Information Circular 8930

Copper Availability—Market Economy Countries

A Minerals Availability Program Appraisal

By R. D. Rosenkranz, E. H. Boyle, Jr., and K. E. Porter

UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

BUREAU OF MINES
Robert C. Horton, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

This publication has been cataloged as follows:

Library of Congress Cataloging in Publication Data

Rosenkranz, Rodney D.
Copper availability—market economy countires.

(Information circular; 8930)

Bibliography: p. 29

Supt. of Docs. no.: I 28.27:

1. Copper industry and trade. I. Boyle, Edward H. II. Porter, K. E. (Kenneth E.) III United States. Bureau of Mines. IV. Title. V. Series: Information circular (United States. Bureau of Mines); 8930.

TN295.U4 [HD9539.C6] 622s [338.4'76733] 82-600393

PREFACE

In order to assess the availability of nonfuel minerals, the Bureau of Mines Minerals Availability Program identifies, collects, compiles, and evaluates information on producing, developing, and explored mines and deposits and mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, identify by cost evaluation resources that are reserves, and prepare analyses of mineral availabilities.

This report is one of a continuing series of minerals availability reports that analyze the availability of 34 minerals from domestic and foreign sources. Questions about the program should be addressed to: Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW, Washington, D.C. 20241.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

lb	pound	ton/d	(metric) ton per day
oz/ton	troy ounce per (metric) ton	ton/yr	(metric) ton per year
pct	percent		

COPPER AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Program Appraisal

By R. D. Rosenkranz,[1] E. H. Boyle, Jr.,[2] and K. E. Porter[3]

ABSTRACT

The Bureau of Mines has investigated the availability of copper from 272 deposits in market economy countries. The deposits studied have demonstrated resources totaling 413 million metric tons of contained copper and account for more than 90 pct of the reserve base for market economy countries. Using data gathered as part of its Minerals Availability Program, the Bureau performed geologic, engineering, and economic evaluations in order to determine the copper production potential of each deposit.

At the 1981 copper market price of $0.85/lb, the deposits studied could economically produce an estimated 88 million metric tons of copper (allowing for profit computed at a 15-pct rate of return), primarily from mines operating at the time of the study (1981). At this price, producing mines in market economy countries could economically produce only 2.1 million metric tons of refined copper per year. However, actual 1981 production was 6.2 million metric tons, indicating that many mines continued to operate even though they were unable to cover all production costs. For U.S. producing mines, the estimated average cost of production per pound (including profit at a 15-pct rate of return) was $0.15 higher than the average cost in other market economy countries.

[1] Mineral economist.
[2] Geologist.
[3] Mining engineer.
All authors are with the Minerals Availability Field Office, Bureau of Mines, Denver, Colo.

INTRODUCTION

BACKGROUND

The world copper industry has been in a depressed state since 1974. Because of low copper prices throughout the 1970's, many mines curtailed production, and new developments were postponed or canceled. In early 1980, a brief increase in copper and byproduct prices temporarily relieved the industry. However, because of recent decreases in these prices, combined with the effects of inflation and the high cost of borrowed money, the future of the world copper industry remains uncertain.

In the United States, since 1981, many copper mines have experienced temporary shutdowns, and several have closed, perhaps permanently. Low copper and byproduct prices, together with production costs that were higher than those in foreign countries (an average of $0.15 higher per pound of refined copper), resulted in 1982 U.S. copper production estimated at only 65 pct of capacity.

SUMMARY OF EVALUATION PROCEDURE

The Bureau's primary objectives in this study were to evaluate the availability of copper from the world's market economy countries and to assess domestic copper resources in relation to those of all other market economy countries. The procedures used to accomplish these objectives were as follows:

1. The quantity and quality of world copper resources were evaluated in relation to physical, technological, political, and other factors that affect production for each of the deposits studied.
2. Capital investments and operating costs for appropriate mining, concentrating, and processing methods were estimated for each deposit.
3. An economic analysis was performed for each deposit. (The results of these analyses indicate the unit cost and associated tonnages of copper that could be recovered from each deposit at specific production levels. The analyses concentrated on determining the cost of production and did not consider the effects of demand and market price.)
4. Price-production relationships were combined and analyzed in the form of total and annual availability curves to show combined market economy and regional copper production potentials at various commodity prices.

OTHER STUDIES

Copper availability studies quickly become obsolete because of changes in the many factors that influence the industry. Previous Bureau studies of domestic copper resources were based on 1964 *(19)*,[4] 1970 *(1)*, and 1978 data *(22)*. A 1980 Bureau study presented a perspective on the financial health of the U.S. copper industry *(27)*; and a 1981 Bureau report studied the problems, issues, and outlook for the U.S. copper industry *(25)*.

ACKNOWLEDGMENTS

Production and cost data for domestic deposits were developed at Bureau of Mines Field Operation Centers in Denver, Colo., Juneau, Alaska, Pittsburgh, Pa., and Spokane, Wash. Foreign data were collected through a contract with Golder Associates, Inc., of Denver, Colo.

WORLD COPPER PRODUCTION

World mine production of copper in 1980 was 7.7 million tons of contained copper;[5] of this total, 6 million tons was from market economy countries. World mine production for 1981 has been estimated at 7.8 million tons of contained copper, with market economy country mines producing 6.2 million tons.

World mine production for 1960, 1970, and 1980 is shown by region and country in table 1. Between 1960 and 1970, world mine production increased 43 pct from 4.2 million tons of contained copper to 6 million tons. During this time, Canada, Chile, the Philippines, the Republic of South Africa, the United States, and Zambia all greatly expanded production. From 1970 to 1980, world mine production increased at a slower rate, rising 27 pct. During this time, production increased by at least 100,000 tons of contained copper in Chile, China, Peru, the Philippines, Poland, and the U.S.S.R., while production in the United States dropped nearly 500,000 tons. However, the 1980 decline in U.S. production can be attributed primarily to strikes. Domestic production in 1981 has been estimated at 1.52 million tons of contained copper, which is about equal to 1970 production.

In 1980, North American mines produced 2.07 million tons of contained copper, accounting for 27 pct of world mine production and 34 pct of all market economy production. Central and South America was the next largest market economy region in terms of copper output, producing 1.44 million tons (24 pct of all market economy production), followed by Africa, which produced 1.35 million tons (22 pct). Central economy mines produced an estimated 1.63 million tons of contained copper in 1980, and more than 55 pct of this production came from the U.S.S.R.

Although U.S. mine production (of contained copper) dropped nearly 20 pct in 1980, to 1.2 million tons, owing to an industrywide labor strike, the United States remained the world's largest producer. However, 1980 Chilean mine production was 1.1 million tons, only 100,000 tons less

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

[5] In this report, "ton" refers to the metric ton (2,204.8 lb), except where otherwise indicated.

Table 1.—World mine production of copper, by region and country[1] *(2, 23, 28, 31)*
(Thousand metric tons)

Region and country	1960	1970	[p]1980
MARKET ECONOMY COUNTRIES			
North America:			
Canada[2]	399	610	[3]716
Mexico	60	61	175
United States[2]	980	1,560	[3,4]1,181
Total	1,439	2,231	2,072
Central and South America:			
Brazil	1	4	1
Chile	536	711	[3]1,068
Peru[2]	182	220	[3]367
Other	9	18	4
Total	728	953	1,440
Europe:			
Finland	28	31	37
Norway[5]	15	20	28
Spain	8	9	42
Sweden	18	26	43
Yugoslavia[6]	33	91	134
Other[e]	14	18	12
Total	116	195	296
Middle East and western Asia:			
Cyprus[5]	35	18	–
India[e]	9	11	22
Iran	–	–	4
Israel	6	8	1
Turkey	27	27	21
Total	78	64	48
MARKET ECONOMY COUNTRIES—Continued			
Eastern Asia and Oceania:			
Australia	111	158	[3]232
Indonesia	–	–	[3]58
Japan[6]	89	120	[3]52
Malaysia	–	–	27
Papua New Guinea	–	–	[3]147
Philippines	44	160	304
Other[e]	3	4	2
Total	247	442	822
Africa:			
Botswana[7]	–	–	[3]16
Namibia	21	31	[3]39
Republic of South Africa	46	150	[3]201
Zaire	302	386	[3]459
Zambia	576	684	[3]596
Zimbabwe	14	27	27
Other[e]	19	23	9
Total	978	1,303	1,347
Total, market economy countries	3,586	5,186	6,025
CENTRAL ECONOMY COUNTRIES			
Bulgaria	11	43	58
China[e]	70	100	200
Poland[2]	11	72	[3]346
U.S.S.R.[2,5,e]	499	571	900
Other	43	50	127
Total	634	836	1,631
Grand total	4,220	6,022	7,656

[e] Estimate. – indicates 0 or negligible tonnage in the year shown. [p] Preliminary.
[1] Data presented represent copper content (recoverable, where indicated) of ore mined wherever possible. If such data are not available the figures presented are the nonduplicative total copper content of ores, concentrates, matte, metal, and/or other copper-bearing products measured at the last stage of processing for which data are available. Table includes data available through June 29, 1981.
[2] Recoverable.
[3] Reported figure.
[4] The year 1980 was a strike year for U.S. mines and therefore is not representative of actual U.S. production. Production for 1981 was estimated to be 1.52 million tons.
[5] Includes copper content of cupriferous pyrite.
[6] Copper content of concentrates produced.
[7] Copper content of matte produced.

than that of the United States. Although the ore grade of Chilean copper has decreased in recent years, the Chilean Government has committed large amounts of capital to expand existing capacities and maintain or possibly increase output during the 1980's. Other large market economy producers include Canada, 716,000 tons; Zambia, 596,000 tons; Zaire, 459,000 tons; Peru, 367,000 tons; and the Philippines, 304,000 tons. Additional copper production and consumption data are available in other Bureau publications *(2, 24, 28)*.

IDENTIFICATION AND SELECTION OF COPPER DEPOSITS

Any study of copper availability that encompasses most of the world runs the risk of becoming bogged down in time-consuming efforts to collect data on insignificant deposits. Because of money and time constraints, a necessary first step in such a study is to rank deposits according to their significance. Using the criteria and procedures described below, the Bureau selected 272 copper deposits[6] in 40 market economy countries for this study. (Most deposits in the market economy countries not included in the study are insignificant.) The 272 deposits studied account for more than 90 pct of the copper reserve base for all market economy countries.

Using in-house and published data, the Bureau first compiled a list of neary 300 foreign deposits. Each deposit appeared to have a published resource of at least 100,000 tons of contained copper. The Bureau then issued a contract for the collection of additional deposit data. Of the approximately 300 initial deposits, about 100 were found to be raw prospects with very little exploration data, or they contained resources much smaller than 100,000 tons of contained copper. No further investigation was made of these deposits. (Reasons why individual deposits were not evaluated are listed in the appendix to this report.) Complete engineering and economic evaluations were performed on each of the remaining 199 foreign deposits and on 73 domestic deposits. Nearly all of these deposits have resources of at least 100,000 tons of contained copper. Most reserve and resource tonnage and grade calculations were computed from company measurements, samples, or production data and from estimations based on geologic evidence.

This study did not address the availability of copper from central economy countries. Although Bulgaria, China, Poland, and the U.S.S.R. are major producers, it

[6] In this report, "deposits" refers either to developing and/or explored copper properties or to all the properties and operations studied (i.e., producing, developing, and explored). "Mines" refers only to operations that were producing (or temporarily shut down) at the time of the study.

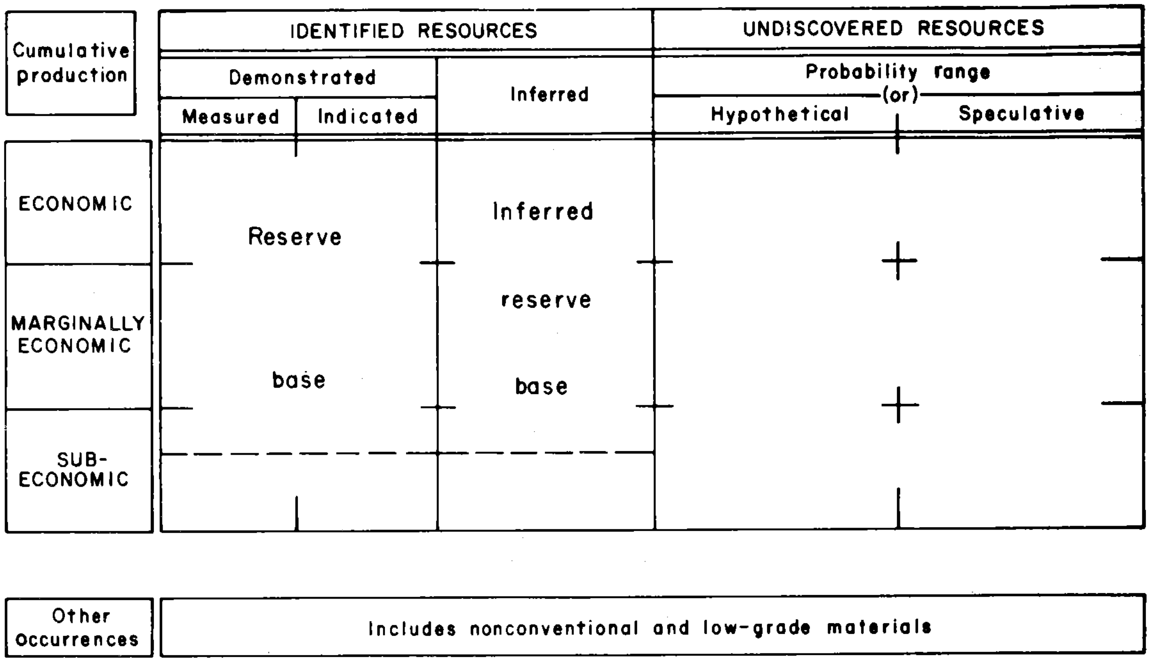

Figure 1.—Bureau of Mines-U.S. Geological Survey system for classification of mineral resources.

was not possible to collect the detailed data necessary to evaluate deposits in these countries.

Resource estimates for the deposits evaluated were made at the demonstrated resource level according to the mineral resource classification system developed by the U.S. Geological Survey and the Bureau of Mines (fig. 1) *(29)*. Using this classification system, a portion of the resources is termed the reserve base, which is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base includes resources that are currently economic (reserves), marginally economic (marginal reserves), and some that are currently subeconomic (subeconomic resources).

The world copper reserve base amounts to 505 million tons of contained copper, of which 445 million tons occurs in market economy countries *(28)*. U.S. deposits contain an estimated 90 million tons of copper. The 272 deposits analyzed in this study together have demonstrated resources of 413 million tons of contained copper.

Although low copper and byproduct prices have not encouraged exploration in recent years, known resources for many deposits are large enough to last for many years. In comparison with the demonstrated resource of 413 million tons of contained copper evaluated for this study, total land-based copper resources, including hypothetical and speculative deposits, are estimated to contain 1,627 million tons of copper. U.S. operating mines are estimated to contain an inferred tonnage of 68 million tons of copper in resources that have not been included in mining plans *(6)*. An additional 690 million tons is estimated to exist in deep-sea-nodule resources *(28)*. These additional resources were not evaluated in this study.

MARKET ECONOMY COPPER RESOURCES

Demonstrated resources for the 272 deposits analyzed have been estimated at 50 billion tons of in-place material averaging 0.83 pct copper. This material contains an estimated 413 million tons of copper which is 80 pct potentially recoverable with present technology.

Of the 330 million tons of copper potentially recoverable from the deposits analyzed, 63 pct exists in the 146 mines that were producing (or only temporarily shut down) at the time of the study, and 37 pct is contained in the 126 developing and explored deposits. An estimated 76 pct of the recoverable copper occurs in porphyry deposits (including disseminated, stockwork, and skarn), 16 pct is in stratabound sedimentary deposits, 3 pct is in massive sulfide deposits (including volcanogenic), and 5 pct occurs in other type deposits.

Figure 2[7] shows that a small percentage of the deposits analyzed accounts for a large percentage of the available copper. Of the resource potentially recoverable from producing mines, nearly 60 pct is attributable to only 10 pct of the mines (i.e., the 15 mines with the largest resources), and more than 80 pct is attributable to 25 pct of the mines (40 mines). Of the potential recoverable resource from nonproducing deposits, nearly 45 pct is attributable to 10 pct of the deposits (i.e., the 12 deposits with the largest resources), and about 70 pct is attributable to 25 pct of the deposits (31 deposits).

For this analysis, the market economy countries were disaggregated into six regions: North America, Central and South America, Europe, the Middle East and western

[7] Unless otherwise specified, all data in the illustrations and tables in this report are combined data for the 272 deposits studied.

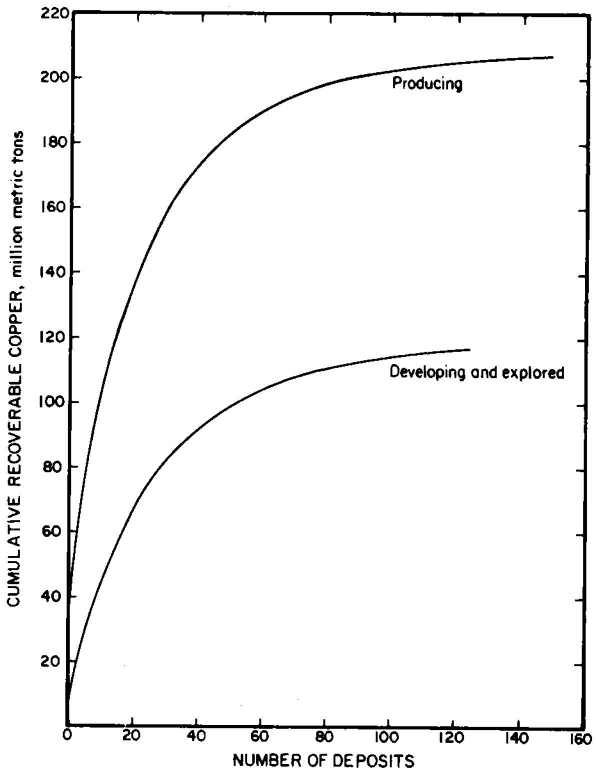

Figure 2.—Copper availability from producing and nonproducing deposits, based on number of deposits, with deposits ranked by size.

Table 2.—Number and status of copper deposits evaluated, by region and country

Region and country	Number of deposits	
	Producing	Nonproducing
North America:		
Canada	22	17
Mexico	2	4
United States	32	40
Central and South America:		
Argentina	0	3
Brazil	0	3
Chile	10	8
Panama	0	2
Peru	5	7
Europe:		
Finland	3	0
Norway	1	0
Portugal	1	1
Spain	3	1
Sweden	2	1
Yugoslavia	3	1
Middle East and western Asia:		
India	4	2
Iran	0	1
Israel	1	0
Jordan	0	1
Oman	0	1
Pakistan	0	1
Saudi Arabia	0	1
Turkey	3	2
Eastern Asia and Oceania:		
Australia	7	8
Burma	0	1
Fiji	0	1
Indonesia	1	0
Japan	2	0
Malaysia	1	0
Papua New Guinea	1	3
Philippines	14	9
Africa:		
Botswana	1	0
Mauritania	0	1
Morocco	1	0
Namibia	3	1
South Africa	5	1
Sudan	0	1
Uganda	0	1
Zaire	8	1
Zambia	9	1
Zimbabwe	1	0
Total	146	126

Asia, eastern Asia and Oceania, and Africa. Countries included in each of these regions are listed in table 2, which also shows how many deposits from each country were evaluated. As shown in table 3,[8] the Central and South American countries have the largest recoverable copper resources, and the recoverable resources of the North American countries are nearly as large. Individual countries with the largest recoverable copper resources include Chile, the United States, Peru, Zaire, Canada, Zambia, and Mexico. These countries account for over 75 pct of the copper potentially recoverable from the market economy deposits studied. Table 4 shows that of these countries' recoverable copper resources, over 60 pct, or approximately 206 million tons, occurs in mines that were producing at the time of the study. An estimated 55 pct of these resources will probably be mined by surface methods. Recoverable copper resources occurring in nonproducing deposits are described in table 5.

