commodity, and 19 mines and deposits that were evaluated as copper operations with lead and zinc as significant byproducts. The assignment of a particular commodity as the primary product, generally based on that product providing the largest proportion of sales revenue at current market prices, is a necessary requirement of the evaluation process using a price determination model. In reality, owing to the complexity of lead-zinc ores, lead and zinc are often coproducts. In the case of a number of mines in Mexico and Peru, lead and zinc are byproducts of silver production. Moreover, the relationship between individual mineral commodities as coproducts and byproducts is dynamic, and can change as metal prices fluctuate in the marketplace.

In cases where revenues from byproducts are able to cover total production costs (which are burdened against the primary product in the analysis), the curve will show the total cost of producing the primary product to be zero. This situation exemplifies the complexity of lead and zinc ores and underscores the effect that byproduct values (particularly silver) can have on the profitability of a mining operation.

LEAD

The 30 mines and deposits evaluated as primary lead operations in 10 market economy countries have an in situ demonstrated resource of 540.9 million t of ore, containing 26.2 million t of recoverable lead. Total availability curves illustrating potential availability of lead from primary lead mines and deposits in all market economy countries and the United States are shown in figure 13. The United States contains the largest recoverable lead resource, 18 million t (17.35 million in Missouri), accounting for 68.7 pct of the

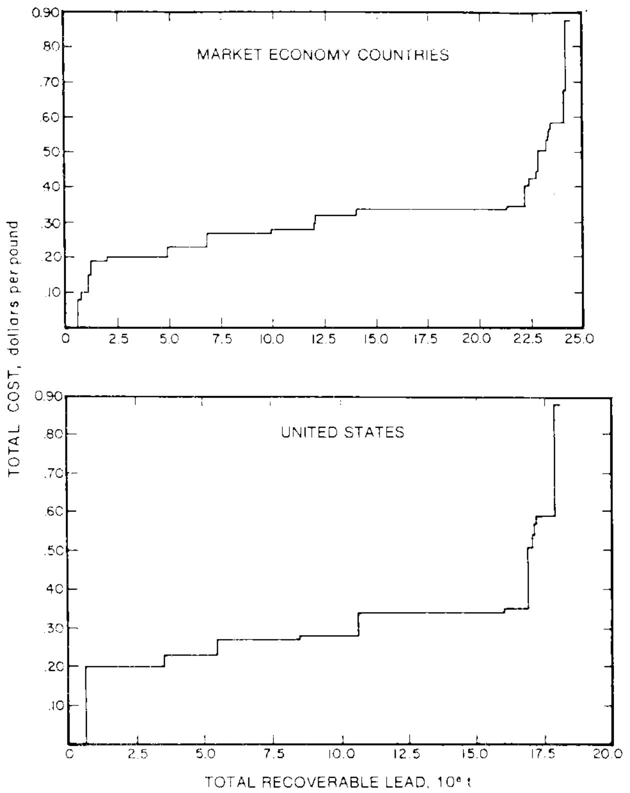

Figure 13.—Total recoverable lead from lead mines and deposits in market economy countries (including the United States) and the United States.

total, followed by Republic of South Africa with 3.8 million t (14.5 pct), and Morocco with 1.4 million t (5.3 pct). These three countries account for 88.5 pct of the potentially recoverable lead from all of the mines and deposits evaluated with lead as the primary product. One explored South African deposit, with potential total recoverable lead of 1.9 million t at an estimated total cost of over $1 per pound, is not shown on the market economy country curve.

Approximately 43.8 million t of lead is potentially recoverable as a byproduct from mines and deposits evaluated as primary zinc operations (fig. 14). The largest individual sources of potential lead as a byproduct of zinc are Australia with 13.5 million t (30.8 pct), Canada with 11.9 million t (27.2 pct), and the United States with 5.6 million t (12.8 pct). Producing zinc mines account for 23.8 million t of lead, 54.4 pct of the total. Producing U.S. zinc mines account for only 169,000 t of lead.

The 19 mines and deposits that were evaluated as primary copper operations can potentially produce 454,000 t of byproduct lead. The total amount of lead potentially recoverable from primary lead deposits, and as a byproduct of zinc and copper, is 70.4 million t.

Total availability curves for all market economy countries and the United States, with a comparison of potentially recoverable lead from producing mines and from undeveloped deposits, are shown in figure 15. Of the 26.2 million t of lead estimated to be potentially recoverable from the 30 mines and deposits evaluated as primary lead operations, 22.1 million t (84.4 pct) is from producing mines and 4.1 million t (15.6 pct) is from undeveloped deposits. The nine mines in the United States account for 72.8 pct (16.1 million t) of the total potential tonnage from the producing mines evaluated for the study, and have a weighted-average total cost of $0.27. The foreign production weighted-average cost is $0.30. As a result, nearly all producing mines in market economy countries are able to produce at or under the January 1981 lead price of $0.34 per pound.

The five undeveloped deposits in the United States have an estimated total cost of $0.50, nearly double that of producing U.S. mines. The three non-U.S. market economy country deposits costs are much higher with an estimated weighted-average total cost of $1.20 per pound. This average, however, is biased by the one South African deposit which has a total cost of well over $1 and is not included in the curve. Excluding this one deposit, the cost for the two remaining deposits drops to $0.55 per pound. None of the undeveloped deposits has a total cost that is less than $0.34 per pound of lead. This indicates that the long-run market price for lead will have to rise above the current (1981) market level, or that the market prices of associated coproducts or byproducts will have to increase before any of these deposits could be developed on a profitable basis. Technological changes, such as the recovery of cobalt and nickel from Missouri lead ores, enhanced recovery of zinc from lead furnace slag, or technological improvements in lead smelting to reduce process costs would also alter the potential profitability of new projects.

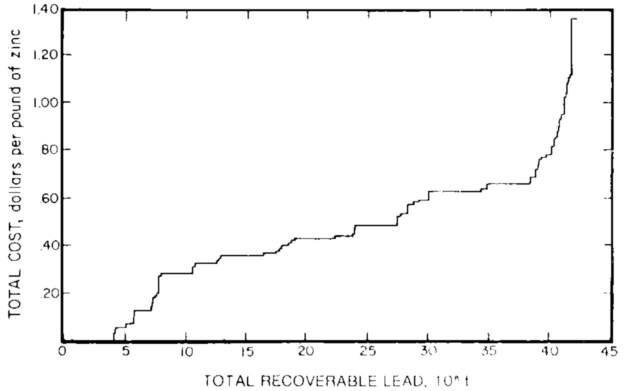

Figure 14.—Total availability of lead as a byproduct of primary zinc mines and deposits in market economy countries.

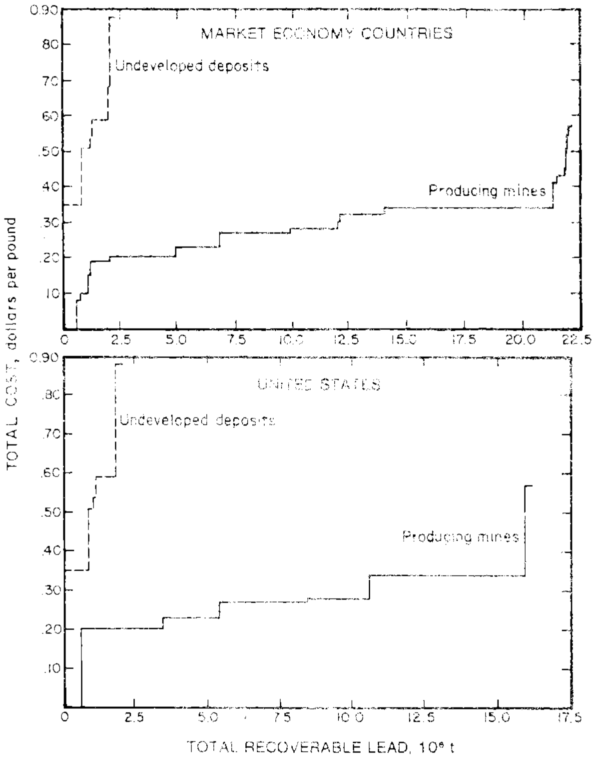

Figure 15.—Total recoverable lead from producing mines and undeveloped deposits in market economy countries (including the United States) and the United States.

Potential annual production levels for producing lead mines in market economy countries and the United States for 1981 to 1995 are shown in figure 16. The market economy country curve begins a gradual annual production decline in 1989, and begins to decline at a faster rate in 1994. Almost all the decline is from the potential depletion of non-U.S. mines as evidenced by the almost constant curve for the United States. However, it is doubtful that the demonstrated resource of these producing mines will decline at the rate indicated by the curve. Many of the lead mine operators in the world report their demonstrated

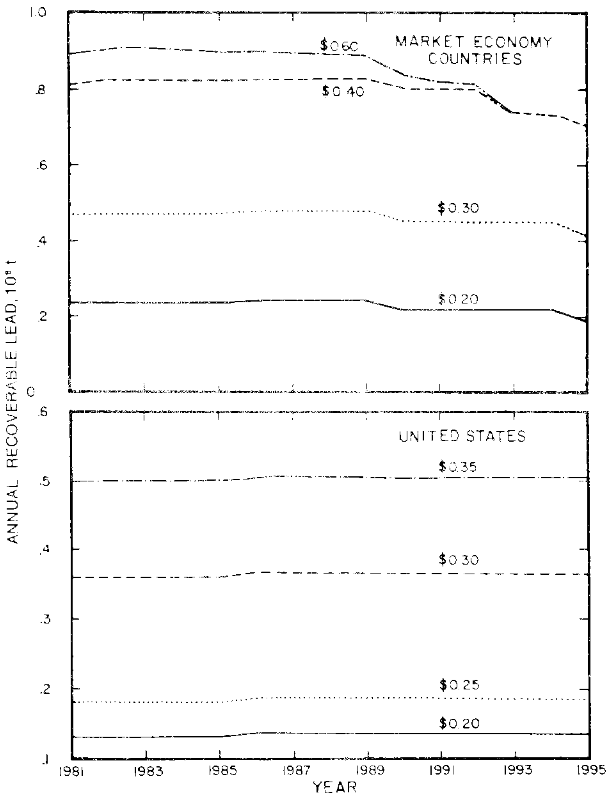

Figure 16.—Potential annual availability of primary lead from producing lead mines in market economy countries (including the United States) and the United States, at various production costs per pound.

resources for only a few years ahead of their current mining position and increase or maintain their reserves as mining continues. Also, in many cases demonstrated resources are increased each year as a result of ongoing exploration programs. The demonstrated resource estimates that appear in this report are based on 1981 company reported data. However, there is a high probability that additional resources exist that will allow most of the currently producing mines to continue beyond the time frame of reported reserves.

