Information Circular 9086

Tin Availability—Market Economy Countries

A Minerals Availability Appraisal

By D. I. Bleiwas, Andrew E. Sabin, and G. R. Peterson

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, 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 environment 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.

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PREFACE

The Bureau of Mines is assessing the worldwide availability of selected minerals of economic significance, most of which are also critical minerals. The Bureau identifies, collects, compiles, and evaluates information on producing, developing, and explored deposits, and on mineral processing plants worldwide. Objectives are to classify both domestic and foreign resources, to identify by cost evaluation those demonstrated resources that are reserves, and to prepare analyses of mineral availability.

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

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	tr oz/mt	troy ounce per metric ton
cm	centimeter	pct	percent
d/yr	day per year	mt	metric ton
kg	kilogram	mt/d	metric ton per day
km	kilometer	mt/yr	metric ton per year
km^2	square kilometer	tr oz	troy ounce
kV•A	kilovolt ampere	yr	year
lb	pound	$/lb	dollar per pound
m	meter	$/mt	dollar per metric ton
m^3/yr	cubic meter per year		

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A Minerals Availability Appraisal

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ABSTRACT

The Bureau of Mines determined demonstrated tin resources and costs associated with tin production in order to evaluate the potential for tin production from 18 market economy countries (MEC's). Data were collected from tin producers, in most cases during on-site visits. The analyses evaluated the relative economic and resource position of 146 mines, deposits, or regions in January 1984 dollars. The demonstrated resource of recoverable tin within the nations studied is approximately 2.8 million metric tons (mt). Of this total, over 73 pct is recoverable from the Southeast Asian countries of Malaysia, Thailand, and Indonesia, which in 1983 accounted for almost 60 pct of the world's tin production. Brazil has joined the Southeast Asian countries as a major low-cost, high-volume supplier of tin and is likely to continue to expand its production.

Given the 1984 market structure, over 60 pct of the tin in demonstrated resources was economically recoverable. Historically, the International Tin Council (ITC) has helped maintain relatively stable tin prices through a buffer stock and sales quotas. In late 1985, exhaustion of buffer stock funds led to suspension of tin trading on the world's major tin metal exchanges.

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INTRODUCTION

The purpose of this Bureau of Mines report is to identify and define demonstrated tin resources and evaluate the potential production from 1 domestic and 145 foreign deposits, mines, and regions in 17 foreign countries and the United States. The objectives was to evaluate at least 85 pct of the tin resources and 85 pct of the tin production from producing operations in MEC's.[4] Tin is unlike most other commodities in that large amounts are produced, on a cumulative basis, from state-owned enterprises (in major tin-producing countries), small family groups, communes, and individuals. Where data on individual resources and associated costs were unavailable, as in the case of gravel pumps, entire states or regions were evaluated. Malaysian tin resources, in particular, were evaluated in this manner. Mines and deposits were evaluated according to their January 1982 status, with regard to mining and milling methods, ownership, costs, and resources.

This study included identification of tin resources and the engineering and economic parameters that affect production from the deposits selected for evaluation. Information on the 147 foreign mines and regions was gathered by the Davy McKee Corp. under Bureau contract J0225004 (*1*).[5] Demonstrated and, in some cases, identified resources and grades were defined. Also obtained or estimated were capital investment and operating costs (direct and indirect) and transportation costs to postmill processing destinations. Data for the one potential domestic operation were collected and evaluated by the Bureau of Mines Field Operations Center in Anchorage, AK. The overall data and economic evaluation analyses were performed by the Bureau's Minerals Availability Field Office, Denver, CO.

Of the 161 tin mines and regions initially investigated, 2 were excluded because of exhaustion of the demonstrated resource, 3 were excluded because their resource tonnage was estimated only at the inferred level, 8 were excluded because tin was actually a minor byproduct, 1 was excluded due to a lack of available data, and 1 was excluded because the resource was small and costs were exceedingly high. The excluded deposits are listed in appendix A.