In the sections that follow, the copper resource of each of the six regions identified in table 2 is discussed. Tables in each section provide a description of each of the deposits evaluated. The deposit descriptions include production status, year of first production, mining and geological type, annual capacity, and size range of copper resource.

NORTH AMERICA

The 117 North American deposits analyzed in this study are listed in table 6. These deposits have a resource potential of 105 million tons of recoverable copper, or 32 pct of the total potentially recoverable from market economy countries. Of the three North American countries, the United States has by far the largest recoverable resources, totaling 66 million tons, with over half occurring in Arizona. (Only Chile's copper resources are larger than those of the United States.) Canada and Mexico also have significant resources of recoverable copper, with totals of 20 and 18 million tons, respectively. (Not included in tables 3-6 is an additional 4 million tons of copper that is potentially recoverable as a byproduct of Canadian nickel deposits. These deposits were not included in the analyses because cost information was unavailable at the time of the study.) Over 60 pct of North American resources occur in mines that were producing at the time of the study.

Ore grades for North American copper deposits are generally lower than those of the other regions, ranging from 0.67 pct Cu in Mexico to 0.52 pct Cu in Canada. The average grade for U.S. deposits is 0.66 pct Cu. From many Canadian deposits, low-grade copper is economically recoverable only as a coproduct or byproduct of other metal production.

Thirty-five North American deposits have copper resources of greater than 1 million tons of contained

[8] Unless otherwise specified, all data in the tables in this report are for January 1981, and costs and prices are average 1981 dollars.

Table 3.—Copper resource information, by region and country

Region and country	Number of deposits	In-place copper grade, pct	Million metric tons: In-place material	Million metric tons: Contained copper	Million metric tons: Recoverable copper[1]	Recoverable copper as a percent of market economy total
North America:						
Canada	39	0.52	4,505	23.4	20.3	6.2
Mexico	6	.67	3,339	22.5	18.0	5.5
United States	72	.66	12,527	83.0	66.3	20.1
Total or average[2]	117	.63	20,371	128.9	104.5	31.7
Central and South America:						
Argentina	3	.56	1,279	7.2	6.2	1.9
Brazil	3	1.38	120	1.7	1.3	.4
Chile	18	.97	10,352	100.1	85.7	26.0
Panama	2	.77	1,551	11.9	9.2	2.8
Peru	12	.85	2,974	25.3	21.6	6.6
Total or average[2]	38	.90	16,276	146.1	124.1	37.7
Europe:						
Spain	4	.64	256	1.7	1.2	.4
Yugoslavia	4	.57	1,347	7.1	5.6	1.7
Other	9	.68	719	4.9	3.7	1.1
Total or average[2]	17	.59	2,322	13.6	10.6	3.2
Middle East and western Asia:						
India	6	1.26	244	3.1	2.3	.7
Turkey	5	1.91	99	1.9	1.3	.4
Other	6	.87	856	7.4	6.1	1.9
Total or average[2]	17	1.04	1,198	12.4	9.7	2.9
Eastern Asia and Oceania:						
Australia	15	1.77	894	15.8	11.8	3.6
Papua New Guinea	4	.50	2,141	10.8	8.6	2.6
Philippines	23	.48	3,219	15.4	11.0	3.3
Other	6	.66	951	6.3	3.9	1.2
Total or average[2]	48	.67	7,205	48.3	35.3	10.7
Africa:						
Namibia	4	2.53	32	.8	.5	.2
South Africa	6	.66	521	3.4	2.9	.9
Zaire	9	4.01	693	28.3	21.4	6.5
Zambia	10	3.04	997	30.4	19.4	5.9
Other	6	1.90	72	1.4	1.1	.3
Total or average[2]	35	2.77	2,314	64.2	45.3	13.7
Grand total or average[2]	272	.83	49,686	413.4	329.5	100.0

[1] Losses from mining and processing have been subtracted.
[2] Data may not add to totals shown because of independent rounding.

copper each. Resources from these deposits account for nearly 80 pct of the copper recoverable from all North American operations and total nearly 16 billion tons of material averaging 0.65 pct Cu.

Five North American deposits were either developing or planned for development at the time of this study; one was in Canada, and four were in the United States. The Valley Copper deposit (also known as Lake Zone) in Canada, which was recently purchased by Cominco, Ltd., has published reserves of 726 million tons of ore, with grades of 0.475 pct Cu and 0.005 pct Mo, and minor amounts of gold and silver. Production may be possible by 1984 *(3)*. Two U.S. deposits, the Copper Flat deposit in New Mexico and the Troy deposit in Montana, were in development at the beginning of this study but have since begun production. Copper Flat, a joint venture of Quintana Minerals Corp. and Philbro Mineral Enterprises, has published ore reserves of 54 million tons grading 0.4 pct Cu, 5.5 oz/ton Ag, and 0.22 oz/ton Au; it also contains significant amounts of molybdenum *(15)*. The open pit mine began production in early 1982 but was shut down several months later because of market conditions. The Troy copper-silver mine, owned by ASARCO Incorporated, began limited production in August 1981 and is expected to become the largest U.S. producer of silver. A room-and-pillar mining method is yielding 7,700 tons of ore per day. Reserves are sufficient for 17 years of production; grades average 1 pct Cu and approximately 2 oz/ton Ag. About $82 million has been invested *(14)*. The Miami East, Ariz., deposit, owned by Cities Service Co., will be an underground cut-and-fill operation. Production was originally scheduled for mid-1982, but has been postponed owing to market conditions. At a daily production of 1,800 tons of ore, the ore body is expected to be mined out in about 13 years *(12)*. The Casa Grande, Ariz., deposit will be an underground operation with a planned daily copacity of 6,350 tons of ore. Production was originally scheduled to begin in 1984, but startup of this mine has also been postponed due to market conditions.

CENTRAL AND SOUTH AMERICA

The 38 mines and deposits evaluated in Central and South America are listed in table 7. Demonstrated resources for this region, estimated at 124 million tons of recoverable copper, are larger than those of any other region and account for 38 pct of the copper potentially

Table 4.—Average ore grade and recoverable copper from producing mines,[1] by region and country

Region and country	Surface mines			Underground mines		
	Average ore grade, pct	Recoverable copper, million metric tons	Average life, yr	Average ore grade, pct	Recoverable copper, million metric tons	Average life, yr
North America:						
Canada	0.38	4.4	15	2.10	3.6	14
Mexico	.71	12.7	44	NAp	NAp	NAp
United States	.67	30.7	26	.88	7.6	27
Total or average[2]	.65	47.9	28	1.03	11.1	21
Central and South America:						
Chile	1.02	18.6	33	1.00	44.2	90
Peru	.79	9.6	31	1.36	.8	21
Total or average[2]	.93	28.2	32	1.01	45.0	85
Europe	.51	5.0	32	1.00	1.2	24
Middle East and western Asia	1.19	.5	15	1.16	.5	27
Eastern Asia and Oceania:						
Australia	1.79	.1	7	3.01	5.7	33
Philippines	.49	3.6	22	.47	2.0	19
Other	.44	2.4	16	2.56	1.6	18
Total or average[2]	.48	6.1	19	1.33	9.3	26
Africa:						
Zaire	4.05	11.7	32	3.90	5.8	33
Zambia	NAp	NAp	NAp	3.20	10.1	29
Other	.55	1.8	15	1.48	1.3	12
Total or average[2]	2.29	13.4	28	3.13	17.2	27
Grand total or average[2]	.75	101.1	28	1.27	84.3	40

NAp Not applicable.
[1] Does not include mines having leach operations only or combined surface and underground operations. An additional 21 million tons of copper is recoverable from these mines.
[2] Data may not add to totals shown because of independent rounding.

Table 5.—Average ore grade and recoverable copper from developing and explored deposits,[1] by region and country

Region and country	Surface deposits			Underground deposits		
	Average ore grade, pct	Recoverable copper, million metric tons	Average life, yr	Average ore grade, pct	Recoverable copper, million metric tons	Average life, yr
North America:						
Canada	0.47	10.3	24	0.88	0.4	11
Mexico	.59	5.1	20	1.57	.1	13
United States	.42	10.5	25	.95	11.9	23
Total or average[2]	.47	26.0	23	.95	12.4	22
Central and South America:						
Argentina	.56	6.2	31	NAp	NAp	NAp
Chile	.84	20.5	32	1.20	1.1	33
Peru	.87	11.1	25	3.20	.2	11
Other	.77	9.2	45	1.05	.1	11
Total or average[2]	.78	47.1	32	1.28	1.4	24
Europe	.43	2.4	33	1.57	.8	18
Middle East and western Asia	.85	6.0	34	2.38	1.1	18
Eastern Asia and Oceania:						
Australia	.92	.5	24	1.29	5.1	40
Philippines	.52	2.5	15	.60	.5	36
Other	.52	8.6	27	NAp	NAp	NAp
Total or average[2]	.52	11.7	23	1.17	5.6	40
Africa:						
Zaire	5.70	3.0	36	NAp	NAp	NAp
Zambia	NAp	NAp	NAp	4.08	.2	15
Other	2.63	.6	12	1.03	.8	19
Total or average[2]	4.68	3.5	27	1.26	1.0	18
Grand total or average[2]	.63	96.6	28	1.09	22.3	24

NAp Not applicable.
[1] Does not include deposits having leach operations only or combined surface and underground operations. An additional 4.2 million tons of copper is potentially recoverable from these deposits.
[2] Data may not add to totals shown because of independent rounding.

Table 6.—Descriptive information for individual North American copper deposits

Country and deposit name	Ownership	Status[1]	Year of first production[2]	Mining type[3]	Geological type[4]	Copper resource[5]	Capacity,[6] thousand metric tons copper per year
Canada:							
Afton	Teck Corp.–Iso Mines Ltd.	P	1977	S	P	A	17.3
Bell Copper	Noranda Mines Ltd.	P	1972	S	P	A	21.4
Berg	Kennco Explorations (Western)	E	—	S	P	C	54.7
Bethelem–JA Zone	Bethlehem Copper Ltd.	P	1962	S	P	B	23.2
Brenda	Brenda Mines–Noranda	P	1970	S	P	A	11.4
Casino	Casino Mining Co.	E	—	S	P	B	25.2
Catface	Falconbridge–Catface Copper	E	—	S	P	B	29.5
Copper Mountain–Needle Mountain.	Mines Gaspe–Noranda	P	1955	S/U	P	B	36.1
Copper Rand	Patino Mines	P	1959	U	O	A	10.6
Coppermine River	Coppermine River Ltd.	E	—	S	M	A	6.1
Detour Project	Selco Mining Corp. Ltd.	E	—	S/U	O	A	9.5
Flin Flon	Hudson Bay Mining and Smelting Co. Ltd.	P	1930	U	M	A	8.6
Fox	Sherritt Gordon Mines Ltd.	P	1970	U	M	A	8.7
Galore Creek	Stikine Copper Ltd.	E	—	S	P	C	46.5
Geco	Noranda Mines Ltd.	P	1957	U	M	A	25.7
Gibraltar	Gibraltar Mines Ltd.	P	1972	S	P	B	37.7
Granduc	Granduc Mines–Esso Resources	P	1971	U	O	A	20.0
Granisle	Noranda Mines Ltd.	P	1966	S	P	A	14.8
Great Lakes Nickel	Boliden Canada Ltd.	E	—	U	O	A	9.0
Heath Steel (Little River JV)	Heath Steel Mines Ltd.–Noranda–Asarco	P	1957	U	M	A	7.1
High Lake	Kennarctic Explorations	E	—	U	P	A	8.7
Highmont	Highmont Mining Corp.	P	1981	S	P	A	18.8
Huckleberry Mountain	Kennco Explorations Ltd.	E	—	S	P	A	13.6
Island Copper	Utah Mines Ltd.	P	1971	S	P	B	48.9
Izok Lake	Texasgulf Inc.	E	—	S	M	A	16.8
Kidd Creek	....do.	P	1966	U	M	D	111.1
Lake Dufault Division	Falconbridge Copper Ltd.	P	1964	U	M	A	10.6
Lornex	Lornex Mining Corp. Ltd.	P	1972	S	P	C	86.8
Maggie	Bethlehem Copper Ltd.	E	—	S	P	A	13.3
Opemiska Division	Falconbridge Copper Ltd.	P	1954	U	O	A	14.3
Poison Mountain	Long Lac Copper Giant	E	—	S	P	B	14.0
Ruttan	Sherritt Gordon Mines Ltd.	P	1973	U	M	A	41.6
Sam Goosly	Equity Mining–Placer Development	P	1980	S	P	A	4.9
Shaft Creek	Teck Corp.–Liard Copper Mines	E	—	S	P	C	29.2
Similkameen	Newmont Mining Corp.	P	1925	S	P	B	23.8
Summer Creek	Global Energy Corp.	E	—	S	P	A	15.7
Sustut	Falconbridge Nickel Mines Ltd.	E	—	S	P	B	39.6
Thierry	Union Miniere S.A.	P	1976	U	O	A	12.3
Valley Copper	Cominco Ltd.	D	1984	S	P	E	126.8
Mexico:							
Arroyos Azules	Comision de Fomento Minero	E	—	U	O	A	8.9
Cananea	Industrial Minera Mexico	P	1899	S	P	G	149.6
El Arco	Industrial Minera Mexico–Asarco	E	—	S	P	E	150.1
La Caridad	Mexicana del Cobre	P	1980	S	P	E	139.2
La Verde	Compania Cuprifera la Verde	E	—	S	P	A	25.8
Santo Tomas	Industrial Minera Penoles	E	—	S	P	D	77.0
United States:							
Alaska:							
Arctic Camp	Bear Creek Mining Co. (subsidiary of Kennecott Minerals Co.).	E	—	S/U	O	C	109.5
Bornite	....do.	E	—	U	M	B	21.5
Brady Glacier	Newmont Mining Corp.	E	—	U	P	A	12.4
Orange Hill–Bond Creek	Bear Creek Mining Co. (subsidiary of Kennecott)	E	—	S	P	C	29.4
Yakobi Island	Inspiration Development Co.	E	—	S	P	A	1.3
Arizona:							
Bagdad	Cyprus Mines Corp. (subsidiary of AMOCO Metals Co.)	P	1906	S	P	C	51.7
Bluebird	Ranchers Exploration and Development	P	1961	S	P	A	8.0
Casa Grande	Casa Grande Copper Co.	E	—	U	P	E	87.2
Christmas	Inspiration Consolidated Copper Co.	P	1905	S/U	P	B	12.7
Copper Basin	Phelps Dodge Corp.	E	—	S	P	B	25.1
Cyprus Johnson	Cyprus Mines Corp. (subsidiary of AMOCO Metals Co.)	P	1975	S	P	A	4.6
Dubacher Canyon	Occidental Mineral Corp.	E	—	S	P	A	7.9
Esperanza	Duval Corp. (subsidiary of Pennzoil)	P	1959	S	P	A	8.8
Florence Conoco	Continental Oil (Minerals Division)	E	—	S	P	D	57.2
Helvetia East	Anamax Mining Co.	E	—	S	P	C	34.4
Helvetia West	Inspiration Consolidated Copper Co.	E	—	S	P	A	5.5
Inspiration	....do.	P	1915	S	O	B	43.0
Lakeshore	Noranda Mines Ltd.	P	1976	U	P	A	40.6
Magma (Superior)	Magma Copper Corp.	P	1907	U	S	A	36.8
Metcalf	Phelps Dodge Corp.	P	1975	S	P	D	50.9

See explanatory notes at end of table.

recoverable from market economy countries. Nearly 60 pct of the resource occurs in the 15 mines that were producing at the time of the study. Chilean deposits contain an estimated 86 million tons of recoverable copper, which is nearly 70 pct of the region's total. Peru has resources estimated at 22 million tons of recoverable copper, or 17 pct of the region's total, while Panama and Argentina have resources of 9 and 6 million tons, respectively.

Chile has the largest recoverable copper resources of all the market economy countries. (U.S. resources of in-place material are 20 pct larger than those of Chile, but Chile, because of a much higher average ore grade and higher mining and/or processing recoveries, exceeds the United

Table 6.—Descriptive information for individual North American copper deposits—Continued

Country and deposit name	Ownership	Status[1]	Year of first production[2]	Mining type[3]	Geological type[4]	Copper resource[5]	Capacity,[6] thousand metric tons copper per year
United States—Continued:							
Arizona—Continued							
Miami East	Cities Services Co.	E	—	U	P	B	24.5
Miami Leach	....do.	P	1909	S	P	A	5.3
Mineral Park	Duval Corp. (subsidiary of Pennzoil)	P	1965	S	P	A	14.0
Mission–San Xavier	Asarco Incorporated	P	1961	S	P	C	38.7
Morenci	Phelps Dodge Corp.	P	1942	S	P	E	100.2
New Cornelia	....do.	P	1917	S	P	A	43.8
Oracle Ridge	Continental Copper Co. (subsidiary of Union Oil)	E	—	U	P	A	9.8
Ox Hide	Inspiration Consolidated Copper Co.	P	1968	S	P	A	4.3
Palo Verde	Anamax Mining Co.	P	1979	S	P	B	23.7
Peacock	Producers Mineral Corp.	E	—	S	P	A	6.5
Pima	Cyprus Mines Corp. (subsidiary of AMOCO Metals Co.)	P	1957	S	P	A	68.6
Pinto Valley	Cities Services Co.	P	1943	S	P	C	82.8
Ray	Kennecott Minerals (subsidiary of Standard Oil of Ohio)	P	1911	S	P	E	63.5
Red Mountain	Kerr-McGee Corp.	E	—	U	P	B	42.8
Sacaton	ASARCO Incorporated	P	1974	S/U	P	A	22.8
Safford Inspiration	Inspiration Consolidated Copper Co.	E	—	S	P	B	20.7
Safford Kennecott	Kennecott Minerals (subsidiary of Standard Oil of Ohio)	E	—	S	P	D	21.9
Safford Phelps Dodge	Phelps Dodge Corp.	E	—	U	P	D	116.0
San Manuel–Kalamazoo	Magma Copper Ltd.	P	1955	U	P	F	112.6
Sierrita	Duval Sierrita (subsidiary of Pennzoil)	P	1970	S	P	C	85.0
Silver Bell	ASARCO Incorporated	P	1954	S	P	A	18.4
Twin Buttes	Anamax Mining Co.	P	1969	S	P	D	67.2
Van Dyke	Occidental Minerals Corp.	E	—	S	P	A	8.0
Vekol Hills	Newmont Mining Corp.	E	—	S	P	B	28.3
California:							
Lights Creek	Placer Amex Inc.	E	—	S	P	C	27.3
Walker	Calicopia Corp.	E	—	U	P	A	3.5
Michigan:							
Presque Isle Syncline	AMAX Inc.	E	—	U	P	C	30.6
White Pine	Copper Range Co.	P	1953	U	S	E	80.0
Minnesota:							
Ely Spruce	International Nickel Co.	E	—	S	P	C	48.0
Minnamax	AMAX Inc.	E	—	U	P	D	52.0
Montana:							
Butte Copper	Anaconda Co. (subsidiary of Atlantic Richfield Co.)	P	1982	S/U	P	E	81.2
Heddleston	....do.	E	—	S	P	A	16.4
Stillwater	....do.	E	—	S	O	A	18.0
Troy	ASARCO Incorporated	D	1982	U	S	A	16.4
Nevada:							
New Ruth	Kennecott Minerals (subsidiary of Standard Oil of Ohio)	N	1970	S	P	A	2.1
Victoria	Day Mines Inc.	N	1974	U	P	A	5.9
Yerrington	Anaconda Co. (subsidiary of Atlantic Richfield Co.)	N	1953	S	P	A	20.7
New Mexico:							
Chino	Kennecott Minerals (subsidiary of Standard Oil of Ohio)	P	1912	S	P	D	48.8
Continental Surface	U.V. Industries Inc.	P	1968	S	P	A	10.3
Continental Underground	....do.	P	1968	U	P	A	12.5
Copper Flat	Quintana Minerals Corporation–Philbro Mineral Enterprises	D	1982	S	P	A	14.9
Nacimiento	Earth Resources Co.	E	—	S	S	A	1.4
Pinos Altos	Exxon Minerals Co.	E	—	S	O	A	9.8
Tyrone	Phelps Dodge Corp.	P	1970	S	P	C	91.0
Tennessee: Copper Hill	Cities Services Co.	P	1941	S/U	O	A	4.1
Utah:							
Bingham	Kennecott Minerals (subsidiary of Standard Oil of Ohio)	P	1872	S	P	F	250.8
Carr Fork	Anaconda Co. (subsidiary of Atlantic Richfield Co.)	N	1979	U	O	B	49.5
Washington: Sunrise	International Brenmac Development Corp.	E	—	U	O	A	7.8
Wisconsin:							
Crandon	Exxon Mineral Co.	E	—	U	P	B	30.9
Flambeau	Flambeau Minerals Corp. (subsidiary of Kennecott)	E	—	S/U	M	A	9.2
Pelican River	Noranda Mines Ltd.	E	—	U	P	A	3.2
Wyoming: Kirwin	AMAX Inc.	E	—	S	O	A	25.6