Similar curves for undeveloped lead deposits are shown in figure 17. Because startup dates for many undeveloped deposits are not known, construction of annual availability curves for them was based on the assumption that preproduction would begin in year N. For mines that were in the development stage in 1981, production shows up in the first few years of the curve. Potential annual production peaks rapidly and then begins to decline (an exception is the U.S. curve at a lead price of $0.35 per pound, which remains constant). As mentioned previously, none of the deposits can produce lead at an estimated long-run total cost of under $0.34 per pound. One U.S. deposit has an estimated long-run total cost of $0.35 per pound, but it is the only deposit that approaches the 1981 market price. Therefore, it is doubtful that more than three or four of these deposits will be developed in the near future.

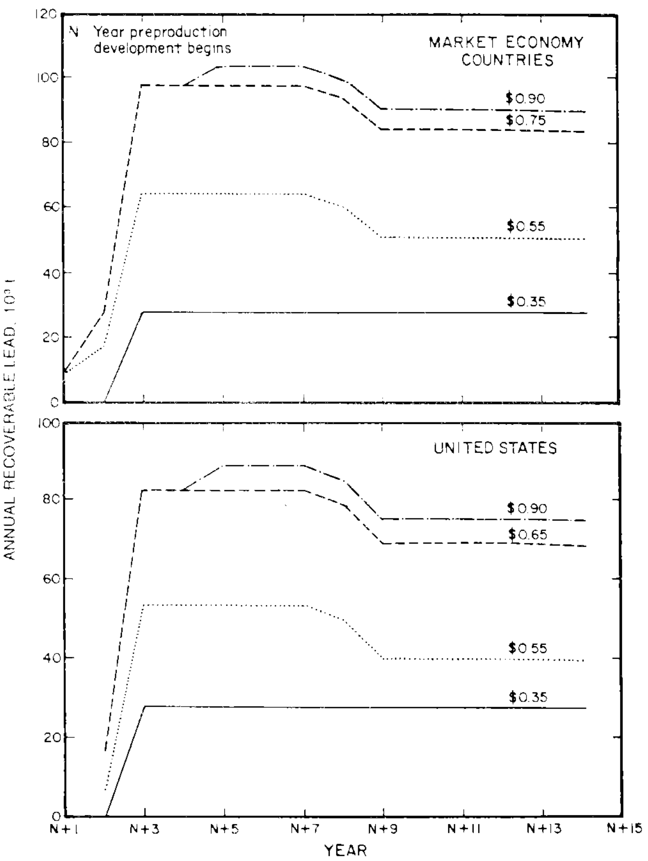

Figure 17.—Potential annual availability of primary lead from undeveloped deposits in market economy countries (including the United States) and the United States, at various production costs per pound.

ZINC

At the demonstrated resource level, approximately 141.1 million t of zinc metal is potentially recoverable from the 186 mines and deposits evaluated as primary zinc operations in 29 market economy countries. The United States contains the largest potentially recoverable resource, 40.3 million t, which accounts for 28.6 pct of the total, followed by Canada with 30.2 million t (21.4 pct), and Australia with 23.2 million t (16.4). The combined total for these three countries amounts to 66.4 pct of the potentially recoverable resource in market economy countries. The total availability curves illustrating potential availability of zinc from primary zinc mines and deposits in all market economy countries, the United States, Canada, and Australia are shown in figure 18. Note that the highest total zinc production cost on any of the curves is $1.50 per pound. Three explored deposits (one each in Australia, Canada, and India) with total zinc production costs estimated at higher than $1.50 per pound and a combined potential production of 1.8 million t, are not shown on the curves. An additional 4.3 million t of zinc is potentially available from 21 mines and deposits evaluated as primary lead operations, with 58 pct (2.5 million t) of this potential tonnage in the United States (fig. 19).

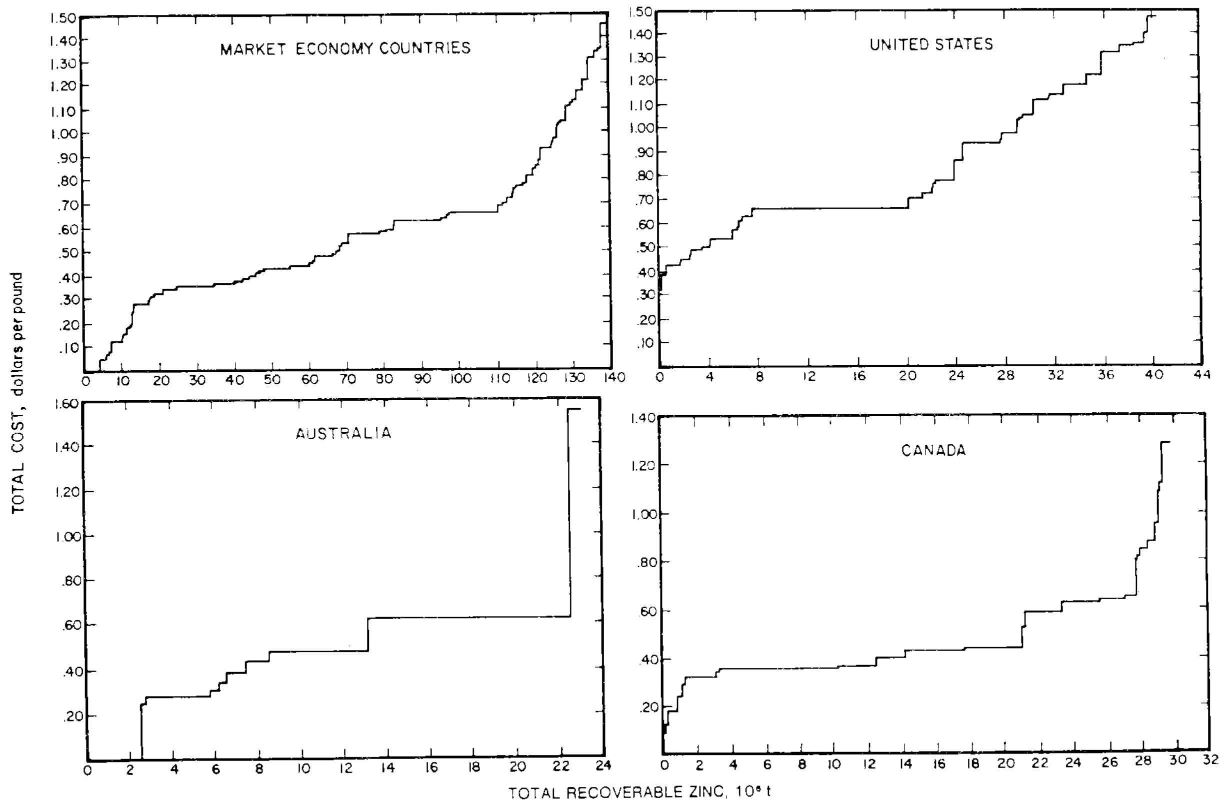

Figure 18.—Total recoverable zinc from market economy countries (including the United States, Australia, and Canada), the United States, Australia, and Canada.

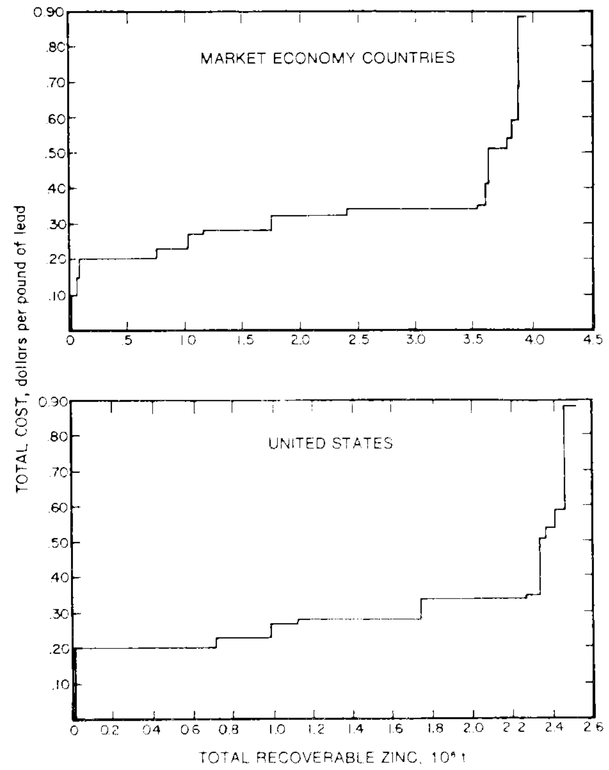

Figure 19.—Total availability of zinc as a byproduct of primary lead mines and deposits in market economy countries (including the United States) and the United States.