METHODOLOGY

The Minerals Availability Program is developing a continuously expanding data base for the analysis of mineral resource availability. An intregral part of this program is the Supply Analysis Model (SAM) developed by the Bureau of Mines Minerals Availability Field Office. SAM is an interactive computer system that is an effective tool for analyzing the economic availability of world mineral resources.

The geologic occurrence particular to the tin operations included in this study were determined in order to develop estimates of the demonstrated resources (fig. 1), in situ grades, and production costs. For each operation evaluated, actual or estimated capital expenditures for exploration, acquisition, development, and mine and mill plant and equipment were included. The capital costs for the mining and processing facilities included expenditures for mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure is a broad category that includes cost for access to the mine and its associated facilities, ports, water supply and treatment, power supply, and personnel accommodations. Working capital is a revolving cash fund for operating expenses such as labor, supplies, insurance, and taxes. All costs given are in terms of January 1984 U.S. dollars (except in a few cases where 1982 U.S. dollars are specified).

The initial capital costs for producing mines and developed deposits were depreciated according to the actual investment year, and the undepreciated portion was treated as a remaining capital investment in 1984. Reinvestments varied according to capacity, production life, age of facilities, and company philosophy. All costs were originally in January 1982 dollars but have been updated to January 1984 dollars (except as noted above) according to local currency factors and individual country inflation indexes. All costs were also weighted proportionately according to the effect of labor, energy, and capital in the tin industry on a countrywide basis.

The total operating cost estimated for a given mining operation is a combination of direct and indirect costs. Direct operating costs include mining and maintenance, labor and supplies, supervision, payroll overhead, insurance, local taxation, and utilities. Indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research. Other costs used in the analyses included standard deductibles such as depreciation, depletion, deferred expenses, investment tax credits, and tax-loss carryforwards.

After the engineering parameters and associated costs for the evaluated tin deposits were established, the SAM system was used to perform economic evaluations pertaining to the availability of tin. The SAM system, a comprehensive economic evaluation simulator, was used in this study to determine the average total cost of tin production over the estimated life of each operation, including a prespecified discounted-cash-flow rate of return (DCFROR) on investments, less all byproduct revenues. This average total cost represents the constant-dollar, long-run price at which the primary commodity must be sold to recapture all costs of tin production, including the prespecified DCFROR.

For this study, DCFROR's of 0 and 15 pct were specified for determining the long-run cost of production over the life of a property. The first rate, 0 pct, was used to determine the break-even cost, the cost at which revenues are sufficient to cover total investment and production