[1] Status: D—developing or scheduled for development in near future; E—explored deposit, no immediate plans for production; P—producing at the time of the study (includes those temporarily shut down).
[2] Dash indicates no known production startup date; where a date later than 1982 is given, production was forecast to start that year.
[3] Mining type: S—surface; U—underground. For explored deposits, mining type is proposed based on geology and technology.
[4] Geological type: P—porphyry, includes disseminated, stockwork, and skarn; S—stratabound sedimentary; M—massive sulfide including volcanogenic deposits; O—other types.
[5] Copper resource (thousand tons of contained copper): A—<500; B—501–1,000; C—1,001–2,000; D—2,001–3,000; E—3,001–5,000; F—5,001–10,000; G—>10,000.
[6] Average annual recoverable copper capacity over the life of the mine. For explored deposits, the capacity is the proposed capacity for this evaluation.

States in recoverable copper.) Nearly 90 pct of Chile's copper resources are controlled through the state copper mining company, Corporacion Nacional del Cobre de Chile (CODELCO-Chile).

Average ore grades for Central and South American deposits range from 1.38 pct Cu for the three Brazilian deposits to 0.56 pct Cu for the Argentinean deposits. Chilean deposits average 0.97 pct Cu, which is nearly 1.5 times greater than the average grade for U.S. deposits. The grade for producing surface mines in Chile averages 1.02 pct Cu compared with only 0.67 pct Cu in the United States; nonproducing surface deposits in Chile average 0.84 pct Cu compared with the U.S. average of 0.42 pct Cu.

Chile has expanded production capabilities for its

Table 7.—Descriptive information for individual Central and South American copper deposits

Country and deposit name	Ownership	Status[1]	Year of first production[2]	Mining type[3]	Geological type[4]	Copper resource[5]	Capacity,[6] thousand metric tons copper per year
Argentina:							
Bajo La Alumbrera	Yacimientos Aqua del Dionisio	E	—	S	P	C	58.5
El Pachon	Cia. Minera Aguilar S.A.	D	1986	S	P	E	89.8
Paramillo Sur	Fabricaciones Militares	E	—	S	P	B	49.5
Brazil:							
Camaqua	Fibase	E	—	S	P	A	11.6
Caraiba	Caraibas Metais S.A.	D	1982	S/U	O	C	51.5
Pedra Verde	Promisa–Caraibas Metais S.A.	E	—	U	P	A	7.3
Chile:							
Andacollo	Enami	E	—	S	P	C	73.8
Andina	CODELCO-Chile	P	1970	U	P	E	65.8
Cerro Colorado	Cerro Colorado Mine Development Co.	E	—	U	P	B	20.3
Chuquicamata	CODELCO-Chile	P	1915	S	P	G	437.9
El Abra	....do.	E	—	S	P	F	118.3
El Salvador	....do.	P	1959	U	P	E	87.4
El Soldado (Disputada)	Exxon Minerals Co	P	1842	U	P	A	15.6
El Teniente	CODELCO-Chile	P	1906	U	P	G	380.4
Escondida	Utah International-Getty Oil	E	—	S	P	F	213.8
Lo Aguirre	Soc. Minera Pudahuel	P	1980	S	P	A	11.2
Los Bronces	Exxon Minerals Co.–Private	P	1925	S	P	F	143.2
Los Pelambres	Anaconda Co. Division of Arco	D	1986	S	P	E	100.7
Mantos Blancos	Empresas Sudamericana Consol.	P	1961	S	P	A	23.1
Mina Sur (La Exotica)	CODELCO-Chile	P	1970	S	P	C	40.1
Pampa Norte	....do.	E	—	S	P	C	45.2
Portrerillos	....do.	E	—	U	P	A	14.1
Quebrada Blanca	Chilean Government–Cia. Exploradora Dona Ines	D	1986	S	P	C	83.2
Sagasca	Soc. Minera Pudahuel	P	1970	S	P	A	11.2
Panama:							
Cerro Colorado	Empresa de Cobre Cerro Colorado S.A.	D	1987	S	P	G	172.2
Cerro Petaquilla	Panamanian Government	E	—	S	P	C	32.4
Peru:							
Antamina	Minero Peru	E	—	S	P	D	122.6
Berenguela	....do.	E	—	S	S	A	11.1
Cerro Verde–Santa Rosa	....do.	P	1977	S	P	F	82.8
Cobriza	Centromin	P	1967	U	S	B	35.8
Coroccohuayco	Minero Peru	E	—	U	O	A	15.3
Cuajone	Southern Peru Copper Corp.-Billiton Nv	P	1976	S	P	E	115.1
El Aguila	Empresa Minera el Aguila	P	1978	S	P	A	11.1
Michiquillay	Minero Peru–Michiquillay Copper Corp.	E	—	S	P	E	81.6
Quellaveco	Minero Peru	E	—	S	P	E	84.7
Tintaya	....do.	D	1984	S	P	B	38.3
Toquepala	Southern Peru Copper Corp.	P	1960	S	P	D	104.4
Toromocho	Centromin	E	—	S	P	E	100.7

[1] Status: D—developing or scheduled for development in near future; E—explored deposit, no immediate plans for production; P—producing at the time of the study (includes those temporarily shut down).
[2] Dash indicates no known production startup date; where a date later than 1982 is given, production was forecast to start that year.
[3] Mining type: S—surface; U—underground. For explored deposits, mining type is proposed based on geology and technology.
[4] Geological type: P—porphyry, includes disseminated, stockwork, and skarn; S—stratabound sedimentary; M—massive sulfide including volcanogenic deposits; O—other types.
[5] Copper resource (thousand tons of contained copper): A—<500; B—501–1,000; C—1,001–2,000; D—2,001–3,000; E—3,001–5,000; F—5,001–10,000; G—>10,000.
[6] Average annual recoverable copper capacity over the life of the mine. For explored deposits, the capacity is the proposed capacity for this evaluation.

producing mines, and plans to continue this expansion, in order to maintain its output of refined copper in the face of falling ore grades. As part of Chile's plan to double copper output by 1990, the Chilean Copper Commission recently announced that during the 1980's CODELCO-Chile will annually invest $250 to $300 million in the Andina, Chuquicamata, El Salvador, and El Teniente Mines. This represents a total investment of $2.5 to $3 billion for CODELCO's existing operations, which may be one reason CODELCO has put many of its undeveloped deposits up for international bid in recent years. The Government plans to enact new legislation allowing private companies to develop large new copper deposits, but plans are for the state to retain control over existing mines *(11)*. Chilean deposits targeted for development during the 1980's are Andacollo, El Abra, La Escondida, Los Bronces, Los Pelambres, and Quebrada Blanca. These deposits are expected to have a combined output potential of 765,000 tons of copper per year.

The Tintaya, Peru, deposit, with proven reserves of 34 million tons and an estimated life of 14 years, is expected to come on-stream in 1984. It is estimated that development costs for the 8,000-ton/d operation, including working capital and interest during construction, will total $300 million *(4)*. Although Peru has several other copper deposits awaiting development, private capital, including foreign capital, is needed to bring them into production. Priority for investment is being given to the Antamina, Tambo Grande, and Toromocho deposits *(13, 17)*.

Other regional projects scheduled for production include the Caraiba in Brazil, Cerro Colorado in Panama, and El Pachon in Argentina. The Caraiba project was originally scheduled to begin production in 1980, but because of high costs and problems in importing equipment, startup was expected to be delayed until 1982. The $1.2 billion operation is expected to reach a production capacity of 125,000 tons of contained copper in 1984 *(9)*. Ore reserves at the Cerro Colorado, Panama, deposit are estimated at 1.3 billion tons, these reserves are graded at 0.78 pct Cu and 0.015 pct Mo and contain significant gold and silver values. The cost of the project, which is expected to produce from 150,000 to 200,000 tons of copper in concentrate per year, is now estimated at $2 billion. Rio Tinto Zinc Corp., Ltd., which has a 40-pct interest in the project, recently stated that the earliest possible startup date would be 1987 and that the equivalent of $1.10/lb to $1.20/lb of copper (at 1980 prices) would be required to make the operation economic *(10)*. Production from the El Pachon, Argentina, deposit is scheduled to begin in 1986. The deposit has ore reserves of 800 million tons (0.71 pct Cu, 0.016 pct Mo, and 0.1 oz/ton Ag), and the production goal is 100,000 tons of copper per year. The investment required to develop El Pachon, once estimated at about $1.2 billion *(32)*, is now expected to total $1.8 billion.

Twenty-five Central and South American deposits have resources of greater than 1 million tons of contained copper each. Together these 25 deposits account for more than 95 pct of the region's recoverable copper. Generally, the largest deposits in Central and South America contain more copper than the largest deposits in the United States; for example, the 12 largest deposits in Chile average 6.6 million tons of recoverable copper per deposit, whereas the 12 largest deposits in the United States average only 3.1 million tons.

EUROPE

Seventeen European deposits were evaluated (table 8). Europe's copper resources are smaller than those of all the other regions except the Middle East and western Asia. Estimated recoverable copper totals 11 million tons, or only 3 pct of that available from market economy countries. Nearly 70 pct of the resource exists in mines producing at the time of the study. Averaging only 0.59 pct Cu, ore grades of the European deposits are the lowest of all the regions. This is due to the large-tonnage, low-grade Yugoslavian deposits and the fact that the Spanish deposits are coproduct or byproduct operations.

The European deposits are also small; only 4 of the 17 deposits analyzed have ore bodies containing more than 1 million tons of copper each. These four are the Aitik Mine, a producing surface mine in Sweden; the Aljustrel Mine, a producing underground mine in Portugal; and two surface deposits in Yugoslavia, the Majdanpek (a producing mine) and the Veliki Krivelj (which is scheduled for production in 1985).

Three European deposits are expected to begin production in the near future. The Neves-Corvo, Portugal, deposit is scheduled to begin operation in early 1986. Initial annual production of copper concentrate is projected at 50,000 tons. An investment of about $160 million is planned *(20)*. The Veliki Krivelj, Yugoslavia, deposit has reserves estimated at 700 million tons of ore, with a copper grade of 0.41 pct. The $370 million project has a planned capacity of 28,000 tons of copper per year *(8, 21)*. Scheduled to begin production in 1983, the Viscaria, Sweden, deposit has published reserves estimated at 50 million tons of ore graded at 1.9 pct Cu. However, feasibility study has indicated that only 50 pct of the reserves are recoverable *(35)*.

MIDDLE EAST AND WESTERN ASIA

Copper resources for this, the smallest of all the regions, are estimated at only 10 million tons of recoverable copper, or 3 pct of that available from market economy countries. Of the 17 deposits evaluated (table 9), 8 were producing at the time of the study; these 8 deposits

Table 8.—Descriptive information for individual European copper deposits

Country and deposit name	Ownership	Status[1]	Year of first production[2]	Mining type[3]	Geological type[4]	Copper resource[5]	Capacity,[6] thousand metric tons copper per year
Finland:							
Keretti	Outokumpu Oy	P	1957	U	M	A	12.3
Pyhasalmi	....do.	P	1962	U	M	A	6.8
Vuonos	....do.	P	1972	U	O	A	11.2
Norway: Tverrfjellet	Folldal Verk A/S	P	1968	U	M	A	5.7
Portugal:							
Aljustrel	Empresa Mineira e Metalurgicado do Alentejo E. P.	P	1892	U	S	C	8.6
Neves-Corvo	Emma–BRGM and Penarroya Sociedade Mineira Neves Corvo SARR.	D	1986	U	S	B	43.1
Spain:							
Aznalcollar	Sociedad Andaluza de Piritas	P	1979	S	M	A	13.4
Cerro Colorado	Rio Tinto Patino S.A.	P	1873	S/U	M	B	32.3
Santiago	....do.	P	1975	S	M	A	7.9
Sotiel	Minas de Almagreras S.A.	E	—	U	O	A	2.6
Sweden:							
Aitik	Boliden Metall AB	P	1968	S	O	C	36.8
Stekenjokk	....do.	P	1975	U	M	A	6.6
Viscaria	Luossavaara-Kiyrunauaara AB	D	1983	S	S	A	17.1
Yugoslavia:							
Bor	RTB Bor	P	1903	S/U	P	B	33.8
Bucim	Bucim Rudnik Za Bakar	P	1978	S	P	B	27.6
Majdanpek	RTB Bor	P	1965	S	P	D	70.1
Veliki Krivelj	....do.	D	1983	S	P	D	57.1

[1] Status: D—developing or scheduled for development in near future; E—explored deposit, no immediate plans for production; P—producing at the time of the study (includes those temporarily shut down).
[2] Dash indicates no known production startup date; where a date later than 1982 is given, production was forecast to start that year.
[3] Mining type: S—surface; U—underground. For explored deposits, mining type is proposed based on geology and technology.
[4] Geological type: P—porphyry, includes disseminated, stockwork, and skarn; S—stratabound sedimentary; M—massive sulfide including volcanogenic deposits; O—other types.
[5] Copper resource (thousand tons of contained copper): A—<500; B—501–1,000; C—1,001–2,000; D—2,001–3,000; E—3,001–5,000; F—5,001–10,000; G—>10,000.
[6] Average annual recoverable copper capacity over the life of the mine. For explored deposits, the capacity is the proposed capacity for this evaluation.

Table 9.—Descriptive information for individual Middle East and western Asia copper deposits

Country and deposit name	Ownership	Status[1]	Year of first production[2]	Mining type[3]	Geological type[4]	Copper resource[5]	Capacity,[6] thousand metric tons copper per year
India:							
Ambaji	Gujarat Mineral Development	E	—	U	M	A	3.2
Khetri–Kolihan–Chandamri	Hindustan Copper Ltd.	P	1973	U	O	B	19.5
Malanjkhand	....do.	E	—	S	O	B	22.0
Mosaboni	....do.	P	1965	U	O	A	13.2
Rakha	....do.	P	1919	U	O	A	15.2
Surda–Pathagora–Kendadih	....do.	P	1975	U	O	A	14.8
Iran: Sar Cheshmeh	National Iranian Copper	D	1983	S	P	E	136.5
Israel: Timna	Israel Chemical Ltd. (Government)	P	1959	U	S	A	4.2
Jordan: Wadi Dana	Jordan National Res. Auth.	E	—	S	S	A	29.2
Oman: Wadi Jiza	Oman Mining Co.	D	1982	U	M	A	17.8
Pakistan: Saindak	Resource Development Corp.	D	1985	S	P	C	12.9
Saudi Arabia: Jabal Sayid	Saudi Arabian Government	E	—	U	M	A	15.6
Turkey:							
Cayeli	Etibank	E	—	U	O	B	12.5
Ergani-Madeni	....do.	P	1980	S	P	A	7.2
Espiye	Etibank–Black Sea Copper Works Corp.	P	1980	S	M	A	7.2
Murgul	....do.	P	1972	S	M	B	30.6
Siirt	Turkish Government	E	—	U	M	A	9.8

[1] Status: D—developing or scheduled for development in near future; E—explored deposit, no immediate plans for production; P—producing at the time of the study (includes those temporarily shut down).
[2] Dash indicates no known production startup date; where a date later than 1982 is given, production was forecast to start that year.
[3] Mining type: S—surface; U—underground. For explored deposits, mining type is proposed based on geology and technology.
[4] Geological type: P—porphyry, includes disseminated, stockwork, and skarn; S—stratabound sedimentary; M—massive sulfide including volcanogenic deposits; O—other types.
[5] Copper resource (thousand tons of contained copper): A—<500; B—501–1,000; C—1,001–2,000; D—2,001–3,000; E—3,001–5,000; F—5,001–10,000; G—>10,000.
[6] Average annual recoverable copper capacity over the life of the mine. For explored deposits, the capacity is the proposed capacity for this evaluation.

account for less than 25 pct of the region's recoverable copper. Copper grades are higher than in most other areas of the world, averaging 1.26 pct in India, 1.91 pct in Turkey, and 1.04 pct for the region.

Only two deposits in the region have resources containing more than 1 million tons of copper each. The Sar Cheshmen deposit in Iran, the largest in the region, contains over 5 million tons of copper. Most of the infrastructure requirements for this deposit were completed by the end of 1978, and ore production had begun. But because of the Iranian revolution, foreign personnel were withdrawn and work was suspended until December 1981, when production resumed. The Saindak deposit in Pakistan, the region's other large deposit, has proven copper resources of 374 million tons at an average copper grade of 0.37 pct. The project is scheduled to begin production in 1984 at an estimated cost of more than $300 million *(33)*. Estimated to cost $120 million, the Wadi Jiza deposit in Oman began production in 1982 *(7)*.

EASTERN ASIA AND OCEANIA

Recoverable copper resources from eastern Asia and Oceania are estimated at 35 million tons, or 11 pct of the total available from market economy countries. Three countries, Australia, the Philippines, and Papua New Guinea account for over 90 pct of the region's resources. As shown in table 10, 48 of the region's deposits were evaluated. Thirteen deposits have resources of more than 1 million tons of contained copper each; together they account for over 75 pct of the region's recoverable copper. Average ore grades vary greatly from country to country, ranging from a high of 1.77 pct Cu for the Australian deposits to 0.50 pct Cu in Papua New Guinea and 0.48 pct Cu in the Philippines.