As shown in figure 20, another 8.3 million t of zinc is potentially recoverable as a byproduct from the 19 mines and deposits evaluated as primary copper operations with Canada accounting for 4.6 million t (55 pct) of the total; none of this potential tonnage is in the United States. The total tonnage of potentially recoverable zinc from all three sources (primary zinc, primary lead, and primary copper) amounts to 153.7 million t, with 42.7 million t (27.8 pct of the total) from U.S. demonstrated resources.

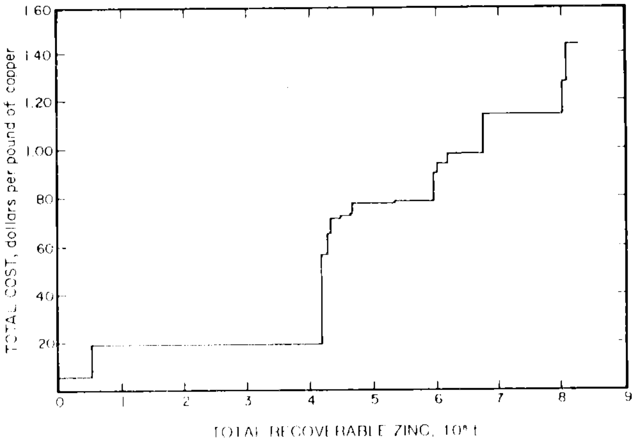

Figure 20.—Total availability of zinc as a byproduct of primary copper mines and deposits in market economy countries.

Total availability curves for all market economy countries and the United States, with a comparison of tonnage from producing mines and from undeveloped deposits (explored deposits and developing mines), are shown in figure 21. Of the 141.1 million t of primary zinc estimated to be potentially recoverable from market economy countries, 43.8 pct (61.8 million t) is from producing mines and 56.2 pct (79.3 million t) is from undeveloped deposits. The 109 producing mines evaluated as primary zinc mines have a weighted-average estimated total cost of $0.35 per pound of zinc (see table 27). Total potential zinc production from these mines amounts to 61.8 million t, with 44.3 million t (72.5 pct of the total) potentially available at an estimated cost level (including a 15-pct DCFROR) below the January 1981 market price of $0.41 per pound. Approximately 11 million additional metric tons of zinc can potentially be recovered from 17 producing mines that can produce at a break-even cost of $0.41 per pound (meaning that they can cover all operating costs and recover capital at a 0-pct DCFROR). This means that 81 of the 109 producing zinc mines could potentially break even at January 1981 estimated costs and prices. Producing mines that cannot cover production costs at a zinc price of $0.41 per pound may eventually have to be closed if prices do not improve (operations in some countries receive a subsidy from the government and therefore can continue to produce at lower zinc prices).

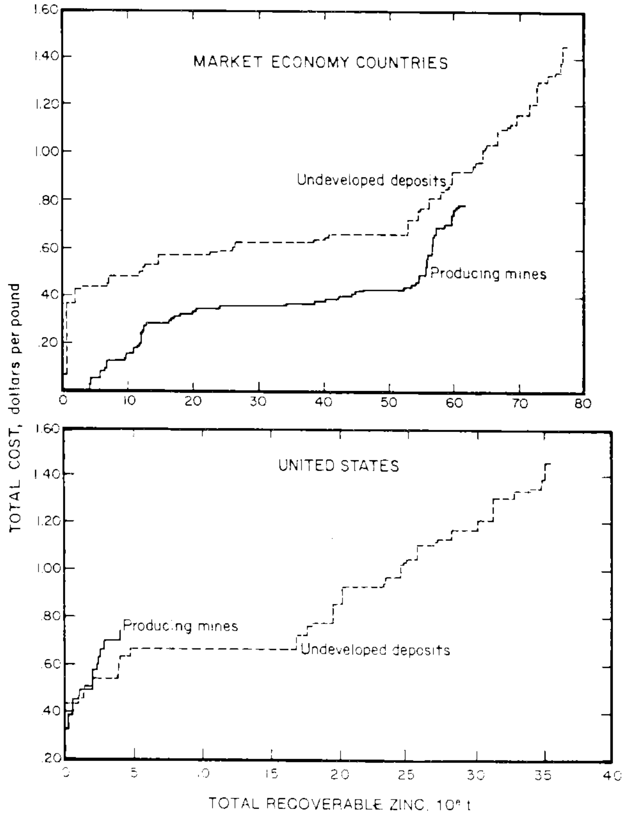

Figure 21.—Total recoverable zinc from producing mines and undeveloped deposits in market economy countries (including the United States) and the United States.

A total of 79.3 million t of zinc is potentially recoverable from the 77 undeveloped deposits evaluated in market economy countries with a weighted-average estimated total cost of $0.74 per pound (table 27). Only 1.85 million t (2.3 pct of the total) is estimated to be recoverable at a total cost below the January 1981 market price of $0.41 per pound of zinc.

The curve for the United States shows that 4.1 million t of zinc is potentially recoverable from the 15 zinc mines that were producing in January 1981, which is only 10.3 pct of the total U.S. recoverable resource of 40.3 million t, and is less than 7 pct of the 61.8 million t of zinc potentially recoverable from producing mines in all market economy countries. The weighted-average total cost of production for these 15 mines is $0.58 per pound of zinc (ranging from $0.00 to $0.74) in January 1981 dollars. From demonstrated resources in 1981, only 454,000 t of recoverable zinc (11 pct of total recoverable zinc from U.S. producers) is potentially recoverable below a long-run total cost of $0.41 per pound of zinc. This cost situation has likely contributed to the number of zinc operations closing or going on a temporary standby status during 1981 and 1982. The evaluations for the 38 undeveloped deposits resulted in potential production of 36.1 million t of zinc with a weighted-average total cost of $0.86 per pound of zinc in constant January 1981 dollars. This situation would make most of these deposits uneconomic under present economic conditions. A shift in the price structures of zinc, lead, or silver would alter this situation, however.

Potential annual production levels for producing zinc mines in market economy countries and the United States for 1981 to 1995 are shown in figure 22. As with the curves for lead mines, the curves indicate a fairly rapid depletion rate, which is based more on the criteria of this study rather than what will probably occur.

Potential annual production levels for undeveloped zinc deposits in market economy countries and the United States are shown in figure 23. If preproduction of all undeveloped deposits were to begin in year N, production would peak in the seventh year and remain constant through year N + 14. Only three of the undeveloped deposits evaluated for this study have estimated total production costs that are less than the January 1981 market price ($0.41 per pound) for zinc. Actual development of these deposits will depend on the level of demand and the associated market prices for zinc, lead, silver, copper, gold, and other coproducts or byproducts of zinc production.

The foregoing availability analyses can be concisely summarized by the use of tables showing potential recoverable zinc and lead, by country, with the associated weighted-average estimated long-run average total costs of production. These data are presented in tables 29 through 34.

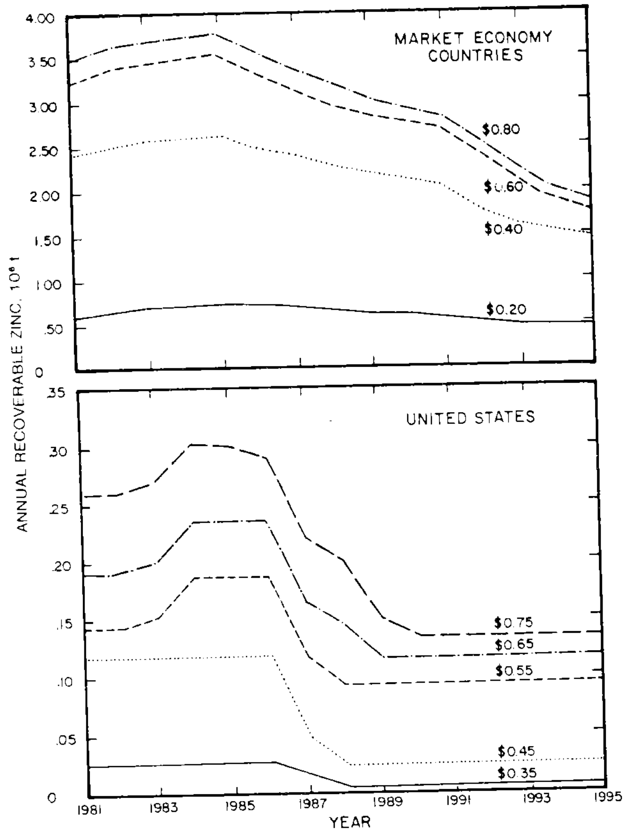

Figure 22.—Potential annual availability of zinc from producing zinc mines in market economy countries (including the United States) and the United States, at various production costs per pound.