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

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

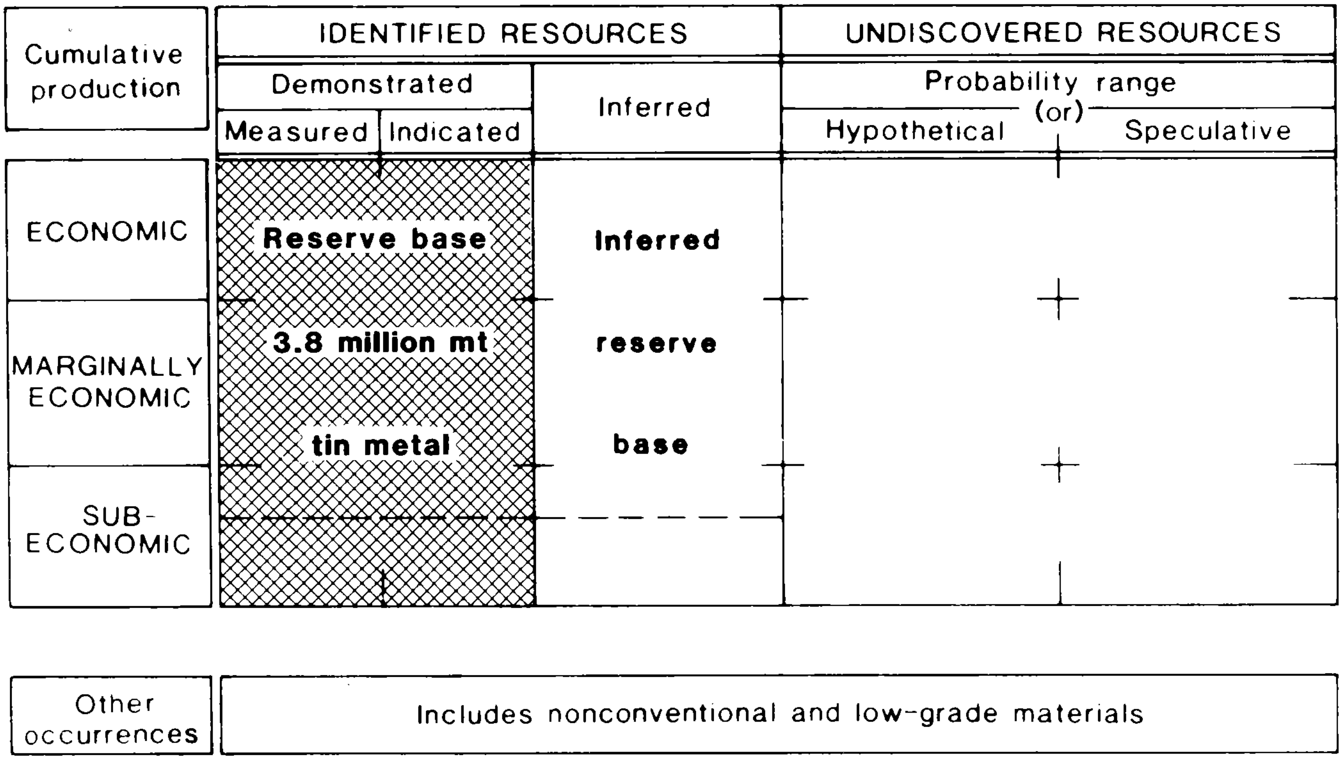


Figure 1.—Classification of mineral resources (as developed by the Bureau of Mines and the U.S. Geological Survey).

Table 1.—Tin byproduct commodity prices[1] used in economic evaluations

Commodity	Price, per lb unless otherwise specified[1]
Bismuth	$2.31
Copper	.70
Fluorspar, per mt:	
Acid grade	171.00
Metallurgical grade	125.00
Gold ... per tr oz	370.89
Lead	.25
Silver ... per tr oz	12.40
Tantalum oxide	29.50
Tungsten (WO_3):	
Ammonium paratungstate (APT)	4.99
Scheelite, artificial or concentrate	3.39
Zinc	.49

[1] Jan. 1984 U.S. dollars.

Table 2.—Tin market prices, 1975-84, U.S. dollars per pound[1]

Year	Lowest	Highest	Weighted average
1975	3.01	3.78	3.40
1976	3.09	4.31	3.75
1977	4.30	6.49	5.33
1978	4.87	7.64	5.89
1979	6.21	7.92	7.07
1980	6.87	8.99	7.86
1981	5.97	7.67	6.80
1982	5.84	7.53	6.20
1983	5.91	6.55	6.23
1984[e]	5.92	6.03	5.96

[e] Estimate based on projected trends.
[1] Based on New York prices (actual dollars) as reported by the ITC; Penang (Malaysia) prices may have been slightly different.

costs over the operation's life but provide no positive rate of return. This rate could reflect commitment to a project which seeks only a market share or other advantages such as social benefits, foreign capital, technological progress, or an expectation of better market prices that would offset current unprofitability. A 0-pct DCFROR could be acceptable for government-operated mining ventures. For privately owned enterprises, a more reasonable economic decision-making parameter is that represented by the 15-pct DCFROR. This rate is considered the minimum rate of return sufficient to maintain adequate long-term profitability and attract new capital to the industry.

The SAM program contains a separate tax records file for each country and State and includes all the relevant tax parameters under which mining firms operate. These tax parameters are applied to each evaluated mine, based on the assumption that each operation represents a separate corporate entity. The SAM system also contains a separate file of 12 economic indexes for each country to enable updating of cost estimates for both producing and nonproducing mines and undeveloped deposits in 95 countries.