Several deposits in the region are being developed or are targeted for development in the near future. The largest of these, the OK Tedi deposit in Papua New Guinea, is currently being developed. Three stages of mining are planned; phase 1, scheduled to begin in 1984, will involve mining of the gold cap ore; in phase 2, scheduled for mid-1986, copper and gold ore will be mined; in phase 3, scheduled for 1989, copper production will be doubled and gold production will be converted to copper production, effectively tripling copper output. The project is estimated to cost as much as $2 billion *(16)*.

Construction problems and bad weather have delayed startup of the Amacan (North Davao) deposit in the Philippines until mid-1982. The original estimated cost of $100 million has been increased to $175 million. Planned capacity is 30,000 tons per day ore *(18)*. Construction is expected to begin soon on the Hinobaan, Philippines, project, and a 1984 production startup is planned. Published reserves are estimated at 98 million tons of ore graded at 0.5 pct Cu.

A feasibility study is expected to be completed on the Golden Grove, Australia, deposit by 1983, with production possibly beginning in 1986. A partnership of four companies, the project comprises two combined deposits, Gossan Hill and Scuddles. Besides copper, significant quantities of lead, silver, and zinc are present.

Development is ahead of schedule for the Monywa, Burma, deposit; production was scheduled to begin in 1982. Planned mine capacity has been increased to 12,000 tons of ore per day. A proposal to build a smelter on-site for $30 million is being considered *(34)*.

AFRICA

Copper resources from African deposits are estimated at 45 million tons of recoverable copper, or 14 pct of those

Table 10.—Descriptive information for individual eastern Asia and Oceania copper deposits

Country and deposit name	Ownership	Status[1]	Year of first production[2]	Mining type[3]	Geological type[4]	Copper resource[5]	Capacity,[6] thousand metric tons copper per year
Australia:							
Benambra	Western Mining–British Petroleum	E	—	U	O	A	14.4
C.S.A.	Conzinc Riotinto Australia Ltd.	P	1907	U	O	A	10.8
Cadia	Pacific Copper Ltd.–Estel NV Hoesch	E	—	S	O	A	3.5
Chesney	Conzinc Riotinto Australia Ltd.	E	—	U	O	A	7.0
Golden Grove	Esso–Amax (Australia)–EZ Industries–Aztec	D	1986	U	M	A	25.5
Gunpowder (Mammoth)	Gunpowder Copper Joint Venture	P	1927	S	O	A	3.4
Kanmantoo	Conzinc Riotinto Australia Ltd.	E	—	U	O	A	5.3
Lady Annie	Traiko Mines–Mount Isa Mines Ltd.	E	—	S	S	A	6.6
Mons Cupri–Whim Creek	Whim Creek–Texasgulf	E	—	S	M	A	11.7
Mount Isa	Mount Isa Mines Ltd.	P	1931	U	M	F	135.5
Mount Lyell	Mount Lyell Mining and Railway	P	1935	U	M	A	17.5
Roxby Downs	Western Mining – British Petroleum	E	—	U	O	F	80.2
Tennant Creek	Peko Wallsend Ltd.	P	1953	U	O	A	19.3
Teutonic Bore	Seltrust–Mount Isa Mines Ltd.	P	1979	U	M	A	6.5
Woodlawn	St. Joe–Phelps Dodge–Conzinc	P	1979	S	O	A	7.3
Burma: Monywa	Burma Government	D	1987	S	P	A	17.1
Fiji: Namosi	Viti Copper Ltd.	E	—	S	P	E	57.8
Indonesia: Ertsberg	Freeport Indonesia Inc.	P	1972	U	P	C	63.9
Japan:							
Hanaoka	Dowa Mining Co. Ltd.	P	1973	U	M	B	16.8
Kosaka	....do.	P	1898	U	M	A	6.5
Malaysia: Mamut	Overseas Mineral Resource Development	P	1975	S	P	A	14.2
Papua New Guinea:							
Bougainville	Papua New Guinea Government–CRA–Public–Panguna	P	1972	S	P	D	130.5
Freida River	Conzinc Rio Algom	E	—	S	P	E	82.7
OK Tedi	Papua New Guinea Government–Metallgesellschaft–BHP–AMOCO Metals Co.	D	1984	S	P	D	85.7
Yandera	Triaco–Buka–Broken Hill	E	—	S	P	C	70.3
Philippines:							
Amacan (North Davao)	North Davao–Private	D	1982	S	P	B	23.3
Basay	Southern Star Mining and Industrial Corporation–Construction and Development Corporation of the Philippines.	P	1979	S	P	C	25.1
Batong-Buhay	Development Bank of Philippines	E	—	U	P	B	14.1
Biga (Atlas)	Atlas Consolidated Mining and Development Corp.	P	1962	S	P	B	38.8
Black Mountain	Various claim holders	P	1969	U	P	A	8.9
Boneng-Lobo	Western Minolco Corp.	P	1974	S	P	A	19.5
Carmen (Atlas)	Atlas Consolidated Mining and Development Corp.	P	1977	S	P	C	61.1
Dizon	Benquet Corp.	P	1980	S	P	A	22.8
Hinobaan	Lepanto Consolidated Mining–Philippine Government	D	1984	S	P	A	28.3
Inayawan	Denmag (Philippines) Inc.	E	—	S	P	A	15.8
Ino-Capayang	Consolidated Mines Inc.	P	1978	S	P	A	21.2
Lepanto	Lepanto Consolidated Mining Co. Inc.	P	1865	U	P	A	14.6
Lutopan (Atlas)	Atlas Consolidated Mining and Development Corp.	P	1966	U	P	C	47.1
Mapula–Masara	Apex Mining Co.	E	—	S	P	A	6.9
Sabena	Sabena Mining Corp.	P	1979	S	P	A	17.4
San Antonio	Philippine Government	E	—	S	P	C	61.1
Santo Nino	Baguio Gold Mining Co., Inc.	P	1972	U	P	A	5.1
Santo Tomas	Philex Mining Corp.	P	1957	U	P	B	27.4
Sipalay	Marinduque Mining and Industrial Corp.	P	1936	S	P	E	44.8
Tapian	Philippine Government	P	1969	S	P	B	43.4
Tawi-Tawi	Benquet Corp.	E	—	S	P	A	5.0
Taysan	....do.	E	—	S	P	A	21.7
Trident (Sulat)	Trident Mining and Industrial Co.	E	—	S	P	A	10.0

[1] Status: D—developing or scheduled for development in near future; E—explored deposit, no immediate plans for production; P—producing at the time of the study (includes those temporarily shut down).
[2] Dash indicates no known production startup date; where a date later than 1982 is given, production was forecast to start that year.
[3] Mining type: S—surface; U—underground. For explored deposits, mining type is proposed based on geology and technology.
[4] Geological type: P—porphyry, includes disseminated, stockwork, and skarn; S—stratabound sedimentary; M—massive sulfide including volcanogenic deposits; O—other types.
[5] Copper resource (thousand tons of contained copper): A—<500; B—501-1,000; C—1,001-2,000; D—2,001-3,000; E—3,001-5,000; F—5,001-10,000; G—>10,000.
[6] Average annual recoverable copper capacity over the life of the mine. For explored deposits, the capacity is the proposed capacity for this evaluation.

available from market economy countries. Thirty-five deposits were analyzed (table 11). Ninety percent of Africa's copper resources are from mines producing at the time of the study; only six of the deposits analyzed were not producing. Zaire and Zambia account for nearly 90 pct of the region's resources; Zaire has an estimated 21 million tons of recoverable copper and Zambia has 19 million tons.

Of the 10 Zambian deposits analyzed, three, the Chingola, Konkola, and Rokana, are operating copper divisions. Each of the divisions, owned by Zambia Consolidated Copper Mines, Ltd., is composed of multiple ore bodies and mines. The mines for each of the divisions are combined for analysis in this report.

Copper grades for the African deposits are among the highest in the world. For the region, copper grades average 2.77 pct; this is nearly three and one-half times greater than the average for all the deposits studied. The 9 Zairian deposits, 8 of which were producing, have an average grade of 4.01 pct Cu; the 10 Zambian deposits, 9 of which are producing average 3.04 pct Cu. The high ore grade in these countries is due to the fact that the deposits occur as massive sulfides in sediments (as compared to lower grades associated with disseminated prophyry

Table 11.—Descriptive information for individual African copper deposits

Country and deposit name	Ownership	Status[1]	Year of first production[2]	Mining type[3]	Geological type[4]	Copper resource[5]	Capacity,[6] thousand metric tons copper per year
Botswana: Selebi–Phikwe	BCL Ltd.	P	1974	U	O	A	13.9
Mauritania: Akjoujt	Societe Nationale Industrielle et Miniere	E	—	S	S	A	23.4
Morocco: El Bleida	Societe Miniere de Bou Gaffer	P	1977	U	O	A	15.6
Namibia:							
Klein Aub	Klein Aub Kopermaatskappy Beperk	P	1966	U	S	A	4.2
Kombat–Asis West	Tsumeb Corp. Ltd.	P	1965	U	O	A	9.0
Otjihase	Tsumeb Corp. Ltd.–Otjihase Ltd.	E	—	U	O	A	12.4
Tsumeb	Tsumeb Corp. Ltd.	P	1900	U	M	A	7.6
South Africa:							
Black Mountain	Phelps Dodge–G.F.S.A.	E	—	U	M	A	18.0
Broken Hill	....do.	P	1980	U	M	A	5.4
Messina	Messina (Transvaal) Development Ltd.	P	1906	U	O	A	7.1
O'Okiep	O'Okiep Copper Co. Ltd.	P	1965	U	O	A	23.8
Palabora	Palabora Mining Co.	P	1965	S	P	D	116.7
Prieska	Prieska Copper Mine Ltd.	P	1973	U	M	A	23.5
Sudan: Hofrat en Nahas	Sudan Government	E	—	S	O	A	22.5
Uganda: Kilembe	Ugandan Government	D	1983	U	O	A	10.2
Zaire:							
Dikuluwe–Mashamba	Gecamines	P	1975	S	S	F	122.8
Kakanda–Diselle	....do.	P	1930	S/U	S	B	14.0
Kambove	....do.	P	1926	U	S	B	37.7
Kamoto Underground	....do.	P	1972	U	S	F	103.5
Kipushi	....do.	P	1926	U	O	C	21.6
Kov Open Pit	....do.	P	1956	S	S	F	219.5
Musoshi–Kinsenda	Sodimiza	P	1972	U	S	C	37.1
Mutoshi Ruwe	Gecamines	P	1945	S	S	A	24.8
Tenke Fungurume	Cogema–Charter–Mitsui–Gecamines	E	—	S	S	F	82.2
Zambia:							
Baluba	Roan Consolidated Mines Ltd.	P	1973	U	S	C	57.2
Chambishi	....do.	P	1965	U	S	C	40.2
Chibuluma	....do.	P	1965	U	S	C	20.0
Chingola Division	Zambia Consolidated Copper Mines Ltd.	P	1965	S/U	S	F	267.5
Kalulushi East	Roan Consolidated Mines Ltd.	E	—	U	S	A	14.0
Kansanshi	Zambia Consolidated Copper Mines Ltd.	P	1978	S/U	S	A	3.9
Konkola Division	....do.	P	1957	U	S	F	44.3
Luanshya	Roan Consolidated Mines Ltd.	P	1931	U	S	C	44.5
Mufilira	....do.	P	1933	U	S	F	121.0
Rokana Division	Zambia Consolidated Copper Mines Ltd.	P	1919	S/U	S	E	66.6
Zimbabwe:							
Mangula (Miriam)	MTD (Mangula) Ltd.	P	1958	U	O	A	10.2

[1] Status: D—developing or scheduled for development in near future; E—explored deposit, no immediate plans for production; P—producing at the time of the study (includes those temporarily shut down).
[2] Dash indicates no known production startup date; where a date later than 1982 is given, production was forecast to start that year.
[3] Mining type: S—surface; U—underground. For explored deposits, mining type is proposed based on geology and technology.
[4] Geological type: P—porphyry, includes disseminated, stockwork, and skarn; S—stratabound sedimentary; M—massive sulfide including volcanogenic deposits; O—other types.
[5] Copper resource (thousand tons of contained copper): A—<500; B—501–1,000; C—1,001–2,000; D—2,001–3,000; E—3,001–5,000; F—5,001–10,000; G—>10,000.
[6] Average annual recoverable copper capacity over the life of the mine. For explored deposits, the capacity is the proposed capacity for this evaluation.

deposits in igneous rocks). South African deposits, which contain 6 pct of Africa's recoverable copper resource, have a much lower grade, averaging only 0.66 pct Cu.

Fifteen African deposits, 14 of which were producing, each have resources of greater than 1 million tons of contained copper. These 15 deposits account for over 90 pct of the region's recoverable copper. According to available information, none of the African deposits were developing. However, feasibility studies are planned for the Kilembe, Uganda, deposit to determine the possibility of recovering cobalt from concentrate stockpiled on site and the feasibility of reopening mining operations. Extensive exploration to delineate the Kilembe ore body was planned for 1981 *(36)*.

DEPOSIT EVALUATION PROCEDURE

Illustrated in figure 3 is the flow of the Bureau's Minerals Availability System (MAS) evaluation process, from deposit identification to the development of availability curves. This flowsheet shows the various evaluation stages used in this study to assess the availability of copper from individual properties. After a deposit was identified for analysis, an economic evaluation of the property was performed. Optimal mining, concentrating, smelting and refining methods, production rates, and other production parameters were chosen using current engineering principles. Startup dates for developing deposits were based on announced company plans. For explored deposits, a near-term development schedule (5 to 10 years) was developed. Planned expansions for operating mines were included when known.

Information on average grades, ore tonnages, and different physical characteristics affecting production was obtained from various sources, including Bureau and U.S.

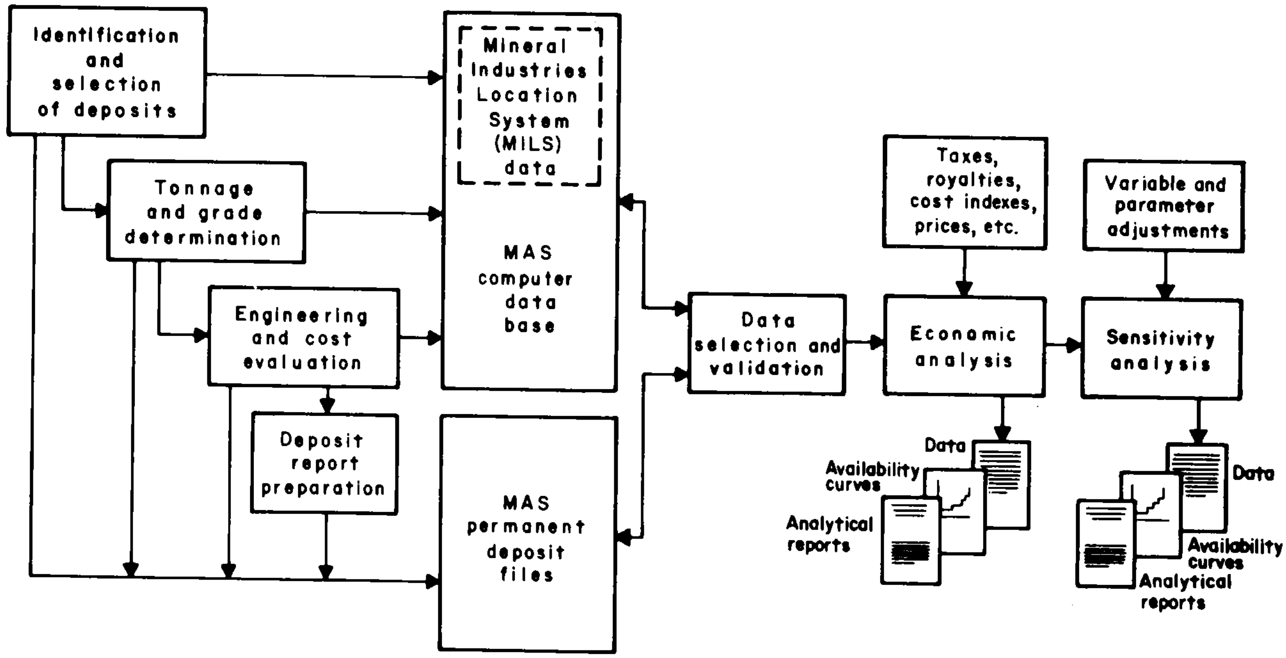

Figure 3.—Deposit evaluation procedure.

Geological Survey publications, professional journals, State and industry publications, annual reports, company 10K reports and prospectuses filed with the Securities and Exchange Commission, private companies, and estimates made by Bureau personnel. Much of the foreign data was collected through Bureau contracts.

CAPITAL AND OPERATING COST ESTIMATION

When possible, actual company cost data were used. If these data were not available, the required capital and operating costs were estimated by standardized costing techniques or in limited cases from a costing system prepared for the Bureau *(5)*. This system is designed to prepare capital and operating cost estimates through the use of equations, curves, and factors. Based on an average of the costs for existing mining operations in the United States and Canada, the system covers operations of different size. Because the system was developed using U.S. and Canadian costs, it is necessary to apply exchange rates, inflation rates, and productivity differences (compared to those of the United States) in order to determine the U.S.-dollar-equivalent cost of doing business in a foreign country. Correct use of this costing system will produce reliable estimates, which historically have fallen within 25 pct of actual costs.

The cost data were used to perform an economic analysis for each property. Capital and operating costs for developing and explored deposits were adjusted to average 1981 dollars. Mine and mill capital costs incurred prior to 1981 by producing mines (and some developing and explored deposits) were adjusted to average 1981 using the remaining book value of the investments. Foreign deposit costs were adjusted to U.S. dollars based on foreign exchange rates, productivity factors, and inflation rates. These computations reflect the cost of doing business in the foreign country in U.S. dollar equivalents.

Capital expenditures were calculated for exploration, acquisition, development, and mine and mill plant and equipment. Capital expenditures for mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. A broad category, infrastructure includes, among other things, the costs of the water system, power system, fire protection, roads, port facilities, construction of necessary rail facilities, and, in remote areas, construction of town and housing facilities. Working capital is a revolving cash fund for such operating expenses as labor, insurance, supplies, and taxes.

Mine and mill operating costs were also calculated for each deposit. The total operating cost is a combination of direct and indirect costs. Direct operating costs include direct and maintenance labor, materials, payroll overhead, and utilities. Indirect operating costs include administrative costs, facilities maintenance and supplies, research, and technical and clerical labor. Other costs not included in operating costs but used in the analysis include deferred expenses, depreciation, insurance, interest payments (if applicable), and taxes.

The Bureau previously developed a Supply Analysis Model (SAM) to perform an economic analysis which presents the results as the primary commodity price (total production cost) needed to provide a stipulated rate of return *(7)*. The rate of return (ROR) used in this study is the discounted-cash-flow ROR, most commonly defined as the ROR that makes the present worth of cash flows from an investment equal to the present worth of all after-tax investments *(26)*. For this study, a 15-pct ROR was considered necessary to cover the opportunity cost of capital plus risk. For some government-owned operations, a 15-pct ROR may not be required for continued production. However, for comparison purposes, each deposit was analyzed at this ROR.

For producing mines, analysis was also performed at a 0-pct ROR, which is roughly equivalent to a break-even production cost. In the short run, a mine may continue to produce at copper prices even below this cost in anticipation of improved market conditions.