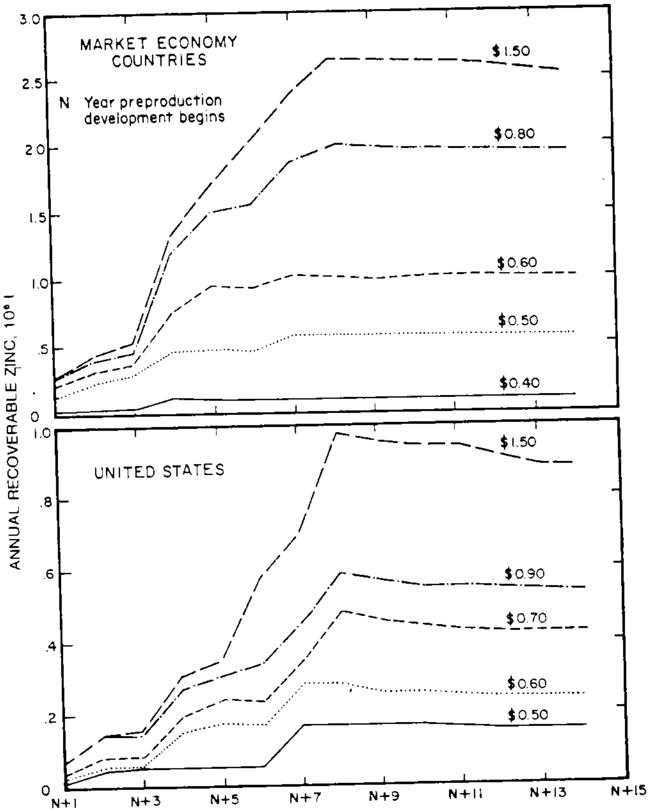

Figure 23.—Potential annual availability of zinc from undeveloped deposits in market economy countries (including the United States) and the United States, at various production costs per pound.

Table 29.—Comparison of estimated long-run average total costs of potential zinc metal production from primary zinc mines and deposits

	Producing mines		Undeveloped deposits	
	Potential production, 10^3 t	Cost[1]	Potential production, 10^3 t	Cost[1]
Algeria	144.7	W	NAp	NAp
Argentina	428.6	W	NAp	NAp
Australia	7,416.7	$0.20	15,772.2	$0.61
Austria	318.0	W	NAp	NAp
Bolivia	148.6	.28	NAp	NAp
Brazil	709.1	W	605.3	W
Burma	94.3	W	NAp	NAp
Canada	17,128.8	.36	13,118.4	.72
Finland	666.7	.43	NAp	NAp
France	349.8	.57	202.1	.68
Germany, Fed. Rep. of	1,861.6	.24	NAp	NAp
Greece	616.2	.00	NAp	NAp
Greenland	378.6	W	NAp	NAp
Honduras	404.2	W	NAp	NAp
India	1,055.2	W	2,171.0	.82
Ireland	2,540.5	.43	1,179.0	1.02
Italy	927.3	$0.50	58.3	W
Japan	2,312.9	.44	NAp	NAp
Mexico	4,946.9	.16	590.9	W
Morocco	NAp	NAp	75.9	W
Namibia	273.8	W	NAp	NAp
Peru	5,346.6	.35	NAp	NAp
Portugal	2,305.3	W	NAp	NAp
South Africa, Rep. of	NAp	NAp	7,751.5	W
Spain	2,203.5	.51	1,592.2	$0.82
Sweden	1,697.0	.35	NAp	NAp
Turkey	154.2	W	NAp	NAp
Zaire	2,945.8	W	NAp	NAp
Zambia	327.8	W	NAp	NAp
Total or average	57,702.7		43,1[illegible]8	
United States	4,139.7	.58	36,138.5	.86
Grand total or av.	61,842.4	.34	[2]79,255.4	.74

NAp Not applicable. W Withheld, company proprietary data.

[1] Weighted-average total cost of production per pound of zinc.

[2] Data do not add to total shown because of independent rounding.

Table 30.—Comparison of estimated zinc metal production as a byproduct from lead mines and deposits at the estimated long-run average total costs of primary lead production

	Producing mines		Undeveloped deposits	
	Potential production, 10^3 t	Cost[1]	Potential production, 10^3 t	Cost[1]
Australia	488.5	W	NAp	NAp
France	31.8	W	NAp	NAp
Mexico	NAp	NAp	129.3	W
Morocco	20.6	W	10.5	W
Namibia	42.1	W	NAp	NAp
South Africa, Rep. of	628.4	W	297.7	W
Sweden	163.3	W	NAp	NAp
Total or average	1,374.7		437.5	
United States	2,208.2	$0.28	246.5	$0.50
Grand total or av.	[2]3,582.8	.28	684.0	.87

NAp Not applicable. W Withheld, company proprietary data.

[1] Weighted-average total cost of production per pound of lead.

[2] Data do not add to total shown because of independent rounding.

Table 31.—Comparison of estimated zinc metal production as a byproduct from copper mines and deposits at the estimated long-run average total costs of primary copper production

	Producing mines		Undeveloped deposits	
	Potential production, 10^3 t	Cost[1]	Potential production, 10^3 t	Cost[1]
Australia	616.6	W	159.1	W
Canada	4,477.6	$0.25	81.7	W
Finland	35.4	.69	NAp	NAp
Japan	649.2	W	NAp	NAp
Norway	87.0	W	NAp	NAp
Peru	NAp	NAp	1,267.3	W
South Africa, Rep. of	131.4	W	NAp	NAp
Sweden	156.1	W	NAp	NAp
Turkey	NAp	NAp	650.5	$1.06
Total or average	6,153.3	$0.42	[2]2,158.7	1.14

NAp Not applicable. W Withheld, company proprietary data.

[1] Weighted-average total cost of production per pound of zinc.

[2] Data do not add to total shown because of independent rounding.

Table 32.—Comparison of estimated long-run average total costs of potential lead metal production from primary lead mines and deposits

	Producing mines		Undeveloped deposits	
	Potential production, 10^3 t	Cost[1]	Potential production, 10^3 t	Cost[1]
Australia	708.4	W	NAp	NAp
Canada	35.8	W	NAp	NAp
France	170.1	W	NAp	NAp
Mexico	136.8	W	211.3	W
Morocco	1,281.4	$0.26	82.7	W
Namibia	375.8	W	NAp	NAp
South Africa, Rep. of	1,905.4	W	1,874.3	W
Spain	83.5	W	NAp	NAp
Sweden	1,307.7	$0.33	NAp	NAp
Total or average	6,004.9		2,168.3	
United States	16,104.9	.27	1,927.7	$0.50
Grand total or av.	22,109.9	.28	4,095.9	.87

NAp Not applicable. W Withheld, company proprietary data.

[1] Weighted-average total cost of production per pound of lead.

NOTE.—Data do not add to totals shown because of independent rounding.

Table 33.—Comparison of estimated lead metal production as a byproduct of primary zinc mines and deposits at the estimated long-run average total costs of primary zinc production

	Producing mines		Undeveloped deposits	
	Potential production, 10^3 t	Cost[1]	Potential production, 10^3 t	Cost[1]
Algeria	35.1	W	NAp	NAp
Argentina	367.5	W	NAp	NAp
Australia	5,878.8	W	7,585.0	$0.61
Austria	84.5	W	NAp	NAp
Bolivia	19.0	$0.28	NAp	NAp
Brazil	NAp	NAp	181.1	W
Burma	134.0	W	NAp	NAp
Canada	7,745.7	.36	4,107.7	.73
Finland	21.2	W	NAp	NAp
France	18.0	.57	59.4	.68
Germany, Fed. Rep. of	404.5	.24	NAp	NAp
Greece	484.0	.00	NAp	NAp
Greenland	120.8	W	NAp	NAp
Honduras	223.0	W	NAp	NAp
India	389.6	W	1,001.1	.82
Ireland	583.1	.43	225.8	1.02
Italy	311.7	$0.50	28.2	W
Japan	361.4	.44	NAp	NAp
Mexico	2,132.4	.16	697.9	W
Morocco	NAp	NAp	13.9	W
Namibia	79.0	.43	NAp	NAp
Peru	1,970.8	.35	NAp	NAp
Portugal	1,014.1	W	NAp	NAp
South Africa, Rep. of	NAp	NAp	434.2	W
Spain	787.5	.50	172.6	W
Sweden	336.4	.35	NAp	NAp
Turkey	4.8	W	NAp	NAp
Zambia	158.4	W	NAp	NAp
Total or average	23,665.3		14,506.9	
United States	168.5	.44	5,440.5	$0.72
Grand total or av.	[2]23,833.7	.33	19,947.4	.68

NAp Not applicable. W Withheld, company proprietary data.

[1] Weighted-average total cost of production per pound of zinc.

[2] Data do not add to total shown because of independent rounding

Table 34.—Comparison of estimated lead metal production as a byproduct from copper mines and deposits at the estimated long-run average total costs of primary copper production

	Producing mines		Undeveloped deposits	
	Potential production, 10^3 t	Cost[1]	Potential production, 10^3 t	Cost[1]
Australia	198.3	W	8.5	W
Canada	71.0	W	NAp	NAp
Japan	107.6	W	NAp	NAp
Namibia	68.5	W	NAp	NAp
Total or average	445.4	$0.98	8.5	W

NAp Not applicable. W Withheld, company proprietary data.

[1] Weighted-average total cost of production per pound of copper.

IMPORTANCE OF SILVER AS A BYPRODUCT OF LEAD AND ZINC PRODUCTION

The most important byproduct associated with the production of lead and zinc is silver. The 186 mines and deposits evaluated as zinc operations contain approximately 3.3 billion tr oz of recoverable silver, and the 30 mines and deposits evaluated as lead operations account for 468 million tr oz. The 19 mines and deposits evaluated as copper operations with lead and zinc as byproducts account for an additional 242 million tr oz of recoverable silver. Approximately two-thirds of total world silver resources are associated with copper, lead, and zinc deposits (*11*). Recoverable silver as a byproduct of potential lead and zinc production, by country, is shown in table 35.

The impact of byproduct silver on the economics of lead and zinc availability is illustrated in figures 24 and 25. Figure 24 shows potential recoverable lead

Table 35.—Total recoverable silver as a byproduct of potential lead and zinc production, thousand troy ounces

	Producing mines		Undeveloped deposits	
	Primary lead	Primary zinc	Primary lead	Primary zinc
Algeria	NAp	910	NAp	NAp
Argentina	NAp	25,959	NAp	NAp
Australia	37,703	360,192	NAp	373,928
Bolivia	NAp	16,266	NAp	NAp
Burma	NAp	9,857	NAp	NAp
Canada	120	476,626	NAp	268,520
Finland	NAp	7,683	NAp	NAp
France	14,250	8,373	NAp	8,439
Germany, Fed. Rep. of	NAp	17,750	NAp	NAp
Greece	NAp	48,078	NAp	NAp
Greenland	NAp	2,819	NAp	NAp
Honduras	NAp	25,447	NAp	NAp
India	NAp	15,456	NAp	28,282
Ireland	NAp	10,233	NAp	NAp
Italy	NAp	11,203	NAp	853
Japan	NAp	55,945	NAp	NAp
Mexico	25,388	508,117	15,185	165,220
Morocco	19,081	NAp	4,945	6,310
Namibia	14,593	1,962	NAp	NAp
Peru	NAp	252,150	NAp	NAp
Portugal	NAp	109,224	NAp	NAp
South Africa, Rep. of	82,707	NAp	44,704	37,663
Spain	1,385	20,250	NAp	21,737
Sweden	8,741	39,195	NAp	NAp
Zaire	NAp	13,968	NAp	NAp
Zambia	NAp	592	NAp	NAp
Total	203,968	2,038,255	64,834	910,952
United States	191,384	10,210	7,282	328,657
Grand total	[1]395,354	[1]2,048,465	72,116	[1]1,239,610
Total	2,443,819		1,311,726	

NAp Not applicable. [1] Data do not add to totals shown because of independent rounding.

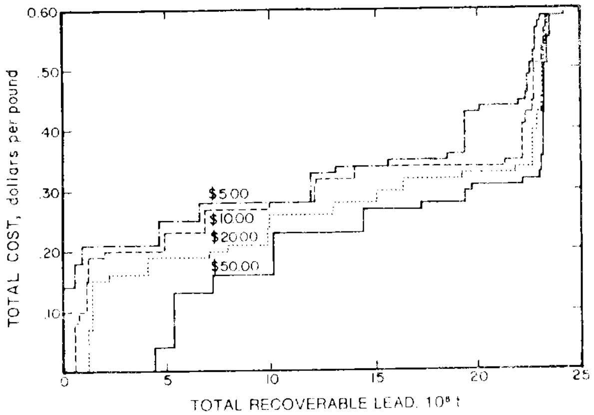

Figure 24.—Total availability of lead from mines and deposits in market economy countries with byproduct silver at varying prices.

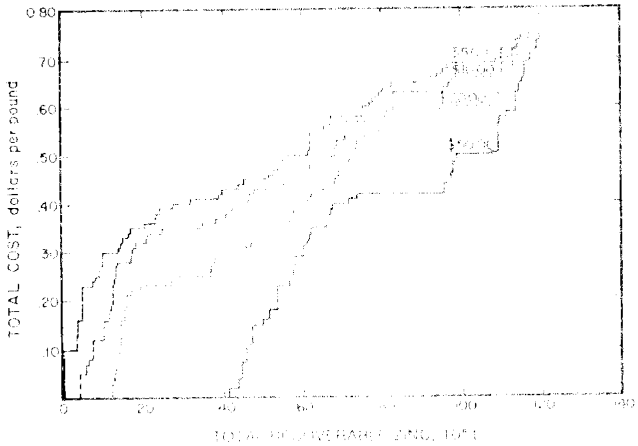

Figure 25.—Total availability of zinc from mines and deposits in market economy countries with byproduct silver at varying prices.

from lead mines and deposits in market economy countries with different prices for byproduct silver, and figure 25 illustrates the effect of different silver prices on the availability of zinc from primary zinc mines and deposits. These curves were constructed by holding all costs and revenues constant except for the revenues for byproduct silver at varying prices. It should be kept in mind that these are long-run analyses and that the silver price variations are long-run prices in constant January 1981 dollars, and do not reflect short-run fluctuations in the price of silver. In order to effect the shifts in the curves shown in figures 24 and 25, any price change of silver would have to be sustained over a number of years.

The results of the analyses illustrated in the these figures are presented in tabular form, in tables 36 and 37, which show the weighted-average total costs of lead and zinc production for producing mines and undeveloped deposits in market economy countries with byproduct silver prices at $5, $20, and $50 per tr oz. These weighted-average total costs can be compared with the costs presented in tables 29 and 32 which were determined with a byproduct silver price of $10 per troy ounce. It is not surprising that the greatest impact of byproduct silver revenues appears in countries with the largest silver resources, namely Australia, Mexico, and Peru. This analysis further underscores the competitive advantage enjoyed by the major producers of zinc with high byproduct silver content compared with most of the U.S. zinc producers in Tennessee, which have no byproduct silver at all.

Table 36.—Weighted-average total cost of production per pound of lead with various prices per troy ounce of byproduct silver

	$5		$20		$50	
	Producing mines	Undeveloped deposits	Producing mines	Undeveloped deposits	Producing mines	Undeveloped deposits
Australia	W	NAp	W	NAp	W	NAp
Canada	W	NAp	W	NAp	W	NAp
France	W	NAp	W	W	W	NAp
Mexico	W	W	W	W	W	W
Morocco	$0.29	W	$0.22	NAp	$0.12	W
Namibia	W	NAp	W	W	W	NAp
South Africa, Rep. of	W	W	W	NAp	W	W
Spain	W	NAp	W	NAp	W	NAp
Sweden	.34	NAp	.31	NAp	.24	NAp
United States	.28	$0.50	.26	$0.48	.22	$0.46
Average	.31	.91	.24	.80	.19	.63

NAP Not applicable. W Withheld, company proprietary data.

Table 37.—Weighted-average total cost of production per pound of zinc with various prices per troy ounce of byproduct silver

	$5		$20		$50	
	Producing mines	Undeveloped deposits	Producing mines	Undeveloped deposits	Producing mines	Undeveloped deposits
Algeria	W	NAp	W	NAp	W	NAp
Argentina	W	NAp	W	NAp	W	NAp
Australia	$0.26	$0.65	$0.15	$0.51	$0.06	$0.31
Austria	W	NAp	W	NAp	W	NAp
Bolivia	.52	NAp	.26	NAp	.24	NAp
Brazil	W	W	W	W	W	W
Burma	W	NAp	W	NAp	W	NAp
Canada	.41	.76	.26	.64	.06	.43
Finland	.45	NAp	.38	NAp	.24	NAp
France	.60	.77	.50	.49	.30	.01
Germany, Fed. Rep. of	.26	NAp	.19	NAp	.09	NAp
Greece	.01	NAp	.00	NAp	.00	NAp
Greenland	W	NAp	W	NAp	W	NAp
Honduras	W	NAp	W	NAp	W	NAp
India	W	.85	W	.76	W	.58
Ireland	.43	1.02	.42	1.02	.41	1.02
Italy	.53	W	.48	W	.48	W
Japan	.48	NAp	.36	NAp	.22	NAp
Mexico	.37	W	.05	W	.00	W
Morocco	NAp	W	NAp	W	NAp	W
Namibia	W	NAp	W	NAp	W	NAp
Peru	.44	NAp	.22	NAp	.07	NAp
Portugal	W	NAp	W	NAp	W	NAp
South Africa, Rep. of	NAp	W	NAp	W	NAp	W
Spain	.52	W	.47	W	.36	W
Sweden	.40	NAp	.29	NAp	.16	NAp
Turkey	W	NAp	W	NAp	W	NAp
United Sates	.58	.88	.57	.82	.56	.72
Zaire	W	NAp	W	NAp	W	NAp
Zambia	W	NAp	W	NAp	W	NAp
Average	.40	.78	.27	.69	.16	.56

NAp Not applicable. W Withheld, company proprietary data.

DEMAND FOR LEAD AND ZINC

The long-run situation for the lead industry is more complicated than that for zinc, since primary lead producers not only face stiff competition from each other, but from the large and growing secondary industry as well. Total world primary lead demand is forecast to increase at an annual rate of 2.4 pct per year through 2000, with a cumulative primary demand of 77 million t over the 20-yr period. Total demand for lead, including secondary lead, is forecast to increase at an annual rate of 2.8 pct (3.2 pct for secondary lead). For the United States, total demand is forecast to grow at an annual rate of 1.8 pct, with primary lead demand increasing at a 1.5-pct annual rate and demand for secondary lead growing at an annual rate of 2.0 pct. The part of U.S. demand met by secondary lead is expected to approach 60 pct by 2000, as opposed to slightly over 50 pct at the present time, owing to gradual structural and technological changes in the industry and a relative increase in nondissipative end uses for lead (*3*). Based on this forecast, cumulative demand for primary lead in the United States between 1981 and 2000 is estimated to be 13.3 million t.

Current demonstrated resources estimated to be recoverable in the United States at long-run production costs under the 1981 market price of $0.34 per pound amount to 16.13 million t, which is well above the estimated cumulative demand of 13.3 million t. Total recoverable resources in market economy countries amount to 70.4 million t (41.1 million t potentially available at 1981 market prices), and cumulative demand for primary lead through 2000 (including central economy countries) equals 77 million t. As with zinc resources, demonstrated resource estimates for lead have increased significantly over the past 20 yr. The 1962 resource estimate for lead (*12*) was 45.2 million t for the total world, with 17 million t in the United States. These resources were deemed adequate to satisfy demand for 20 yr.

The World Bank–LME lead price forecast (*13*) predicts constant 1981 dollar lead prices of $0.29 per pound in 1985, $0.358 in 1990, and $0.38 in 1995. The $0.38-per-pound estimate for 1995, if reasonably accurate, would indicate that 84 pct of the 26.4 million t of lead metal from the mines and deposits evaluated as primary lead operations could potentially be produced and earn a 15-pct DCFROR for each respective operation. The United States, with the largest low-cost resource, appears to have a comparative advantage over the rest of the world industry.