ASSUMPTIONS

The objective of the engineering-economic analysis for each deposit was to determine the total cost necessary to produce a specified level of output from the deposit. Total cost, also called commodity or incentive price, is defined as the average total cost of production for the deposit. In this study, profit computed at a 15-pct ROR was included in the total cost. Total cost, then, is the minimum copper price (in constant dollars) at which a firm would be willing to develop its property; at this price, the firm would recover its investment and make a 15-pct profit.

Determinations of the quantity of copper that could be produced and the cost required to achieve this production were based on the following assumptions:

1. Each operation will produce at full planned operating capacity throughout its life. (Capacities were based on 1980 and/or 1981 company plans or on engineering judgments.)
2. Competition and demand conditions are such that each operation will be able to sell all its output at its total production cost. (This condition implies that the level of copper demand will support the highest cost deposit, or that existing government subsidies will equal the difference between the market price and the total cost for each submarginal deposit.)
3. All byproducts will be sold at the prices shown on table 12.
4. Concentrates produced by the deposits analyzed can be processed at existing smelters and refineries on a custom basis, or new smelter and refinery facilities can be constructed at a comparable cost. (The adequacy of existing smelting and refining capacities was not analyzed.)
5. Startup dates for deposits not producing at the time of the study were proposed. If a deposit was not scheduled for production, initial development was scheduled for 1981.

Time lags involved in filing environmental impact statements and receiving necessary permits, financing, etc., were not included in the analysis. Existing laws and regulations, environmental, political, legal, or other constraints may limit production from some of the deposits included in this study.

The byproduct and coproduct prices used in this study (table 12) were based on 1981 averages with the exception of gold, silver, molybdenum, and cobalt prices, which were lowered from the temporary highs that existed at that time to more realistic long-run prices. Because the study was conducted using constant 1981 dollars, no escalation of either costs or prices was included.

Table 12.—Byproduct commodity prices used in analysis[1]

Commodity and unit	Price
Cadmium ... lb..	$2.50
Cobalt ... lb..	5.00
Gold ... tr oz..	425.00
Iron ... ton..	80.50
Lead ... lb..	.34
Molybdenum[2] ... lb..	4.00
Nickel ... lb..	3.45
Silver ... tr oz..	10.00
Sulfur ... ton..	117.50
Uranium[3] ... lb..	25.00
Zinc ... lb..	.41

[1] Based on average commodity prices except for gold, silver, molybdenum, and cobalt, which were lowered from temporary highs to long-run prices.
[2] In concentrate.
[3] As U_3O_8.

AVAILABILITY CURVES

After price and quantity data were determined for each deposit, total and annual resource availability curves were constructed to indicate copper availability. These curves are discontinuous functions relating the total cost (as defined in the "Assumptions" section) for a deposit to its level of production. The total or annual quantity of copper from each deposit was accumulated from lowest to highest total cost to show copper availability. A total resource availability curve is not an ordinary supply curve because it ignores the paramenter of time and is not the industry's marginal cost curve. Rather, a total resource availability curve is an aggregate of the industry's total production potential at a stipulated cost which covers full production costs.

For the engineering analysis, it was necessary to determine a development schedule for each property. For producing mines, expansions considered to have a high probability of occurring were included. For nonproducing deposits, the time required for development depends upon a number of factors, including the location of the deposit, the need for further exploration, plant construction and infrastructure requirements, depth of overburden, and the mining method to be used. Curves that take these factors into consideration, called annual resource availability curves, were included in the study. Annual resource availability curves are disaggregations of total resource curves to an annual production basis. Compared with total availability curves, annual availability curves more closely resemble true supply curves since they show annual production; but they also indicate average total cost of production rather than marginal cost.

Separate annual availability curves were constructed for producing mines and nonproducing (developing and explored) deposits. Annual curves for producing mines showed the copper capacity of existing mines and for planned expansions when known. Annual curves for most nonproducing deposits cannot be related to any given year since production is not expected in the near future. They do, however, show required lead times before production can begin and indicate potential annual production capabilities. Annual availability curves for nonproducing deposits are important because they show production costs and capabilities for future mines.

OPERATING AND CAPITAL COSTS

The average total cost calculated for each of the deposits analyzed included mining, concentrating, and smelting and refining operating costs; transportation costs to the mill, smelter, and refinery; capital recovery; taxes and profit. (The cost of transportation from the refinery to the copper market is not included.) These costs often vary greatly, depending on such factors as size of operation, mining method, deposit location, stripping ratio, depth of ore body, grade of copper and byproducts, processing losses, energy and labor costs, and applicable tax structure.

The operating costs presented in this section are weighted averages based on producing ore and refined metal over the life of the operation. Capital costs for deposits not producing at the time of the study reflect the total investment required to develop a 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 cost has been depreciated.

MINE AND MILL OPERATING COSTS

This section presents operating cost data for all surface and underground copper mines (except combined surface and underground operations) that were producing at the time of this study. Mine and mill cost data for the 57 surface mines and 57 underground mines that were producing are summarized in table 13; data for 32 additional producing mines with combined operations or which have only leaching facilities are not included. Costs for individual deposits may vary greatly from the country averages shown.

As shown in table 13, the average mining and milling cost for producing surface mines was $7.40 per ton of ore; $3.80/ton for mining and $3.60/ton for milling. (In this section, all costs per ton are costs per ton of ore.) The United States, which accounts for over 30 pct of the annual capacity of producing surface mines in market economy countries, had average costs of $4.10/ton for mining and $3.90/ton for milling, which were slightly greater than foreign producers' costs. Chile, which accounts for 16 pct of the capacity from producing surface mines in market economy countries, had average costs of $5.40/ton for mining, and $2.90/ton for milling. Although the Chilean mining cost is high, Chile's mines are able to compete with other mines because of the high quality of Chilean ores; the average grade is more than 1 pct Cu. The Philippine surface mines had the lowest mining and milling cost, averaging $6.00/ton. The average mining and milling cost in Zaire, at $22.30/ton, was 300 pct higher than the average for all surface mines. This is because the productivity of Zaire's mines is low, and additional processing is required to recover byproducts from the ore. However, the extremely high quality of Zaire's ores (which average 4.05 pct Cu) and significant byproducts enable its mines to compete with lower cost operations.

Mining and milling costs per ton of ore are higher for underground mines than those for surface mines. Although the average milling cost for underground mines ($3.50/ton) is about equal to the average milling cost for

Table 13.—Estimated mine and mill operating costs for producing copper mines

Type of operation and country	Number of mines	Average ore grade, pct Cu	Total annual capacity, thousand metric tons recoverable copper	Cost per metric tons of ore[1]		
				Mine	Mill[2]	Total
Surface:[3]						
Canada	10	0.38	286	$3.00	$3.10	$6.20
Chile	3	1.02	571	5.40	2.90	8.30
Peru	4	.79	313	3.40	4.30	7.70
Philippines	6	.49	169	2.90	3.20	6.00
Zaire	3	4.05	367	14.10	8.20	22.30
Other countries	12	.61	744	2.50	3.30	5.80
Total or average foreign countries[1]	38	.79	2,451	3.70	3.50	7.10
United States	19	.67	1,163	4.10	3.90	8.00
Total or average, all countries[1]	57	.75	3,614	3.80	3.60	7.40
Underground:[3]						
Australia	4	3.01	172	12.40	7.00	19.40
Canada	10	2.10	252	13.30	5.80	19.20
Chile	4	1.00	491	4.30	2.20	6.50
Philippines	5	.47	103	3.20	2.60	5.80
Zaire	3	3.90	178	29.70	11.40	41.20
Zambia	6	3.20	349	15.50	7.60	23.10
Other countries	20	1.43	302	13.70	5.70	19.40
Total or average, foreign countries[1]	52	1.34	1,847	6.70	3.30	10.00
United States	5	.88	282	8.50	4.90	13.40
Total or average, all countries[1]	57	1.27	2,129	6.90	3.50	10.50
Grand total or average:[1]						
Foreign countries	90	1.01	4,297	4.90	3.40	8.30
United States	24	.71	1,445	4.90	4.00	8.90
All countries	114	.93	5,742	4.90	3.60	8.50

[1] Data may not add to totals shown because of independent rounding.
[2] Does not include mines having leach facilities only. Mines having combined float and leach operations are included.
[3] Does not include mines having combined surface and underground operations. An additional 960,000 tons of copper is recoverable annually from these mines.

surface mines ($3.60/ton), the average mining cost for underground mines ($6.90/ton) is nearly twice as high as the mining cost average for surface mines ($3.80/ton). However, much of the difference in mining cost is offset by the fact that ore grades are generally much higher for underground mines; the average grade is 1.27 pct Cu for underground ores versus 0.75 pct Cu for surface ores.

Mining costs vary depending on depth of deposit, mining method, and other factors. For the underground mines, average costs ranged from $3.20/ton to mine the low-grade ores from the Philippine mines (average grade: 0.47 pct Cu) to $29.70/ton for the high-grade Zairian ores (average: 3.90 pct Cu).

The four underground Chilean mines, which account for 23 pct of the annual capacity of producing underground mines in market economy countries, had average costs of $4.30/ton for mining and $2.20/ton for milling. The average ore grade for these mines is 1 pct Cu. Mining and milling costs for the seven U.S. producing underground mines, which account for 13 pct of underground mine capacity, were about 35 pct greater than foreign mines. The six Zambian underground mines, which account for 16 pct of the annual capacity of producing underground mines in market economy countries, had an average mining and milling cost of $23.10/ton: $15.50/ton for mining and $7.60/ton for milling. The four Zairian mines had extremely high costs, averaging $41.20/ton for mining and milling combined. Milling costs in Zaire are extremely high, $11.40/ton, due to the additional processing required to recover byproducts. Although costs in Zambia and Zaire are high in dollars per ton of ore, average costs per pound of refined copper are low because of high ore grades, as explained in the following section.

TOTAL PRODUCTION COSTS

Table 14 shows weighted average surface and underground operating costs for producing mines in dollars per pound of refined copper produced. Mines having combined surface and underground operations or leach operations only are not included. Revenues from coproduct and byproduct commodities were computed and subtracted from total operating cost to arrive at net cost. The net costs shown—the average out-of-pocket costs for producing mines in each country—include all operating costs required to produce refined copper and any credits for byproduct production. Net cost is the average cost of production for each country not including recovery of capital or profits. It reflects the average copper price at which the mines in the country would "break even," or cover 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 to this is that State-owned or State-controlled mines may continue to produce at or below the break-even price if the resulting losses are expected to be less than those that would be

Table 14.—Estimated production costs for producing copper mines,[1] per pound of refined copper

Type of operation and country	Number of mines	Mine cost	Mill cost[2]	Smelter-refinery cost[3]	Total operating cost[4,5]	Taxes[6]	Byproduct credits	Net cost[7]	Total cost,[5,8,9] FOB refinery
Surface:									
Canada	10	$0.42	$0.44	$0.27	$1.13	$0.03	$0.29	$0.87	$1.04
Chile	3	.28	.15	.26	.69	.10	.19	.60	.76
Peru	4	.23	.28	.31	.82	.12	.06	.88	1.12
Philippines	6	.33	.36	.27	.96	.09	.14	.91	1.04
Zaire	3	.19	.11	.30	.60	.22	.12	.70	.79
Other countries	12	.24	.30	.27	.81	.14	.34	.61	.81
Total or average, foreign countries[5]	38	.26	.24	.28	.77	.13	.21	.69	.86
United States	19	.30	.28	.38	.96	.05	.16	.86	1.02
Total or average, all countries[5]	57	.27	.25	.31	.83	.11	.20	.74	.91
Underground:									
Australia	4	.22	.12	.39	.73	.08	.09	.73	.89
Canada	10	.32	.14	.83	1.29	.07	.92	.44	.61
Chile	4	.36	.19	.20	.75	.04	.06	.72	.79
Philippines	5	.41	.33	.28	1.02	.10	.40	.72	.85
Zaire	3	.42	.16	.38	.97	.24	.15	1.05	1.14
Zambia	6	.41	.20	.27	.87	.17	.03	1.01	1.09
Other countries	20	.57	.24	.58	1.38	.12	.88	.63	.92
Total or average, foreign countries[5]	52	.38	.19	.32	.88	.09	.21	.77	.88
United States	5	.54	.31	.35	1.20	.07	.10	1.18	1.26
Total or average, all countries[5]	57	.40	.20	.32	.92	.09	.19	.82	.93
Grand total or average:[5]									
Foreign countries	90	.31	.22	.30	.82	.11	.21	.73	.87
United States	24	.35	.29	.37	1.01	.05	.15	.92	1.07
All countries	114	.32	.23	.32	.87	.10	.20	.77	.92

[1] Does not include mines having combined surface and underground operations. Average ore grade and annual refined copper production in table 13.
[2] Does not include mines having leach facilities only. Mines having combined float and leach operations are included.
[3] Includes smelting and refining charges, transportation costs to the smelter and refinery (but not to market), and postmill processing charges for other (noncopper) commodities.
[4] Summation of mine, mill, and smelter-refinery costs.
[5] Data may not add to totals shown because of independent rounding.
[6] Includes property, severance, State, and Federal taxes and royalties.
[7] Total operating cost plus taxes less byproduct credits.
[8] Net cost plus recovery of capital and profit at a 15-pct ROR.
[9] Transportation charges from the refinery to the market are not included. These costs are estimated in table 15.

incurred if the mine were closed. (If the mine were closed, the government might have to pay unemployment and other welfare benefits or incur other costs. Also, the governments may need the sales revenues generated by the mine to import other needed materials into the country.)

In this study, the difference between net cost and total cost is that total cost includes recovery of capital and a profit on all investments at a 15-pct ROR, FOB (free on board) refinery. For some countries, there is no great difference in these costs because 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 because new mines have recently begun production and large amounts of capital have yet to be written off. For some operations, there may be significant transportation charges to ship the copper to the market.

There are many reasons for the differences in the average country costs shown in table 14. Although this report does not provide detailed explanations for all these differences, some country comparisons are presented below, and some of the reasons for variations in costs are discussed.

Mining

The weighted average mining cost for the 57 surface mines producing at the time of the study was $0.27 per pound of refined copper; surface mine costs ranged from a low in Zaire of $0.19/lb to a high of $0.42/lb in Canada. (In this section, all costs per pound are costs per pound of refined copper.) For the surface mines, the cost differences from country to country were due largely to variances in stripping ratios, mining methods, productivity, and average copper ore grades. The average grade for all producing surface mines is 0.75 pct Cu, ranging from 4.05 pct Cu in Zaire to 0.38 pct Cu in Canada (table 13). Chile and the United States, which account for nearly half of the production capacity of the producing market economy surface mines studied, had average mine operating costs of $0.28/lb and $0.30/lb, respectively.

Underground mining costs, ranging from $0.22/lb for Australian mines to $0.54/lb for U.S. mines, averaged $0.40/lb, or $0.13/lb more than the average cost for surface mines. The wide variance in costs again reflected differences in average ore grades, mining methods, and characteristics of individual ore bodies. U.S. underground mines have an average ore grade of only 0.88 pct Cu, compared with an average grade of 1.34 pct Cu for all other market economy countries. Largely because of this low grade, the mining cost per pound of refined copper for U.S. underground mines averaged $0.16 higher than that of underground mines in all other countries.

Milling

Milling costs for copper from surface mines ranged from $0.11/lb for the 3 high-grade Zairian mines to $0.44/lb for the 10 low-grade Canadian mines and averaged $0.25/lb for all surface mines. The average cost of milling from underground mines was $0.20/lb, or $0.05/lb less than the average surface mine milling cost. As mentioned earlier, milling costs per ton of ore are about equal for surface and underground mines. However, when milling cost is converted to dollars per pound of refined copper, the cost is lower for underground mines than for surface mines because of the much higher average ore grade of underground mines.

Smelting, Refining, and Miscellaneous

Smelting and refining costs include transportation charges to the smelter and refinery and postmill processing charges for other (noncopper) commodities. These costs averaged $0.37/lb for U.S. mines, $0.07/lb higher than the average cost in foreign countries. Costs in most foreign countries ranged from $0.20/lb to $0.39/lb and averaged $0.30/lb. Because of additional costs for processing coproducts and byproducts from underground mines in Canada and Zaire, costs in these countries were high, averaging $0.83/lb and $0.38/lb, respectively.

Smelting and refining costs for concentrates originating from mines in the Philippines and surface mines in Canada are low because most of these concentrates are processed in Japan. Custom smelters and refineries typically purchase copper concentrates at prices based on London Metal Exchange (LME) copper prices minus a charge to cover processing charges and profit. However, Japan has its own pricing system which allows Japanese smelters to sell copper within Japan at a premium over the LME price. This premium price, which amounts to a subsidy paid by Japanese consumers, allows smelters to purchase concentrates at the LME price and sell refined copper at their higher internal producer price. As a result, Japanese smelters can offer lower smelting and refinery charges, thereby attracting more concentrates, and recover the added cost when the copper is sold at the premium price *(30)*. Therefore, although U.S. smelting and refining costs are probably competitive with those in Japan, the U.S. smelting industry is not able to compete with Japan's because of the pricing system imposed by the Japanese Government.

Total Operating Cost

The total operating cost (mine, mill, smelter, and refinery) for producing surface mines was estimated to be $0.83/lb. Zaire had the lowest total operating cost, $0.60/lb, whereas Canada had the highest, $1.13/lb. Costs for underground mines were slightly higher, averaging $0.92/lb and ranging from $0.73/lb in Australia to $1.29/lb in Canada.

Taxes

Taxes, including property, severance, state, and federal assessments, averaged $0.10/lb. Taxes in some countries were insignificant ($0.03/lb for surface mines in Canada), while in other countries they added greatly to the cost of production ($0.17/lb in Zambia and $0.24/lb in Zaire for underground mines). For producing mines as a whole, state and federal taxes comprised 53 pct of total taxes, severance taxes accounted for 26 pct, property taxes accounted for 6 pct, and royalties accounted for 15 pct.

Byproduct Revenues

In recent years, byproduct revenues have been very important to the economic viability of the copper mining industry. (As will be shown later in this report, changes in byproduct prices can greatly affect the profitability of a mine.) Since the total operating cost for producing copper mines (in average 1981 dollars) exceeded the 1981 copper selling price, byproduct revenues were essential for continued mine production. Byproduct prices used in this analysis are shown in table 12. Byproduct credits for producing mines averaged $0.20/lb: $0.20/lb for surface mines and $0.19/lb for underground mines. Credits ranged from a low of $0.03/lb for underground mines in Zambia to $0.92/lb for underground mines in Canada. Major byproducts and coproducts for Canadian mines are gold, lead, molybdenum, zinc, and silver. Byproduct credits for the Chilean mines averaged $0.19/lb for surface mines and $0.06/lb for underground mines and were primarily from gold and molybdenum production. Credits for U.S. mines averaged $0.15/lb.

After credits for byproducts, net cost for all producing mines averaged $0.77/lb.

Net and Total Cost

Net cost for producing surface mines averaged $0.74/lb. Because of high-grade ore and good byproduct credits, Chile's mines were the lowest cost surface producers, averaging only $0.60/lb. Zaire's mines are highly sensitive to changes in byproduct prices; recent decreases in these prices have increased net costs greatly to an average of $0.70/lb. Net cost for surface mines in other countries ranged from $0.86/lb in the U.S. to $0.91/lb in the Philippines.

At the 1981 copper price of $0.85/lb, only 4 of the 19 U.S. surface mines were able to cover production costs. This explains why so many domestic mines had extended holidays, reduced output, temporary closures, or shutdowns. Recovery of capital and profit added an additional estimated $0.17/lb to the production cost of surface mines (with total cost computed at a 15-pct ROR). At the 1981 copper price, most surface mines in Chile and Zaire were able to cover production costs and receive at least a 15-pct ROR, but very few U.S. mines operated profitably.