Total world primary zinc demand is estimated to grow by 2.5 pct a year through 2000 (*4*), which is slightly higher than the 2.2-pct annual growth rate projected for the U.S. demand. This would make cumulative primary demand from 1981 through 2000 equal to 23 million t in the United States and 143 million t for the total world. Because the demonstrated recoverable resources of zinc in market economy countries alone equals almost 154 million t, the current zinc resource is adequate to meet demand through the year 2000. At 1981 market prices, however, the available economic tonnage of zinc from market economy countries equals only 56.1 million t, of which 2.7 million t is in the United States. Superficially, this discrepancy between cumulative demand and lower cost potential supply indicates that the price for zinc, in real terms, would have to go up dramatically in order to satisfy cumulative demand through 2000.

This can be quite misleading, however, owing to the dynamic nature of resource estimates. This study is based on a static, conservative resource estimate for zinc based on 1981 data. No effort has yet been made to project potential zinc resources that may exist in 2000. Zinc resource estimates have increased over time as new deposits have been discovered and as exploration programs continue at existing mines. For example, zinc resources in 1962 (*14*) were estimated to equal 77.1 million t (11.1 million in the United States). This resource equaled a 17-yr supply of zinc at 1962 consumption rates. Current resource estimates are deemed sufficient to provide at least a 20-yr supply.

The point is that these resource estimates are based on current data, and are not meant to indicate that we are going to run out of a given commodity in 20 yr. It is not unlikely that resource estimates for zinc in 2000 will indicate that resources are also deemed sufficient for a 20-yr supply of zinc. The key results of this study are not so much the aggregate tonnages presented, which are going to change on an almost annual basis anyway, but the relative distribution of resources between countries and the relative costs of production associated with these tonnages. The current lower cost producers will probably continue to be the low-cost producers, particularly if any significant new tonnage increases of zinc resources over the next 20 yr or so are additions to existing mines. This would suggest that the U.S. position in zinc production will remain weak or will weaken further owing to the small percentage of low-cost zinc potentially available from producing mines. Although the United States contains the largest potentially recoverable zinc resource in market economy countries, slightly less than 11 pct of this resource is from producing mines, and the balance from undeveloped deposits will be much higher cost to exploit than the zinc resources in other market economy countries.

In summary, the results of the analyses indicate that zinc resources in market economy countries should at least be adequate to satisfy projected demand for primary zinc through the balance of this century. The study suggests that the comparative disadvantage faced by the U.S. zinc industry will probably intensify owing to the relative quantity of lower cost zinc resources in other countries, especially Canada, Australia, and Mexico. One World Bank price forecast for zinc (*13*) predicts that, in constant 1981 dollar terms, the price of slab zinc on the London Metal Exchange (LME) will drop to $0.36 per pound in 1985, and then rise to $0.419 in 1990, and to $0.45 in 1995. Such a gradual rise in constant dollar prices for zinc would indicate that the industry will remain fiercely competitive throughout the balance of the century, and profitability will remain an elusive goal for many producers if the long-run constant dollar price for zinc remains at such a low level.

CONCLUSIONS

The demonstrated resources of lead and zinc ore comprising 235 mines and deposits in market economy countries evaluated for this study amount to approximately 4.2 billion t of ore containing 221 million t of zinc and 97 million t of lead. Of these amounts, approximately 154 million t of zinc and 70 million t of lead are estimated to be recoverable. These demonstrated resources are sufficient to satisfy projected demand through the balance of the century. Furthermore, as new lead and zinc deposits are discovered, and as exploration programs at existing mines continue, it is likely that demonstrated resource estimates will continue to increase over time.

Low prices for both lead and zinc have served to make the financial position of producers more precarious over the past several years. Several marginal producers have shut down permanently and other high-cost producers will likely follow suit over the next few years if prices continue to remain at low levels. The 109 producing mines evaluated as primary zinc mines have a weighted-average estimated total production cost (including a 15-pct DCFROR) of $0.34 per pound. Total potential zinc production from these mines amounts to 61.8 million t, with 44.8 million t potentially available at estimated cost levels below the January 1981 market price of $0.41 per pound. The United States appears to be at a competitive disadvantage, with only 454,000 t of zinc potentially recoverable below a long-run total cost of $0.41 per pound, and a weighted-average estimated total cost of $0.58 for the 4.14 million t estimated to be recoverable from U.S. producing mines.

A total of 79.3 million t is potentially recoverable from the 77 undeveloped zinc deposits evaluated in market economy countries with a weighted-average total cost of $0.74 per pound. Only 1.85 million t (2.3 pct of the total) is estimated to be recoverable below $0.41 per pound. The 36.1 million t of zinc potentially recoverable from undeveloped deposits in the United States has an estimated weighted-average total cost of $0.86 per pound.

It is likely that U.S. dependence on imported slab zinc will continue to increase in the future, although stable supplies are virtually assured from Canada, Australia, and Mexico.

The cost picture for producing lead mines in the United States looks somewhat brighter. Nine U.S. mines account for 72.8 pct of the total potential tonnage from the 22 producing mines evaluated for this study, and have a weighted-average estimated total cost of $0.27 per pound. The non-U.S. producing mines have a weighted-average total cost of $0.30 per pound. The five undeveloped U.S. deposits evaluated appear to have a minor cost advantage over the three non-U.S. deposits, although none of the eight deposits has an estimated long-run average total cost that is less than the January 1981 market price of $0.34 per pound.

REFERENCES

1. U.S. Geological Survey and U.S. Bureau of Mines. Principles of a Resource/Reserve Classification for Minerals. U.S. Geol. Surv. Circ. 831, 1980, 5 pp.

2. Clement, G. K., Jr., R. L. Miller, P. A. Seibert, L. Avery, and H. Bennett. Capital and Operating Cost Estimating System Manual for Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada. BuMines Spec. Publ., 1980, 149 pp.; also available as STRAAM Engineers, Inc. Capital and Operating Cost Estimating System Handbook—Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada (contract J0255026), 1977, 374 pp.; available from U.S. Government Printing Office, stock No. 024-004-0215-6.

3. Woodbury, W. D., and J. A. Rathjen. Lead. BuMines Mineral Commodity Profile, 1985, 17 pp.

4. Jolly, J. H. Zinc. BuMines Mineral Commodity Profile, 1983, 18 pp.

5. Davidoff, R. L. Supply Analysis Model (SAM): A Minerals Availability System Methodology. BuMines IC 8820, 1980, 45 pp.

6. Stermole, F. J. Economic Evaluation and Investment Decision Methods. Investment Evaluations Corp., Golden, CO, 1974, 443 pp.

7. Kilgore, C. C., S. J. Arbelbide, and A. A. Soja. Lead and Zinc Availability—Domestic. A Minerals Availability Program Appraisal. BuMines IC 8962, 1984, 30 pp.

8. Jensen, M. L., and A. M. Bateman. Economic Mineral Deposits. 3d ed., 1981, 593 pp.

9. Brown, D. H., and A. Lust. World Directory: Lead and Zinc Mine and Metallurgical Works. MRI 79/5, Mineral Policy Sector, Internal Report. Energy, Mines and Resources of Canada, 1979, 78 pp.

10. Cotterill, C. H., and J. M. Cigan. Survey of World Lead and Zinc Production. Paper in AIME World Symposium on Mining and Metallurgy of Lead and Zinc. AIME, New York, v. 2, 1970, p. 15.

11. U.S. Bureau of Mines. Silver. Ch. in Mineral Commodity Summaries 1984. Pp. 140-141.

12. Moulds, D. E. Lead. Ch. in Mineral Facts and Problems, 1965 Edition. BuMines B 630, 1965, pp. 489-509.

13. The World Bank. Biennial Review of Commodity Price Forecasts, Volume 3: Metals and Minerals. The World Bank, Washington, DC, 1983, 244 pp.

14. Schroeder, H. J. Zinc. Ch. in Mineral Facts and Problems, 1965 Edition. BuMines B 630, 1965, pp. 1083-1104.

15. Purser, W. F. C. Metal Mining in Peru, Past and Present. Praeger Publ., New York, 1971, 329 pp.

APPENDIX.—GEOLOGIC CHARACTERISTICS OF MAJOR LEAD AND ZINC DEPOSITS IN MARKET ECONOMY COUNTRIES

AUSTRALIA

Of the 15 Australian deposits evaluated for this report, 6 contain significant amounts of recoverable copper and all of the deposits have silver present in important recoverable quantities. The major Australian lead and zinc deposits occur in two main districts: Mount Isa and Broken Hill. Mount Isa is the largest Australian lead-zinc deposit, located in west-central Queensland. Mineralization occurs as syngenetic deposition in the Urquhart shale formation of the Lower Proterozoic Mount Isa Group sediments. Galena, sphalerite, and pyrite form closely spaced, concordant bands grouped to form 14 distinct ore bodies in an en echelon pattern. The nearby Dugald River, Hilton, and Lady Loretta deposits are genetically similar to the Mount Isa deposit.

The McArthur River deposit is a large explored deposit located 100 km south of the Gulf of Carpentaria in the Northern Territory. The stratiform deposit is unmetamorphosed and occurs near the center of the McArthur Group, a sequence of dolomitic sedimentary rocks of Middle Proterozoic Age. Fine-grained sphalerite, galena, and other sulfides occur as disseminations in carbonaceous, potassic, dolomitic, and pyritic shales. A small amount of silver is associated with the galena and marcasite; arsenopyrite and chalcopyrite are also present. This deposit may possibly be related genetically to the Mount Isa-type deposits.

The Broken Hill district in western New South Wales occurs within the Willyanna Complex, a system of foliated metamorphic rocks of the Proterozoic Era. The deposit is stratiform type with lens-shaped ore bodies containing sphalerite and galena with minor pyrrhotite and marcasite. Ore is currently extracted by three operations in the Broken Hill deposit: North Broken Hill Holdings Ltd., New Broken Hill Consolidated Ltd., and Zinc Corporation mines.

Volcanogenic massive sulfide deposits are found at Woodlawn, New South Wales; Teutonic Bore in Western Australia; Que River and Rosebery in Tasmania; and Benambra in Victoria. The C.S.A. deposit in the Cobar mining district of western New South Wales is also a massive sulfide deposit localized in siltstones of the Upper Silurian age Cobar Group sediments, which lie on the west limb of an extensively folded anticlinal structure.

CANADA

A total of 42 Canadian lead and zinc deposits were evaluated for this study. These deposits fall into three general geological classifications: limestone replacement, shale-hosted, and volcanogenic massive sulfide. Limestone replacements, also referred to as Mississippi Valley type deposits, consist of brecciated limestone or dolomite reef formations that have been mineralized by mineral-bearing fluids. Major ore minerals are galena and sphalerite with minor occurrences of silver. The Pine Point, Prairie Creek, Great Slave Reef, Nanisivik, and Polaris deposits in the Northwest Territories are examples of limestone replacement ores. The Mel deposit in the Yukon Territory is also an example of a limestone replacement ore body.

In the Selwyn Basin, Yukon Territory, numerous massive pyritic lead-zinc-silver deposits occur as nearly horizontal stratiform, stratabound massive sulfide zones. In the Anvil Range, the sulfide mineralization is in a graphitic schist of Devonian age and is believed to have originally formed syngenetically with its host rocks. The Howard's Pass and Tom deposits are in a pyritic shale environment on the northern fringes of the Selwyn Basin. The Sullivan ore body in southern British Columbia and the Cirque deposit in north-central British Columbia are also shale hosted-type deposits.

Volcanogenic massive sulfide type lead-zinc deposits are formed in a marine environment in the vicinity of volcanic vents. Deposition takes place at the water-sediment interface to form a zoned, polymetallic sulfide deposit. Some stockwork deposition takes place in the fractured and brecciated volcanic rocks around the vent. The Kidd Creek and Geco deposits in Ontario, and Brunswick No. 12 and Heath Steele deposits in New Brunswick, are prime examples of this type of deposit.

INDIA

Three deposits containing lead-zinc mineralization and one containing copper with lead-zinc by-products were evaluated. Lead-zinc mineralization forms either stratiform, massive complex sulfide deposits or stratabound, vein-type deposits. The stratiform deposits generally contain high ore grades, whereas the stratabound vein-type are lower in grade. The deposits in the Zawar Group occur in low-grade metamorphosed graywackes, phyllites, dolomites, and quartzites, with associated minor occurrences of unmetamorphosed intrusive igneous rock. The lead-zinc ore bodies are believed to be of hydrothermal origin. Mineralization consists of sphalerite, pyrite, and galena in association with chalcopyrite, pyrrhotite, and arsenopyrite. Silver and cadmium are associated with the ore minerals.

The Ambaji copper deposit has relatively high lead and zinc contents. The main ore mineral at Ambaji is chalcopyrite with lesser amounts of the copper minerals chalcocite and covellite, plus galena, sphalerite, and pyrite.

IRELAND

Five lead-zinc deposits, three in northeastern Ireland, one in north-central Ireland, and one in western

Ireland, were evaluated. Sphalerite, pyrite, and galena are common sulfide minerals. Gangue minerals consist of dolomite, pyrite, barite, quartz, calcite, and marcasite.

The stratabound Bula and Tara deposits in northeastern Ireland occur in Pale Beds of Carboniferous age, composed of silty and oolitic limestones and dolomites, enveloping the stratabound sulfide mineralized zone. In the lower section of the ore body, mineralization forms five separate lenses that converge in the upper ore body to form a single massive sulfide ore body more than 60 m thick. Three major faults dissect the ore body. Folding and faulting of the host rocks have produced a complex ore body shape.

The Sabina-Tatestown deposit in northeastern Ireland is stratiform, occurring in (lower carboniferous) argillaceous limestones. An east-west fault parallel to the ore body displaces the mineralized zone 70 to 100 m.

In north-central Ireland, the Ballinalack deposit is a stratabound ore body within Reef Limestone of lower Carboniferous period. The lead-zinc mineralization fills fractures and cavities within the Reef Limestone to form a few diffuse lenses.

Mogul deposit, in western Ireland, has two stratiform ore bodies formed within Waulsortian carbonates and a lower, stratabound ore zone contained within lower dolomites of Tournaisian age. The lower zone is delimited by a northwest-trending fault.

JAPAN

Nine lead-zinc deposits were evaluated in Japan; one deposit is located on Hokkaido, four in north Japan, and four in central Japan. Two of the deposits are primary copper deposits with lead-zinc byproducts.

The stratabound Kuroko or "black ore" type deposits of Japan are commonly regarded as the classic type of volcanogenic polymetallic (copper-lead-zinc-silver) massive sulfide (and sulfate) deposits, genetically related to explosive felsic volcanism of Miocene age. Mineral assemblages and mineral zoning are similar among typical Kuroko deposits. In the stratiform ore bodies, the upper half is typically rich in galena, sphalerite, and barite (black ore), while pyrite and chalcopyrite are dominant in the lower half (yellow ore). Underlying the stratiform ore bodies are lower grade stockwork ore bodies, characterized by disseminated and stockwork-type mineralization of pyrite and chalcopyrite distributed in an irregular funnel shape in felsic lavas and pyroclastics. The stockwork ore is generally strongly silicified and is also called siliceous ore.

Along the Japan Sea, from Hokkaido to Kyushu, is a specific geologic province called the Green Tuff Region in which numerous Kuroko deposits occur. In this region, the volcanic rocks show a characteristic greenish color as a result of diagenetic and hydrothermal alterations. Vein-type base metal as well as silver-gold deposits also occur in this region. Mines evaluated in this region include the Ezuri, Fukazawa, Hosokura, Kosaka, and Toyoha deposits.

The geology of the Kamioka-Hida mountain region consists of injection gneiss, acid and basic plutonic rocks (granite and metabasite), Jurassic sediments, and intrusive Cretaceous stocks and dykes of granite porphyry and quartz porphyry. The characteristic feature of the Hida Complex gneissic rocks is the large number of intercalcerated limestone beds. Limestone beds are dragfolded within this complex of metamorphosed Precambrian to Paleozoic geosynclinal sediments are the host rocks for the numerous ore bodies exploited at the Kamioka Mine.

MEXICO

The most important producing State for lead and zinc in Mexico is Chihuahua, followed by Zacatecas, Guerrero, San Luis Potosi, and Hidalgo. In the State of Chihuahua, the Santa Barbara ore bodies consist of veins of sulfide mineralization contained in fissures and fractures in shale country rock and andesitic intrusives. Sulfide minerals are sphalerite, galena, chalcopyrite, and argentite.

In the Parral District of Chihuahua, lead-zinc-silver ore bodies occur as veins in normal-type faults. The veins are more or less continuous along the strike of the fault. An oxidation zone to 300 m (below sea level) overlies an enrichment zone and a sulfide zone.

In northern Coahuila, the La Encantada District has two major ore bodies and several minor ore bodies occurring in a mineralized trend within limestone country rock. Mantos, chimney, vein, and tabular shaped ore bodies are formed along limestone-skarn contacts. The mineralized zones are offset by a series of perpendicular faults. An abundance of iron oxides and complex mineral assemblages characterize the La Encantada deposits. High-grade ore minerals are cerussite, mimetite, acanthite, argentite, and some native silver. Low ore grade minerals consist of dominant hematite, magnetite, limonite, geothite, and malachite. Other minerals are smithsonite, anglesite, lead jarosite, marmatite, hemimorphite, azurite, native copper, chrysocolla, and argentojarosite.

The Taxco Unit in Guerrero, Mexico, comprises three mines. Ore deposits occur as vein fissures or as replacement ore bodies in limestone beds. Lead-zinc mineralization is higher in the vein fissures than in the replacement ore bodies. Mineralization zones include quartz, argentiferous galena, and sphalerite.

Two major ore bodies are located in the Sierra Madre Oriental of southeastern Oueretaro. The ore zones occur in tactite associated with intrusive igneous rocks. Both massive and disseminated mineralization are present. Ore minerals are sphalerite, galena, chalcopyrite, pyrargyrite, proustite, polybasite, and argentite.

Deposits of the Charcas District in the El Altiplano region of San Luis Potosi are mineralized fracture fillings and replacement bodies associated with intrusive rocks that penetrated limestone formations. Paleozoic and Mesozoic sedimentary rocks were penetrated by middle Eocene intrusives. Dykes and small fissures near limestone-porphyry contacts and peripheral fissures within the Cuesta del Cura Formation contain mineralized replacement bodies. The most important ore bodies are located on the San Bartolo and the San Fidel Faults. Sulfide minerals are sphalerite, argentiferous galena, chalcopyrite, and pyrite.

In the San Martin District in Zacatecas, Mexico, a stratabound copper-zinc deposit occurs in the Upper Cretaceous Cuesta del Cura Limestone with mineralization in veins and replacement zones. A silver-lead-zinc deposit occurs as disseminations, stringers, and bands in a folded sequence of graywackes. Mineralization consists of sphalerite, chalcopyrite, bornite, arsenopyrite, pyrrhotite, pyrite, tremolite, quartz, calcite, fluorite, and minor amounts of argentite, native silver, tetrahedite, and scheelite.