Net cost for underground mines was estimated at $0.82/lb or $0.08/lb higher than that for surface mines. This indicates that although grades of ore from underground mines are usually higher than those of ore from surface mines, this difference does not totally offset the higher costs of underground mining. For underground mines, recovery of capital and profit add an estimated additional average of $0.11/lb to the production cost. The total cost at a 15-pct ROR is estimated to be $0.93/lb, which is only $0.02/lb higher than the total cost for surface mines. At the 1981 copper price of $0.85/lb, most underground mines in Canada, Chile, and the Philippines, were able to produce economically. In the United States, however, none of the seven underground mines appeared to be able to make a profit or even cover production costs.

Transportation Cost

Transportation charges for moving copper concentrates to the smelter and refinery or for shipping refined copper to the market often affect the ability of mines to compete on the world market. Mines that are close to the smelter and/or refinery or copper market enjoy a cost advantage over more distant operations.

The costs shown on table 14 are FOB refinery; transportation charges to the smelter-refinery are included in the "smelter-refinery cost." For producing mines, these costs average only about $0.03/lb because many smelters and refineries are located near the mines. For mines that must ship concentrates great distances, however, transportation costs are much larger.

Table 15 provides estimates of transportation charges for concentrates and blister-refined copper. In 1982, U.S. mines exported 148,000 tons of copper in concentrate (75 pct of U.S. exports of concentrate) to Japan. The transportation charge from a mine in Arizona to Japan is estimated to be $80/ton concentrate. About 40 pct of the charge would be for rail haulage to the port (San Diego), 25 pct for the terminal charge, and 35 pct for ocean freight. Charges for Chile and Peru are generally lower than the U.S., averaging $40 to $45 per ton, because the mines are located nearer to the ports.

After copper has been processed to the refined stage, additional costs are incurred to transport the copper to the market. For Chile and Peru these costs are small, averaging $0.025/lb to $0.032/lb refined copper. For Zaire and Zambia, however, these costs are much larger averaging $0.063/lb to $0.07/lb.

In Zaire, most copper is presently railed from the copper belt at Kolwezi 1,050 km to Luebo where it is loaded onto river vessels and barged 700 km to Kinshasa. From

Table 15.—Estimated copper transportation costs for selected countries[1]

From—	To—	Copper concentrates: $/ton conc	Copper concentrates: ¢/lb copper	Blister-refined copper: $/ton blister-refined	Blister-refined copper: ¢/lb copper
Chile	Germany, Fed. Rep. of	45	7.3	NAp	NAp
	Japan	40	6.5	NAp	NAp
	Northwestern Europe	NAp	NAp	60	2.7
	United States	NAp	NAp	55	2.5
Mexico	Germany, Fed. Rep. of	35	5.7	NAp	NAp
	Japan	30	4.9	NAp	NAp
Peru	Germany, Fed. Rep. of, Japan	40	6.5	70	3.2
	Northwestern Europe	NAp	NAp	65	2.9
	United States	NAp	NAp	55	2.5
South Africa	Germany, Fed. Rep. of	25	4.0	NAp	NAp
	Japan	30	4.9	65	2.9
	Northwestern Europe	NAp	NAp	55	2.5
	United States	NAp	NAp	85	3.9
United States, Arizona	Japan	80	13.0	NAp	NAp
Zaire	Japan	NAp	NAp	155	7.0
	Northwestern Europe	NAp	NAp	145	6.6
Zambia	Japan	NAp	NAp	150	6.8
	Northwestern Europe	NAp	NAp	140	6.3

NAp Not applicable.
[1] Costs are estimated; transportation costs are negotiated on an individual deposit basis and may vary considerably.

Kinshasa it is loaded back onto trains and railed 365 km to the port at Matadi. The total shipping charge from the mine to Japan is estimated at $155/ton refined copper ($0.07/lb). Other routes for export exist but at the present time this is the most likely one. In 1981, about 500,000 tons of copper was shipped using this route.

At the present time, about 85 pct of Zambia's copper production is transported by rail 680 km to the port at Dar. The remaining 15 pct is railed 1,120 km to the South African port of East London. The transportation cost from the mine to Japan is estimated to be $150/ton refined copper ($0.068/lb) while the cost to northwestern Europe is about $140/ton ($0.063/lb).

These high transportation costs, combined with large decreases in the price of byproduct cobalt, have made the mines in Zaire and Zambia much less competitive in recent years. As shown on table 14, costs for producing mines in Zaire and Zambia average $0.90/lb and $1.09/lb, respectively. Adding the transportation charges to market of about $0.07/lb raises the cost in Zaire to about $0.97/lb and Zambia to $1.16/lb, both well above the average 1981 copper price of $0.85/lb.

CAPITAL COSTS

Capital costs for exploration, acquisition, development, mine and mill plant and equipment, and infrastructure were calculated for all deposits. (For most deposits, capital costs for smelting and refining were 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 16. The costs shown are averages for the deposits analyzed (and are adjusted to 1981 U.S. dollars); actual costs may vary greatly depending on deposit location, characteristics of the ore body, and other factors.

Capital costs were analyzed for 70 developing and explored surface deposits which had a weighted average daily capacity of 22,800 tons of ore. Total capital costs for these deposits averaged $5,800 per annual ton of copper. Of this average, $1,000 was for exploration, acquisition, and development; $1,200 was for mine plant and equipment; $2,200 was for mill plant and equipment; and $1,400 was for infrastructure. The exploration, acquisition, and development cost can be broken down further to 16 pct for exploration, 8 pct for acquisition, and 76 pct for development.

Analyses indicated that a surface deposit capable of producing 14,000 tons of copper per year (about 3,400 tons of ore per day) would have a capital cost of about $60 million (not including smelter, refinery, or infrastructure costs). A surface deposit that could produce nearly 20,000 tons of copper per year (7,000 tons of ore per day) would cost slightly more than $82 million, while a deposit with capacity of 30,000 tons of copper per year (17,000 tons of ore per day) would cost $125 million. A large surface deposit with a capacity of 75,000 tons copper per year (about 38,000 tons of ore per day) would cost an estimated $350 million.

Of the surface deposits, those with capacities greater than 75,000 tons of ore per day had the lowest capital costs per annual ton of copper. (However, because only three of the deposits studied fell into this category they are not included in table 16.) Capital costs for other surface deposits ranged from $5,300 to $6,000 per annual ton. Determining economies of scale is difficult because the deposits in each category are scattered throughout the world and have many differences in infrastructure and deposit characteristics. Also, inflation and exchange rates vary greatly among countries.

Thirty-seven underground deposits, with an average capacity of 7,300 tons of ore per day, were also analyzed to determine capital costs. Total capital costs for these deposits averaged $5,200 per annual ton of copper: $1,100 for exploration, acquisition, and development; $1,400 for mine plant and development; $2,000 for mill plant and equipment; and $800 for infrastructure. Of the exploration, acquisition, and development costs, 19 pct was for exploration, 5 pct was for acquisition, and 76 pct was for development. Costs ranged from $3,900 per annual ton for deposits with capacities from 2,001 to 5,000 tons of ore per day to $6,000 per annual ton for those with capacities of more than 10,000 tons per day.

Total capital costs (not including smelter, refinery, or infrastructure) for an underground deposit capable of producing 16,000 tons of copper per year (3,000 tons of ore per day) are estimated to be $45 million. An underground deposit with an annual output of 30,000 tons of copper (13,000 tons of ore per day) would cost about $200 million.

Differences in capital costs occur primarily in costs for exploration, mill plant and equipment, and infrastruc-

Table 16.—Estimated capital costs for developing and explored copper deposits

Type and size of operation, metric tons of ore per day	Number of deposits	Average ton/d ore, thousand metric tons	Cost per annual metric ton of refined copper: Exploration, acquisition, development	Mine plant and equipment	Mill plant and equipment	Infrastructure	Total[1]
Surface:							
Less than 2,000	6	1.4	$2,300	$1,100	$1,300	$800	$5,500
2,001 to 5,000	8	3.6	1,000	900	2,400	900	5,300
5,001 to 10,000	8	7.4	1,200	1,100	1,900	1,100	5,300
10,001 to 25,000	26	18.7	1,000	1,000	2,200	1,500	5,600
25,001 to 50,000	16	38.1	1,100	1,400	2,200	1,400	6,000
Greater than 50,000	6	70.0	900	1,100	2,400	1,600	6,000
Total or average[1]	70	22.8	1,000	1,200	2,200	1,400	5,800
Underground:							
Less than 2,000	10	1.4	700	1,500	1,200	1,700	5,100
2,001 to 5,000	14	2.9	600	900	1,300	1,100	3,900
5,001 to 10,000	5	6.4	800	1,200	1,700	1,000	4,800
Greater than 10,000	8	22.8	1,600	1,400	2,700	300	6,000
Total or average[1]	37	7.3	1,100	1,400	2,000	800	5,200

[1] Data may not add to totals shown because of independent rounding.

ture. Economies of scale are not readily visible because of the mixing of many types of underground mining methods. As with surface deposits, underground deposits are scattered throughout the world and have many differences in infrastructure and deposit characteristics.

COPPER AVAILABILITY

Total availability of copper from market economy mines and deposits is illustrated in figure 4. A total of 330 million tons of copper is potentially recoverable from the deposits analyzed; however, a copper price exceeding $3.50/lb would be required in order for all the deposits to produce economically. In 1981, copper was selling for about $0.85/lb. At that price, an estimated 88 million tons could be economically mined and nearly all of the output would be from mines that were producing at the time of the study. If the price of copper were to increase to $1.25/lb, the quantity of copper that would be economically recoverable could increase over 100 pct to 207 million tons. At that price, nearly all the copper that could be economically produced (90 pct) would be from mines that were producing at the time of the study.

As shown in figure 4, several mines received such large revenues from other commodities that no copper revenues were required in order for them to produce economically (with total cost equal to zero). These mines produce copper as a byproduct of other metal production and are heavily dependent on revenues from the other metals.

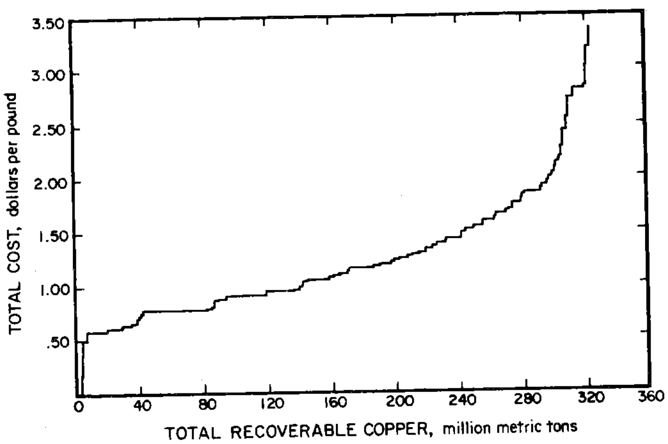

Figure 4.—Total copper availability from mines and deposits. (Costs are in average 1981 dollars and include a 15-pct ROR.)

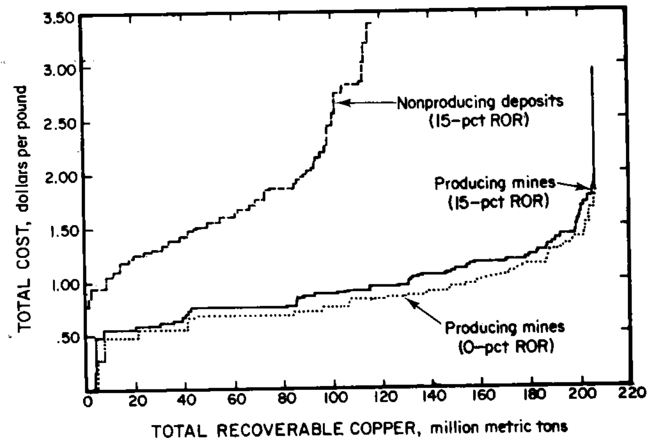

Figure 5.—Breakdown of total copper availability from producing, developing, and explored deposits. (Costs are in average 1981 dollars and include a 15-pct ROR.)

TOTAL AVAILABILITY FROM PRODUCING, DEVELOPING, AND EXPLORED DEPOSITS

Of the total quantity of copper potentially recoverable from the deposits analyzed, 63 pct was from mines that were producing at the time of the study, 12 pct was from deposits that were not producing but were under development or were scheduled for development in the near future, and 24 pct was from explored deposits with no known development schedule or scheduled startup date. Copper potentially available from producing mines and nonproducing deposits is shown in figure 5 and table 17.

The average total cost of production for producing mines (including a 15-pct ROR) was estimated to be $0.92 per pound of copper, or about $0.07/lb more than the 1981 copper selling price. When recovery of capital and profit were not included, the estimated cost of production (break-even cost) for these mines dropped to $0.77/lb. Production costs for developing deposits (including a 15-pct ROR) generally ranged from $1/lb to $2/lb, with an average cost of $1.50/lb. Explored deposits had much higher production costs; the average total cost for these deposits was estimated to be $1.90/lb, or more than double the 1981 copper selling price.

Table 17.—Copper potentially available from producing, developing, and explored deposits at selected copper price ranges

(Thousand metric tons)

Total cost per pound	Producing mines	Developing and explored deposits	Total[1]
Under $0.75	81,400	280	81,680
$0.76 to $1.00	50,670	8,890	59,560
$1.01 to $1.25	51,180	14,360	65,540
$1.26 to $1.50	15,260	26,060	41,320
$1.51 to $1.75	6,780	23,190	29,970
$1.76 to $2.00	1,010	17,910	18,920
$2.01 to $3.00	50	23,530	23,580
Total[1]	206,350	114,220	320,570

[1] Data may not add to totals shown because of independent rounding.

TOTAL AVAILABILITY BY REGION

Potential availability of copper from the six market economy regions is shown in table 18. Similar data for the four major regions, North America, Central and South America, eastern Asia and Oceania, and Africa, are shown in figure 6. Nearly 70 pct of market economy copper resources occurs in North America or in Central and South America.

The data in table 18 indicate that 82 million tons of copper could be economically mined at a total cost of

Table 18.—Copper potentially available by region at selected total production cost ranges
(Thousand metric tons of recoverable copper)

Total cost per pound	North America	Central and South America	Europe	Middle East and western Asia	Eastern Asia and Oceania	Africa	Total[1]
Less than $0.50	2,710	0	3,230	130	830	270	7,170
$0.51 to $0.75	10,730	51,250	2,330	460	3,870	5,880	74,510
$0.76 to $1.00	9,430	14,450	1,750	780	7,440	25,720	59,560
$1.01 to $1.25	34,290	20,080	90	0	8,070	3,020	65,540
$1.26 to $1.50	19,660	8,040	2,650	5,900	1,330	3,740	41,330
$1.76 to $2.00	19,350	19,690	270	1,320	5,190	3,070	48,890
$2.01 to $3.00	6,150	10,600	0	60	3,800	2,960	23,570
Greater than $3.00	2,150	0	240	1,020	4,820	660	8,880
Total[1]	104,470	124,100	10,550	9,660	35,340	45,330	329,450

[1] Data may not add to totals shown because of independent rounding.

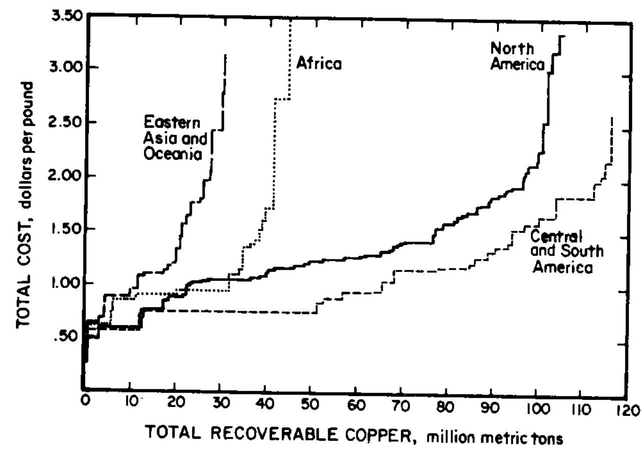

Figure 6.—Total copper availability by major region. (Costs are in average 1981 dollars and include a 15-pct ROR.)

$0.75/lb. At $1/lb, economic output could be expected to increase to 141 million tons. At $1/lb, an estimated 47 pct of the recoverable copper would be from Central and South American deposits, 23 pct would be from Africa, 16 pct would be from North America, and 9 pct would be from eastern Asia and Oceania.

Thirty-two percent of the copper available from North American deposits could be economically produced at a cost of $1/lb or less, and nearly 55 pct could be economically produced at $1.25/lb. From Central and South American deposits, 53 pct of the copper would be economically available at $1/lb, and nearly 70 pct would be economically available at $1.25/lb. African mines, some of which have extremely large revenues from byproduct production, could economically produce over 70 pct of their resource at a cost of $1/lb or less. At this same cost, 70 pct of European resources could be economically mined, and 34 pct of the resources from eastern Asia and Oceania would be available. Because costs for copper resources in the Middle East and western Asia are much higher than in other regions, only 14 pct of these resources could be economically mined at a cost of $1/lb.

ANNUAL AVAILABILITY

Estimated mine production capacities for the deposits analyzed in this study are shown by country, in table 19. The capacities shown are averages of annual production over the lives of the deposits in each country. The 272 mines and deposits analyzed could produce 11.6 million tons of copper per year; however, copper prices significantly above the 1981 level of $0.85/lb would be required to stimulate production. The 146 producing mines studied were capable of producing 7.0 million tons of recoverable copper per year. It has been estimated that 1980 production of primary refined copper from market economy countries totaled 5.9 million tons, or about 85 pct of estimated capacity *(2)*. The 23 deposits under development or scheduled to begin development in the near future had the capacity to produce an additional 1.3 million tons. Explored deposits could increase annual production capacity by an estimated 3.4 million tons; however, since none of these deposits had definite development plans, most will not come into production in the near future.

Table 19.—Estimated average annual copper mine capacity, by region and country
(Thousand metric tons of recoverable copper)

Region and country	Producing mines	Developing and explored deposits	Total[1]
North America:			
Canada	600	480	1,080
Mexico	290	260	550
United States	1,590	1,100	2,700
Total[1]	2,470	1,840	4,320
Central and South America:			
Brazil	0	70	70
Chile	1,380	670	2,050
Peru	350	450	800
Other	0	400	400
Total[1]	1,730	1,600	3,330
Europe	280	120	400
Middle East and western Asia	110	260	370
Eastern Asia and Oceania:			
Australia	200	150	350
Philippines	400	190	590
Other	230	310	550
Total[1]	830	660	1,490
Africa:			
Zaire	610	80	700
Zambia	690	10	700
Other	240	90	320
Total[1]	1,540	180	1,720
Grand total (market economy countries)[1]	6,960	4,660	11,620

[1] Data may not add to totals shown because of independent rounding.

Figure 7 shows potential annual copper production at selected total production costs, from 1981 to 1995, for producing mines and nonproducing deposits. At a cost of $1/lb, nearly all output would be from mines that were producing at the time of the study. At that cost, an estimated 3.7 million tons of copper could be economically produced each year, although it is estimated that economic output would drop to 3.2 million tons by about 1995. Five deposits that were being developed could economically produce at $1/lb; however, these deposits

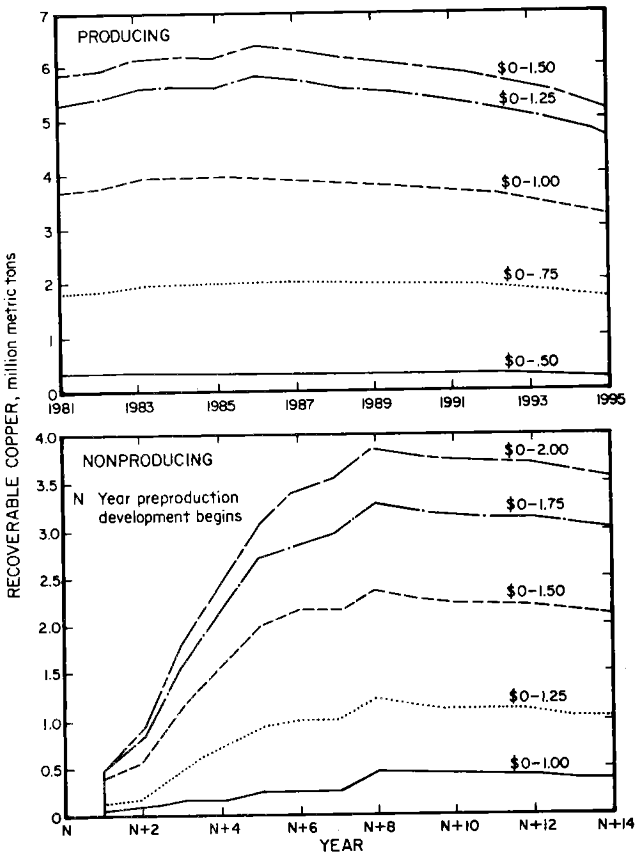

Figure 7.—Potential annual copper production from producing, developing, and explored deposits at selected production costs. (Costs per pound are shown to the right in each graph in average 1981 dollars and include a 15-pct ROR.)

had annual capacities sufficient to produce only an additional 200,000 tons of copper. If copper prices remain below $1/lb, analyses performed as part of this study indicate that market economy mines cannot continue to produce profitably at their 1978-1980 average annual production rate of 6.1 million tons; annual production of 4 to 5 million tons is more likely.

The average total cost for producing mines (including a 15-pct ROR) was estimated to be $0.92 per pound of copper; $1.07/lb for U.S. mines and $0.87/lb for other market economy mines. Of the producing mines, 80 pct of the U.S. mines and 50 pct of the other market economy mines had a total production cost of more than $1/lb. Because of low copper prices, many mines had curtailed production or shut down (temporarily or permanently) in an attempt to reduce losses. Other mines continued to operate at a loss in anticipation of higher copper or byproduct prices in the near future. If prices do not increase, these mines may also reduce production or close.

Generally, developing and explored deposits have a much higher production cost than do producing mines. This is due in part to the higher investments that are required and to generally lower ore grades. Developing deposits had an average total cost of $1.50/lb. Therefore, startup of the higher cost developing deposits will likely be postponed or delayed until the projects are economically feasible. Explored deposit costs are even higher; average total cost for these deposits were estimated to be $1.90/lb. Because startup dates for many developing deposits have been postponed due to economic conditions and startup dates for explored deposits were not known, construction of annual availability curves for them was based on the assumption that preproduction would begin in year "N." These curves indicate that several years would be required from the year development begins before any production could occur. Although an additional 4.7 million tons of copper could be produced annually from these deposits, copper prices of more than $1.75/lb would be required. Therefore, for most of these deposits, production in the near future appeared unlikely.

Potential annual copper output for the four major market economy regions, at selected production costs, is shown in figure 8. At $1/lb, nearly all output would be from mines that were producing at the time of the study. At this price, the mines analyzed could economically produce an estimated 3.7 million tons of copper, which is much less than the estimated 5.9 million tons of refined copper market economy mines produced in 1980. Analyses performed as part of this study indicated that copper prices from $1.25/lb to $1.50/lb would be required to meet the 1980 production level of the market economy countries. At higher copper prices, most production potential would be from North and South America. However, in order to operate profitably, nearly all of the developing and explored deposits in North and South America would require copper prices of more than $1.25/lb.

U.S. AVAILABILITY

Copper production from U.S. mines in 1981 was estimated at 1.5 million tons of contained copper; this represented a nearly 30-pct increase over 1980 production and was the largest production in 8 years. Mine production for 1982 was estimated to drop to 1.1 million tons. Reported U.S. copper consumption in 1981 was estimated at 2.4 million tons. Reported consumption of refined copper was 1.9 million tons. (An estimated 610,000 tons of copper scrap was recycled and converted to refined metal and alloys.) The Bureau has forecast an average annual U.S. growth rate for consumption of primary copper of 2.4 pct *(22)*. This rate of growth would result in a 1990 U.S. demand level of 2.5 million tons of refined copper and a demand level of 3.2 million tons in the year 2000.

Total Production

The 72 U.S. mines and deposits analyzed contain an estimated 83 million tons of copper, of which 80 pct is recoverable with existing technology. Mines producing at the time of the study, including those temporarily shut down, accounted for nearly 65 pct of the recoverable copper. Total copper availability from U.S. mines and deposits is shown in figure 9 and table 20. At the 1981 copper price of $0.85/lb and at average 1981 costs and byproduct prices, U.S. mines could economically produce only 10 million tons of copper; at $1/lb, economic output would increase to 14 million tons. In an earlier study, the Bureau estimated that at January 1978 production costs and byproduct prices, U.S. mines could economically produce slightly more than 50 million tons of copper at a total cost of $1/lb *(21)*. This study, conducted only 3 years later, estimates that as of 1981, costs had risen to $1.65/lb

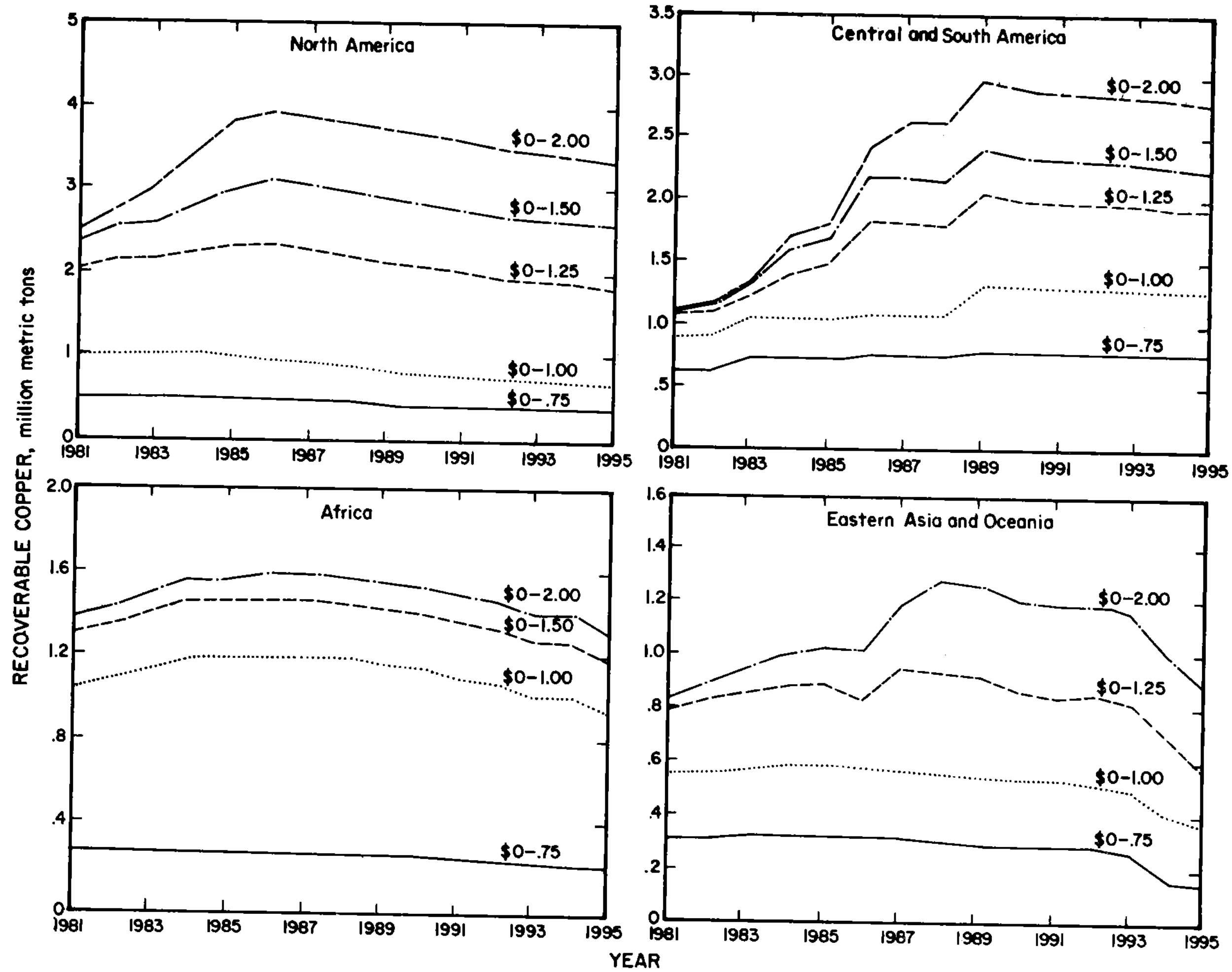

Figure 8.—Potential annual copper production by major region at selected production costs. (Costs per pound are shown to the right in each graph in average 1981 dollars and include a 15-pct ROR.)

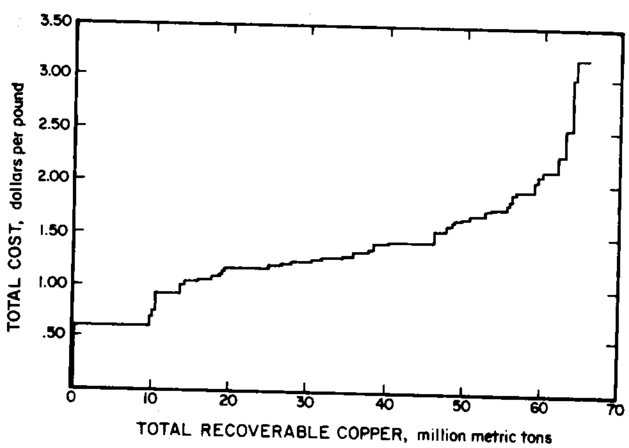

Figure 9.—Total copper availability from U.S. mines and deposits. (Costs are in average 1981 dollars and include a 15-pct ROR.)

to produce the same quantity. More recent data presented later in this section indicates that U.S. production costs increased an additional $0.15/lb through June 1983.

The U.S. mines that were producing at the time of this study had an average break-even production cost of $0.92 per pound of copper (including operating costs, taxes, and miscellaneous costs). Recovery of capital and profit at a 15-pct ROR added an additional average cost of $0.15/lb. Results of this study indicate that at the 1981 copper price of $0.85/lb, only one out of every six producing U.S. mines would have received at least a 15-pct ROR.

Table 20.—Copper potentially available from U.S. mines and deposits at selected total production cost ranges

(Thousand metric tons)

Total cost per pound	Producing mines	Developing and explored deposits[1]	Total[2]
Less than $0.75	10,200	300	10,500
$0.76 to $1.00	3,500	100	3,600
$1.01 to $1.25	15,400	2,000	17,400
$1.26 to $1.50	9,300	5,100	14,400
$1.51 to $1.75	2,900	6,400	9,300
$1.76 to $2.00	300	3,300	3,600
Greater than $2.00	0	7,400	7,400
Total[2]	41,700	24,500	66,200

[1] Only 2 deposits were in development at the time of this study.
[2] Data may not add to totals shown because of independent rounding.

Annual Production

The producing U.S. mines analyzed had a combined capacity of about 1.7 million tons of refined copper per year, but it was estimated that in 1981 these mines operated at only 89 pct of capacity. Production in 1982 dropped to an estimated 65 pct of capacity, due to extremely low copper prices and demand.

Annual production capacities of U.S. mines producing at the time of the study are shown in figure 10; capacity of nonproducing deposits are shown in figure 11. At a total cost of $1/lb, producing mines had the capacity to economically produce about 500,000 tons of copper per year. By 1995, capacity from these mines may drop to about 375,000 ton/yr as some ore bodies become depleted. Historically, however, domestic resources that can be economically mined have increased annually because of exploration and technologic improvements that facilitate mining and processing of lower grade material or the processing of material previously considered waste. With improvements of this kind, actual annual capacities could be higher than those shown in figures 10 and 11. At a total cost of production of $1.25/lb, an estimated additional 700,000 to 750,000 tons of copper could be economically mined by producing mines each year.

Although the annual production capacities of developing and explored U.S. deposits are large, production costs are much higher than those for producing mines, and therefore copper prices above the 1981 price of $0.85/lb would be required before these deposits could produce economically. Only two U.S. deposits, the Troy, Mont., property and the Copper Flat, N.M., property were developing at the time of this study. These deposits began full production in 1982 at a combined annual capacity of about 30,000 tons of recoverable copper. Because of the depressed condition of the copper industry, startup dates for the 34 explored deposits were uncertain. As was done previously (for the developing and explored deposits availability curves in figure 7), annual availability curves for these deposits were constructed (fig. 11) based on the assumption that development of each deposit would begin in year "N." As the curves show, a 4- to 6-year lag time is required after startup (in year N) for development of the deposit before full production can be reached.

Production costs for nonproducing U.S. deposits are high. At a total cost of $1.25/lb, only 100,000 to 150,000 tons of copper per year could be economically produced. However, production from these deposits could more than double to 400,000 ton/yr at a cost of $1.50/lb and could increase to over 600,000 ton/yr at $1.75/lb. Since these production costs are much higher than current market prices, it is doubtful that development would be considered for many of these deposits in the near future.

Due to a lack of foreign index and cost data, it was not possible to show cost data or plot availability curves for foreign deposits beyond 1981. However, because U.S. index information was available, it was possible to update the domestic deposit costs and availability curves to June 1983. Results of this analysis indicate that production costs for U.S. mines and deposits increased about 10 pct between mid-1981 and June 1983. Costs for mines producing at the time of the study (including profit at a 15-pct ROR) increased $0.10 to $1.17 per pound of copper.

Figure 12 shows the shift in total production costs and copper availability for producing domestic mines between mid-1981 and June 1983. As shown, costs increased significantly, from an average of $1.07/lb in mid-1981 to $1.17/lb in June 1983. As a result of these cost increases, the quantity of copper that could be economically mined at a cost of $1/lb dropped from 13.8 million tons in 1981 to 9.9 million in 1983. Most of this $0.10/lb increase was due to

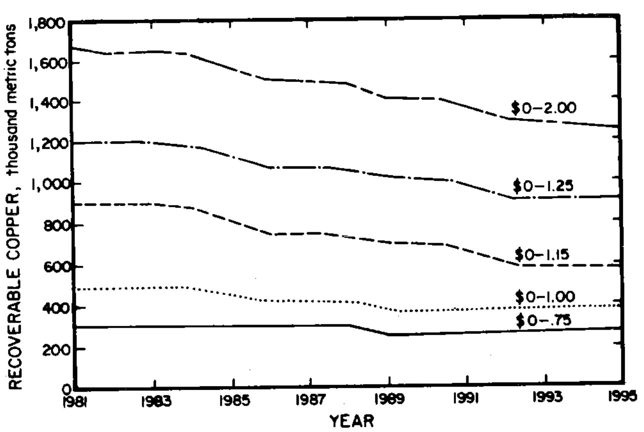

Figure 10.—Potential annual copper production from producing U.S. mines. (Costs per pound are shown at right in average 1981 dollars and include a 15-pct ROR.)

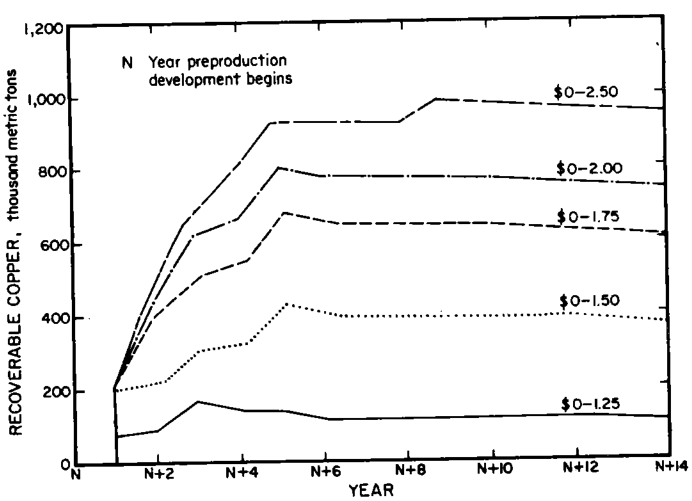

Figure 11.—Potential annual copper production from developing and explored U.S. deposits. (Costs per pound are shown at right in average 1981 dollars and include a 15-pct ROR.)

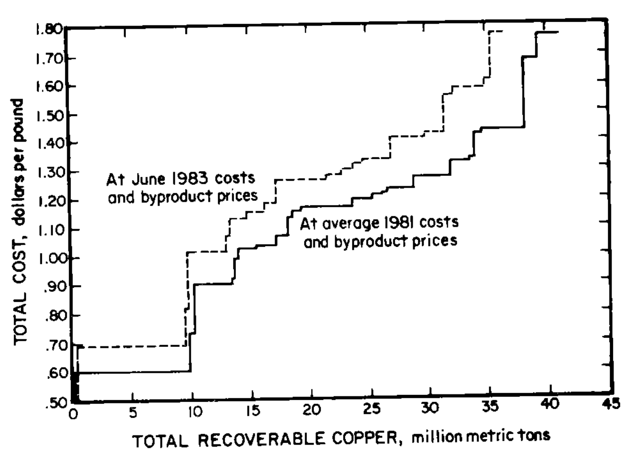

Figure 12.—Total copper availability from producing U.S. mines. (Costs are in average 1981 dollars and include a 15-pct ROR.)

inflation. There were many changes in byproduct prices, but it appeared that decreases in most byproduct prices were small and were offset in part by slight increases in other byproduct prices. Any future increases in prices for the major byproducts—gold, molybdenum, and silver—would help offset the increased costs caused by inflation.

Analysis was also performed to determine the shift in annual production costs between 1981 and 1983 for domestic producing mines. Figure 13 shows production cost and 1983 production potential at capacity levels for domestic mines expected to be in production in 1983. Included are 32 mines that were producing or temporarily shut down at the time of this study. On the average, production costs for these mines (including profit at a 15-pct ROR), increased $0.10 per pound of copper. As a result, the amount of copper that could be economically produced at a cost of $1/lb dropped about 30 pct, from 500,000 ton/yr to 350,000 ton/yr. Producing mines were projected to have the capability to produce 1.7 million tons of copper in 1983; however, production costs (in June 1983 dollars and including a 15-pct ROR) would exceed $1.50/lb. Again, increases in byproduct prices could significantly lower total production costs. Unless current market conditions greatly improve, it appears that in future years the United States will have to rely more heavily on imports of copper to meet demand.