In one of Mexico's oldest silver destricts, the Fresnillo deposits in Zacatecas occur as veins, stockworks, mantos, and chimneys. The sulfide zone contains quartz, pyrite, arsenopyrite, pyrrhotite, sphalerite, galena, chalcopyrite, pyrargyrite, proustite, polybasite, argentite, and calcite.

A number of small lead-zinc deposits and deposits containing lead-zinc as byproducts are located in the Mexican States of Aguascalientes, Durango, Hidalgo, Jalisco, Mexico, Michoacan, Nuevo Leon, Oaxaca, Puebla, Sinaloa, Sonora, and Tamaulipas.

MOROCCO

The Zeida, Touissit, and Aouli-Mibladen deposits are primarily lead producers; Djebel Aouam and Sidi Lachen are lead deposits with byproduct zinc, and Bou Madine is a zinc-lead-silver deposit. Zeida, the largest lead deposit, lies unconformably on a horizontal plane above Moulouya granite. Overlying the ore zone are argillaceous beds and red mudstones. Host rocks are arkosic sediments consisting of granular quartz and feldspar. Galena and cerussite are major lead minerals and minor quantities of anglesite, pyrite, and chalcopyrite are also present.

PERU

Lead and zinc mineralization occurs primarily in the Cordillera Occidental region of the central Sierra, associated with three of five major geologic belts in central Peru: Central Andean Mesozoic Belt, Eastern Paleozoic Belt, and Cenozoic Volcanic Belt. Mineralization is almost always associated with large longitudinal faults and intrusive bodies. Deposits are localized as mineralized faults, breccia pipes, and replacement mantos in adjacent limestone beds.

Cerro de Pasco is the largest of the Peruvian lead-zinc mines, accounting for over 50 pct of the lead and over 35 pct of the zinc resource in Peru. Situated on the line of a major longitudinal fault, it is bounded to the east by the Pucara limestone and to the west by the Paleozoic Excelsior formations. The mineralization is in the debris of a volcanic blasthole (*15*).[1]

Antamina is a low-grade, large-tonnage copper-zinc-silver deposit localized in a tactite zone surrounding a quartz monzonite porphyry intrusion. The host rock is predominantly carbonate with minor shale of Cretaceous age. Approximately 19 pct of the Peruvian zinc resource is contained in this deposit.

The remaining deposits evaluated are primarily silver-zinc-lead deposits related to limestone replacement mantos or vein fillings associated with limestone, igneous intrusives and volcanic beds.

PORTUGAL

The Aljustrel and the Neves-Corvo deposit (which was not evaluated for this study), located in southern Portugal contain lead, zinc, copper, and silver in recoverable amounts. Both deposits are massive sulfide lenses contained in tuffaceous rocks. Aljustrel, the larger deposit, consists of five ore bodies. Mineralization is contained within a schistose sericitic rock formation. A number of faults including the Messejana Fault displace the mineralized zone. Ore minerals are massive pyrite with fine-grained, disseminated chalcopyrite, sphalerite, and bornite.

REPUBLIC OF SOUTH AFRICA

The principal lead-zinc deposits in the Republic of South Africa are the Prieska, Broken Hill-Black Mountain, and Gamsberg deposits. The Prieska deposit is a copper-zinc deposit while the Broken Hill-Black Mountain complex supplies lead and zinc, and Gamsberg is primarily a zinc deposit. The Broken Hill-Black Mountain deposit in Cape Province comprises two massive sulfide ore bodies that were formed on opposite flanks of an Archean complex southeast plunging anticline. Mineralization is believed to be syngenetically related to highly metamorphosed volcanics. Major sulfides are pyrite, chalcopyrite, sphalerite, pyrrhotite, and minor amounts of arsenopyrite, galena, magnetite, neodigenite, and molybdenite. Gamsberg is a high-grade zinc deposit similar to the Broken Hill-Black Mountain deposits.

SPAIN

Of the six deposits evaluated, the Aznalcollar and Sotiel deposits consist of copper mineralization with byproduct lead and zinc; the Cartagena, Reocin, and Rubiales deposits contain zinc ore with byproduct lead; and Linares (El Cobre) contains primarily lead mineralization.

Aznalcollar is located in southwest Spain. The local geology is characterized by folding and deformed stress zones of Hercynian orogeny on the east limb of an anticline. The underlying sequence consists of Lower Cambrian carbonates (limestone and dolomites) and fine-grained clastic rocks. The vertical ore body has intricate drag folds and some brecciation has occurred. Mineralized limestone beds within the mineralized area form ladderlike rungs across the vertical ore body. Minerals are sphalerite, fine-grained galena, and some pyrite and chalcopyrite.

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[1] Italic numbers in parentheses refer to items in the list of references preceding the appendix.

Spain's largest lead-zinc deposit is located near Cartegena on the southeastern coast of Spain. The lead-zinc mineralized zone occurs in a Miocene sequence of pebbly mudstone beds. Mineralization fills cavities and pebble-shaped voids. Ore minerals are marcasite, pyrite, galena, sphalerite, and quartz.

SWEDEN

The Zinkgruven and Garpenberg Mines, located in central Sweden, extract ore from large complex polymetallic sulfide ore bodies. Ore mineralization occurs in highly metamorphosed Precambrian country rocks composed mostly of siliceous volcanics.

The Vassbo-Guttusjo lead-zinc mineral deposits in west-central Sweden are stratabound, occurring in thin sequences of Lower Cambrian age sandstones. Diabase intrusions dissecting the Precambrian basement control the distribution of the ore bodies.

In northwestern Sweden, bordering the eastern slope of the Caledonian Mountains, the Laisvall lead-zinc deposit is stratabound with three major ore zones: a lower ore-bearing sandstone, a middle barren or low-grade sandstone, and an upper ore-bearing sandstone. These flat-lying ore bodies form two thin sheets in the lower and upper layers of the quartzitic sandstone horizons of upper Precambrian-Cambrian rocks.

The Stekenjokk copper-lead-zinc deposit in the Skellefte District of central Sweden is a massive pyritic ore body occurring in Koli metasediments and metavolcanics. The dominant host rock of ore is an altered quartz-keratophyre. Predominant sulfide minerals are galena, sphalerite, chalcopyrite, and pyrite. Other minerals present are barite, fluorite, calcite, and sericite.

UNITED STATES

A detailed geologic summary of lead and zinc deposits in the United States (*7*) has been published. This report will focus only on the two most important areas in the United States; southeast Missouri lead deposits and the eastern Tennessee zinc deposits.

Missouri

The lead deposits in southeastern Missouri occur on the flanks of a dome in a series of Upper Cambrian sedimentary rocks that encircle the St. Francois Mountains. Although there is some mineralized rock in other Paleozoic strata, most of the ore bodies occur in the brown dolomite of the Bonne Terre Formation.

Ore deposits are stratiform and the minerals generally occur either in replacement of disseminated deposits, veinlets, or fillings in open spaces. Although the deposits consist mostly of lead-bearing minerals, enough zinc is present for six of the seven producing mines to be included among the top zinc producers in the United States. Small amounts of copper, nickel, cobalt, and cadmium also occur in the deposits but only zinc, copper, and cadmium are currently recovered as byproducts.

The Old Lead Belt, on the eastern flank of the St. Francois Mountains, is an area of extensive historical production but is almost mined out, and development is now centered in the more recently discovered Viburnum Trend to the west. All of the Missouri sites evaluated in this study are located in the Viburnum Trend except the Higdon and Bonne Terre Mines, which are in the Old Lead Belt. The Indian Creek Mine is not located in the main portion of the Viburnum Trend, but is considered to be in an offset portion of it.

Tennessee

All of the deposits in Tennessee, with the exception of the Copperhill (Ducktown) Mines, are Mississippi Valley-type and occur in dolomite or limestone beds in either the Kingsport Formation and/or the Mascot Dolomite of the Cambro-Ordovician Knox Group.

The deposits evaluated for this study occur in either the central Tennessee-Kentucky area, the Copper Ridge District, or the Mascot-Jefferson City District. Strata are generally horizontal in the central Tennessee-Kentucky region but dip moderately to the southeast in the other two districts.

The minerals generally occur in breccia bodies that are very complex and irregular in shape, forming a netlike pattern around islands of barren rock. Individual breccia bodies located on different stratigraphic levels may be connected by vertical pipe-shaped breccia bodies (breakthrough ore bodies) also containing mineralized rock. All of the deposits are Mississippi Valley-type with sphalerite as the major zinc mineral; minor amounts of galena also occur.

The Copperhill Mines are located in the Ducktown Mining District. For this study, the Boyd, Calloway, Cherokee, and Eureka Mines and the North and South Pits were included in the Copperhill evaluation. Minerals occur in metamorphosed massive sulfide accumulations in metamorphosed interbedded graywackes and mica schists in the Upper Precambrian Copperhill Formation of the Great Smoky Group. These rocks have been folded and faulted. There are two or possibly three series of beds that are favorable for mineralization, and many of the deposits occur where the favorable sediments have been thickened by folding. All of the deposits contain iron, copper, and zinc, with minor gold, silver, and lead.

ZAIRE

The Kipushi District of Shaba Province has the only major zinc-copper deposit of the country. The deposit is a replacement body in sedimentary (dolomitic) formations of the Kundulungu Series. The mineralized zone is located on the Zaire-Zambia border along a transverse fault crossing the northwest strike of Kipushi anticline. The ore mineralization was formed in two stages. The first stage mineralization consists of pyrite-arsenopyrite-sphalerite and minor galena. The second stage has a cobaltiferous chalcopyrite phase and an argentiferous bornite phase.