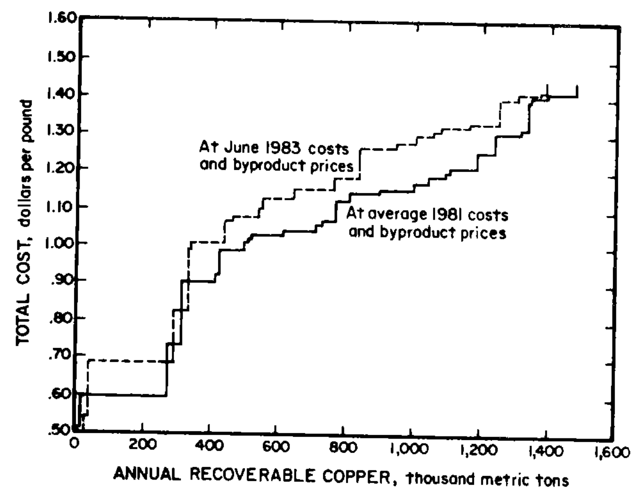

Figure 13.—Potential annual capacity of producing U.S. mines in 1983. (Costs include a 15-pct ROR.)

FACTORS AFFECTING COPPER AVAILABILITY

Of the factors that have significantly affected copper availability from market economy countries in recent years, two major influences, inflation and byproduct commodity prices, were analyzed to determine their possible future impact on copper availability. The same market economy deposits as were used in the previous analyses (i.e., those identified in tables 5-10) were used for the inflation and byproduct price analyses. The results of these analyses are discussed in the following two sections.

INFLATION

Inflation has greatly increased the cost of bringing new mines into production. During recent years, annual increases in capital costs of 10 to 20 pct have been common. As a result, cost estimates for many developing deposits have been revised upward, forcing delays or suspension of projects. Combined with high interest rates and low commodity prices, these high costs have led to a scarcity of capital in the mining industry.

In order to assess the possible impact of continued inflation on copper availability, the effects of 25- and 50-pct increases in capital costs on developing and explored deposits were analyzed while all other parameters were held constant. Figure 14 illustrates the effect of these increases. The analysis indicated that a 25-pct increase in capital costs would raise the average total cost for nonproducing deposits by $0.28/lb, from $1.82/lb (the

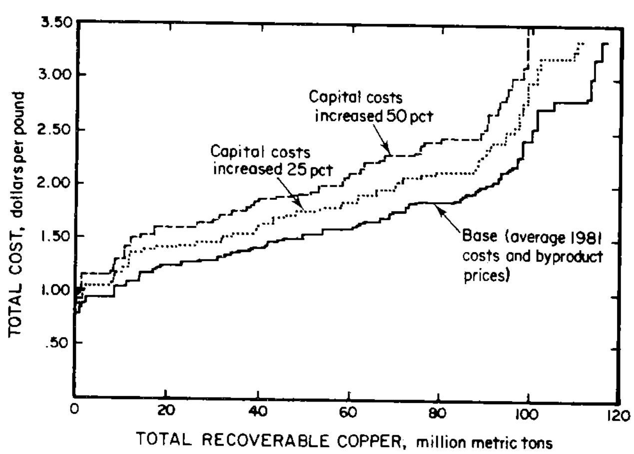

Figure 14.—Impact of capital cost increases on copper availability from developing and explored deposits. (Costs are in average 1981 dollars and include a 15-pct ROR.)

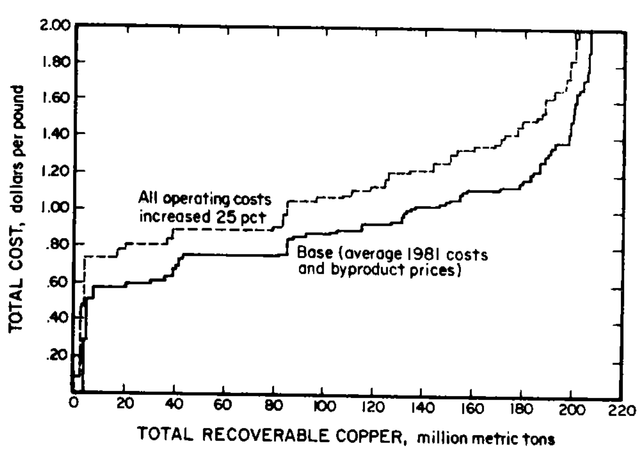

Figure 15.—Impact of 25-pct operating cost increase on copper availability from producing mines. (Costs are in average 1981 dollars and include a 15-pct ROR.)

1981 average total cost) to $2.10/lb. (All costs and prices in this section and the next are costs or prices per pound of refined copper.)

As shown in figure 14, a 25-pct increase in capital cost would lower the quantity of copper economically recoverable at the average 1981 market price ($0.85/lb) by 7.1 million tons. At higher copper prices of $1.25/lb and $1.50/lb, economically recoverable copper would decrease by 11.3 and 17 million tons, respectively.

The impact of inflation on operating costs is even more significant than it is on capital cost. As shown in figure 15, a 25-pct increase in operating costs would cause the availability curve for mines producing at the time of this study to shift upward; the average total cost for these mines would rise 23 pct, from $0.92/lb to $1.13/lb, a $0.21/lb increase. Consequently, the amount of copper that producing mines could economically produce would decrease significantly. At $0.85/lb, the total would drop by more than 60 pct, from 86 million tons to 39 million tons.

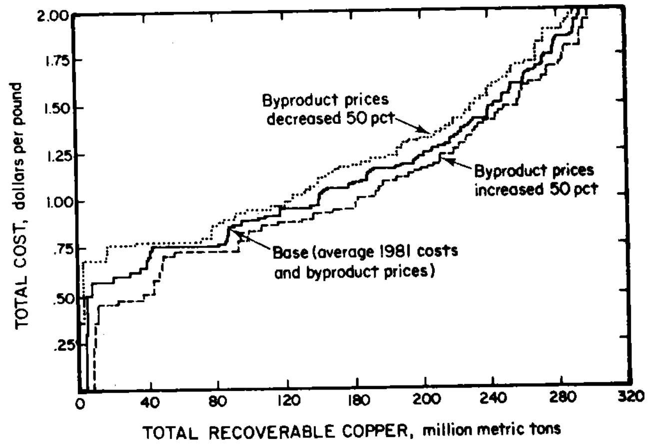

Figure 16.—Impact of byproduct price changes on total copper availability. (Costs are in average 1981 dollars and include a 15-pct ROR.)

BYPRODUCT COMMODITY PRICES

Revenues from byproduct prices may either offset or magnify the effects of inflation. In early 1980, gold and silver prices increased sharply, greatly improving the profitability of the copper industry. These increases caused a renewed interest in the industry, and many companies planned to increase the capacities of existing mines and develop new deposits. The price increases were short-lived, however, and now many mines are not even able to cover production costs.

Figure 16 shows the significant shifts in the total availability curve that would result if byproduct prices were increased or decreased by 50 pct. For producing mines, a 50-pct increase in byproduct prices would lower the average total cost by $0.08/lb, to $0.85/lb, whereas a 50-pct decrease would raise the cost by $0.10/lb, to $1.03/lb. For nonproducing deposits, an increase in byproduct prices would lower the average total cost by $0.14/lb, to $1.68/lb, whereas a decrease would raise the average cost to $1.95/lb.

At a copper price of $0.85/lb, a 50-pct increase in byproduct prices would make available an additional 19 million tons of copper, and a 50-pct byproduct price decrease would reduce copper availability by 10 million tons. At a copper price of $1.25/lb, the impact of byproduct price changes would be greater; a 50-pct byproduct price increase would make available an additional 12 million tons of copper, whereas a 50-pct byproduct price decrease would reduce copper availability by 21 million tons.

SUMMARY AND CONCLUSIONS

The 272 mines and deposits the Bureau analyzed for this study contain an estimated 413 million tons of copper, of which 80 pct is recoverable using present mining and processing technology. Of the copper potentially recoverable from these mines and deposits, 63 pct is from mines that were producing at the time of the study, and 37 pct is from developing or explored deposits.

Forty-six percent of the copper potentially recoverable from market economy countries occurs in Chile and the United States, which have the world's largest copper resources. At the average 1981 market price of $0.85 per pound of copper, the market economy countries could economically produce an estimated 88 million tons of copper, which would be equal to about 27 pct of the copper available from these countries. At a price of $1/lb (in constant 1981 dollars), the quantity of copper that could be economically produced would increase to 141 million tons. At both these prices, nearly all output would be from mines that were producing at the time of the study.

Copper mine production from market economy countries during 1981 was estimated at 6.2 million tons. At the average 1981 copper price of $0.85/lb, analyses indicated that producing operations could economically produce (realizing a 15-pct ROR) only 2.1 million tons of copper per year; therefore, many mines were operating at less than a 15-pct ROR. Analysis indicated that copper prices of $1.25/lb to $1.50/lb would be required for the copper industry to produce economically at the 1981 production level.

The average total cost for producing mines (including profit at a 15-pct ROR) was estimated to be $0.92 per pound of copper: $1.07/lb for U.S. mines and $0.87/lb for other market economy mines. An estimated 80 pct of U.S. producing mines and 50 pct of other market economy mines have a total cost (including profit) of greater than $1/lb. Because of recent low copper prices, many mines have curtailed production or shut down; unless market prices increase, additional mines may follow suit. Total cost was much higher for developing deposits, averaging $1.50/lb. Startup of the higher cost developing deposits will likely be postponed or delayed until market conditions improve. Costs for nonproducing deposits averaged $1.82/lb, which is more than double the January 1981 market price. Production from most of these deposits is unlikely for many years.

Over the last 3 years, production costs for U.S. mines have increased greatly. In a 1978 study, the Bureau estimated that at a copper price of $1/lb, slightly more than 50 million tons of copper could be mined economically. This study indicates that a copper price of $1.65/lb is now required for mines to produce this same amount economically. The break-even production cost (including operating costs, taxes, and miscellaneous costs but not recovery of capital or profit) for the U.S. mines producing at the time of this study was $0.92 per pound of copper; recovery of capital and profit, at a 15-pct ROR, added an additional $0.15/lb. At the January 1981 price of $0.85/lb, it was estimated that only one out of every six U.S. mines was operating economically.

Capital costs per annual ton of refined copper were estimated to be $5,800 (in 1981 dollars.) These costs include exploration, acquisition, development, mine and mill plant and equipment, and infrastructure but do not include smelting and refinery costs. Analyses indicated that inflationary impacts on capital and operating costs have greatly affected deposit profitability, as have recent shifts in byproduct commodity prices.

This study (based on 1981 data) confirmed that recent copper and byproduct price levels imposed extreme hardships on the copper industry of the market economy countries. The situation was even more acute for U.S. producers, whose production costs (in average 1981 dollars) averaged $1.07 per pound of copper, which was $0.20/lb more than the costs encountered by producers in other market economy countries. More recent data (projections for June 1983) showed that cost escalations have not abated. Unless market conditions greatly improve, many additional mines in the United States and around the world may be forced to close.

REFERENCES

1. Bennett, H. J., L. Moore, L. E. Welborn, and J. E. Toland. An Economic Appraisal of the Supply of Copper From Primary Domestic Sources. BuMines IC 8598, 1973, 156 pp.
2. Butterman, W. C. Copper. Ch. in BuMines Minerals Yearbook 1980, v. 1, pp. 261-291.
3. Canadian Mining Journal. Cominco's Bethlehem Purchase Paves Way for Valley Development. Nov. 1981, pp. 24-31.
4. Centromin Peru S.A. 1981 Annual Report, 55 pp.
5. 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. (Also known as the STRAAM handbook.) BuMines Special Pub., 1980, 149 pp.
6. Cox, D. P., N. A. Wright, and G. J. Coakley. The Nature and Use of Copper Reserve and Resource Data. U.S. Geol. Survey Professional Paper 907F, 1981, p. F10.
7. Davidoff, R. L. Supply Analysis Model (SAM): A Minerals Availability System Methodology. BuMines IC 8820, 1979, 45 pp.
8. Engineering and Mining Journal. 1982 Survey of Mine and Plant Expansion. V. 183, No. 1, pp. 51-71.
9. ———. Brazil Takes First Steps on the Long Road to Copper Self-Sufficiency. V. 182, No. 10, p. 57.
10. ———. Cerro Colorado Project May Be Delayed by Costs and Low Copper Price. V. 183, No. 2, p. 11.
11. ———. Chile Sees Larger Role for Private Copper Mines to Achieve Output Goals. V. 182, No. 10, p. 48.
12. ———. Miami East Project May Utilize Dasco Mining Machines in Stopes. V. 183, No. 3, pp. 35-39.
13. ———. Peru Mounts New Campaign to Attract Foreign Capital for Mine Development. V. 182, No. 7, pp. 35-37.
14. ———. Production Begins at Asarco's Troy Project. V. 182, No. 9, p. 55.
15. ———. This Month in Mining. New Mexico section. V. 182, No. 9, p. 258.
16. ———. This Month in Mining. Papua New Guinea section. V. 183, No. 2, p. 162.
17. ———. This Month in Mining. Peru section. V. 182, No. 11, p. 310.
18. ———. This Month in Mining. Philippines section. V. 183, No. 3, p. 222.
19. Everett, F. D., and H. J. Bennett. Evaluation of Domestic Reserves and Potential Sources of Ores Containing Copper, Lead, Zinc, and Associated Metals. BuMines IC 8235, 1967, 78 pp.
20. Mining Magazine. Gravity Surveys the Key at Neves-Corvo, Portugal. V. 145, No. 5, p. 345.
21. ———. New Mine in Bor Cu Field. V. 142, No. 4, p. 389.
22. Rosenkranz, R. D., R. L. Davidoff, J. F. Lemons, Jr. Copper Availability—Domestic. A Minerals Availability System Appraisal. BuMines IC 8809, 1979, 31 pp.
23. Schroeder, H. J. Copper. Ch. in BuMines Minerals Yearbook 1971, v. 1 pp. 461-494.
24. Schroeder, H. J., and J. H. Jolly. Copper. Ch. in Minerals Facts and Problems. BuMines Bull. 671, 1980, pp. 227-244.
25. Sousa, L. J. The U.S. Copper Industry—Problems, Issues, and Outlook. BuMines Mineral Issues, 1981, 86 pp.
26. Stermole, F. J. Economic Evaluation and Investment Decision Methods. Investment Evaluations Corp., Golden, Colo., 2d ed., 1974, 443 pp.
27. Tomimatsu, T. T. The U.S. Copper Mining Industry. A Perspective on Financial Health. BuMines IC 8836, 1980, 20 pp.
28. U.S. Bureau of Mines. Copper. Ch. in Mineral Commodity Summaries, 1982, pp. 40-41.
29. U.S. Geological Survey. Principles of a Resource/Reserve Classification for Minerals. U.S. Geol. Survey Circ. 831, 1980, 5 pp.
30. White, L. Why are Copper Concentrates Produced in Arizona and Montana Being Smelted in Japan? Eng. and Min. J., v. 183, No. 5, pp. 72-75.
31. Wideman, F. L., G. N. Greenspan, and W. F. Washington. Copper. Ch. in BuMines Minerals Yearbook 1962, v. 1, pp. 483-530.
32. World Mining. Argentina section. June 1981, p. 155.
33. ———. Asia section. May 1981, p. 49.
34. ———. Burma section. June 1981, p. 142.
35. ———. Sweden section. June 1981, p. 156.
36. ———. Uganda section. March 1981, p. 72.

APPENDIX

Table A-1.—Deposits investigated but not included in this study

Country and deposit name	Comments
NORTH AMERICA	
Canada:	
Cariboo Bell	Raw prospect.
Caribou	Zinc mine.
Gambier Island	Raw prospect.
Giant Yellowknife	Gold mine.
Goldstream River	Zinc mine.
Lyon Lake	Do.
Mattabi	Do.
Ming	Small resource.
Morrison	Raw prospect.
Nabs	Do.
OK	Do.
Red Group	Do.
Spruce Point	Small zinc-lead-silver deposit.
Sturgeon Lake	Reserves depleted.
Sudbury (Inco)	Nickel mines.
Sudbury (Falconbridge)	Do.
Tasu	Small resource.
Thompson	Nickel mine.
Whitehorse Copper	Small resource.
Mexico:	
Cumobabi	Small mine.
Inguaran	Reserves depleted.
CENTRAL AND SOUTH AMERICA	
Argentina:	
Cerro Mercedario	Raw prospect.
Cerro Rico	Do.
Famatina	Do.
Bolivia:	
Chacarilla	Small resource.
Corocoro	Do.
Brazil:	
Carajas	Raw prospect.
Eloma	Do.
Chile:	
Carolina Michilla	Small resource.
Cerro Colorado	Raw prospect.
Copaquire	Molybdenum deposit, raw prospect.
El Indio	Primarily a small gold-silver deposit.
La Africana	Raw prospect.
Puntillas	Do.
Sierra Gorda	Do.
Colombia:	
Pantanos—Pegadorcito	Do.
Ecuador:	
Chaucha	Do.
Loja	District name.
Panama: Rio Pito	Geochemical anomaly.
Peru:	
Canariaco	Raw prospect.
Chalcobamba (Las Bambas)	Do.
La Granja	Do.
Pashpap	Do.
Quechua	Geochemical anomaly.
Tambo Grande	Raw prospect.
EUROPE	
Finland:	
Hammaslahti	Small resource.
Vihanti	Zinc mine.
Virtasalmi	Small resource.
France: Salisgne	Do.
Greece:	
Ermonis	Reserves depleted.
Kassandra	Lead-zinc mine.
Norway: Sulitjelma	Small resource.
United Kingdom:	
Coed-Y-Brennin	Raw prospect.
Yugoslavia: Kapaonik	Do.

Country and deposit name	Comments
MIDDLE EAST AND WESTERN ASIA	
Cyprus: Limni	Small resource.
India:	
Agnigundala	Raw prospect.
Kalyadi	Small resource.
Rajpura-Dariba	Lead-zinc mine.
Iran: Meiduk (Lacher)	Small resource.
Saudi Arabia: Al Masane	Raw prospect.
Turkey:	
Asikoy	Do.
Kure-Bakibaba	Small resource.
Maaden Luoto	Geochemical anomaly.
EASTERN ASIA AND OCEANIA	
Australia:	
Attutra	Small resource.
Burra	Do.
Mount Dianne	Do.
Mount Gunson	Do.
Mount Morgan	Do.
Olympia Dam	Resource estimation in progress.
Indonesia:	
Timor Island	Deposit unknown.
Sulawesi	Raw prospect.
Japan:	
Akenobe	Small resource.
Furutobe	Do.
Hanawa	Do.
Shakanai	Do.
Shimokawa	Do.
Yanahara	Pyrite deposit.
Papua New Guinea: Aerie	Raw prospect.
Philippines:	
Bagacay	Raw prospect.
Balete	Small resource.
Barlo	Do.
Black Rock	Do.
Cauayan	Raw prospect.
Hercules	Small resource.
Luna	Raw prospect.
Omico Mining	Small resource.
Polar	Raw prospect.
Regalian	Small resource.
Vulcan	Do.
Thailand: Phu Hin Lek Fai	Raw prospect.
AFRICA	
Angola:	
Cachoeiras de Binga	Raw prospect.
Namibia:	
Haib River	Do.
Matchless	Small resource.
Oamites	Do.
Okahandja	Do.
Onganca	Do.
South Africa:	
Bafokeng	Platinum mine.
Foskor	Phosphate mine at Palabora.
Marikana	Platinum mine.
Rustenberg	Do.
Zambia:	
Bwana Mkubwa	Small resource.
Chimiwungo	Raw prospect.
Malundwe	Do.
Mokambo	Small resource.
Zimbabwe:	
Empress	Nickel mine.
Inyati	Small resource.
Norah	Do.
Shackleton	Do.
Shangani	Nickel mine.