Prices tables are maintained for all coproducts and byproducts that are applicable to the availability analyses. The byproduct prices used in this study are shown in table 1 and tin prices from 1975 to 1984 are listed in table 2. Stiff tin price control measures were maintained through most of 1985. In October, the exhaustion of price-controlling funds led to the suspension of all tin trading on the London Metal Exchange and the Kuala Lumpur market.

Detailed cash-flow analyses were generated with the SAM system for each preproduction and production year of an operation beginning with 1984, the initial year of analysis. Individual deposit or region analyses were aggregated to produce a total availability curve.

Availability curves are constructed as aggregations of all evaluated operations, ordered from those having the lowest average total costs to those having the highest. The potential availability of tin can be seen by comparing an expected long-run constant-dollar market price to the average total cost values shown on the availability curves. Availability curves are explained in greater detail in the "Tin Availability" section.

Certain assumptions are inherent to all analyses presented in this report. It was assumed that—

1. All mines could (and did) produce at design capacity throughout the estimated life of the operation, unless they were known to be producing at reduced levels or were temporarily shutdown because of depressed market conditions. (Full capacity could be resumed after a 1- to 4-year preproduction period.)

2. Each operation was able to sell all of its output at no less than the determined total cost required to obtain at least the minimum specified DCFROR.

3. Each operation was able to sell its coproducts and byproducts at the January 1984 market prices. Preproduction development of undeveloped deposits began in a hypothetical base year "N." Unless specified data were available, time delays relating to permits, environmental impact statements, and other factors affecting actual or potential production were minimized.

Some of the deposits evaluated could unexpectedly be prevented from development, forced to reduce production, or forced to close owing to lack of capital, environmental problems or issues, political reasons, a poor economic climate, or other constraints not known at the time of the evaluations.

U.S. PERSPECTIVE

In general, U.S. import reliance for tin is about 75 pct. About 25 pct of total U.S. tin requirements is derived from recycled scrap, solder, brass and bronze, and secondary tin-bearing materials. Total domestic tin production, from a placer operation in Alaska and as a byproduct from the Climax molybdenum mine in Colorado, amounts to less than 100 mt/yr. This is less than 0.2 pct of total annual domestic consumption. The one evaluated domestic tin resource, Alaska's Lost River deposit (a potential hard-rock open pit mine), is relatively small and probably would not be competitive at current or projected tin market prices. The Lost River placer mine, near Tin City, AK, is a very small producer and was not evaluated owing to very small demonstrated resources and its low historical production.

The major foreign suppliers of tin to the United States (fig. 2) are Malaysia, Thailand, Bolivia, and Indonesia. During the period 1979-82, Malaysia and Thailand supplied more than half of all U.S. tin imports (*2*). Since that time, Malaysia has lost part of its market share to Bolivia, Brazil, and Thailand.

In order to maintain a guaranteed supply of tin to the United States during a war emergency, the General Services Administration (GSA) maintains a stockpile. The tin stockpile has the highest monetary value of any of the 61 listed stockpile commodities, exceeding $2 billion (*3*). The GSA stockpile is the world's single largest readily available supply of tin metal. As of March 31, 1984, the stockpile contained 190,354 mt tin (*3*). This is down from a peak of 346,472 mt between 1946 and 1955. The current stockpile is sufficient to satisfy world market economy tin metal consumption for 1 yr. Sales from the stockpile were started in 1962 and have continued intermittently. In 1983, approximately 2,865 mt was sold. The Defenses Authorization Bill, approved in 1982, allowed GSA to sell up to 25,400 mt of tin in fiscal year 1985, although annual sales exceeding 3,000 mt were unlikely through 1986. The Association of South East Asian Nations (ASEAN) memorandum of understanding limited annual sales of tin from the stockpile to 3,000 mt/yr for 1983 and 1984 and continued into 1985. There are claims, especially by the ITC, that GSA sales produce significant downward pressure on the price of tin; however, GSA's tin sales continue. Owing to the availability of tin through the open market and the current size of the U.S. stockpile, the position of the United States in relation to its immediate need for tin is relatively secure.

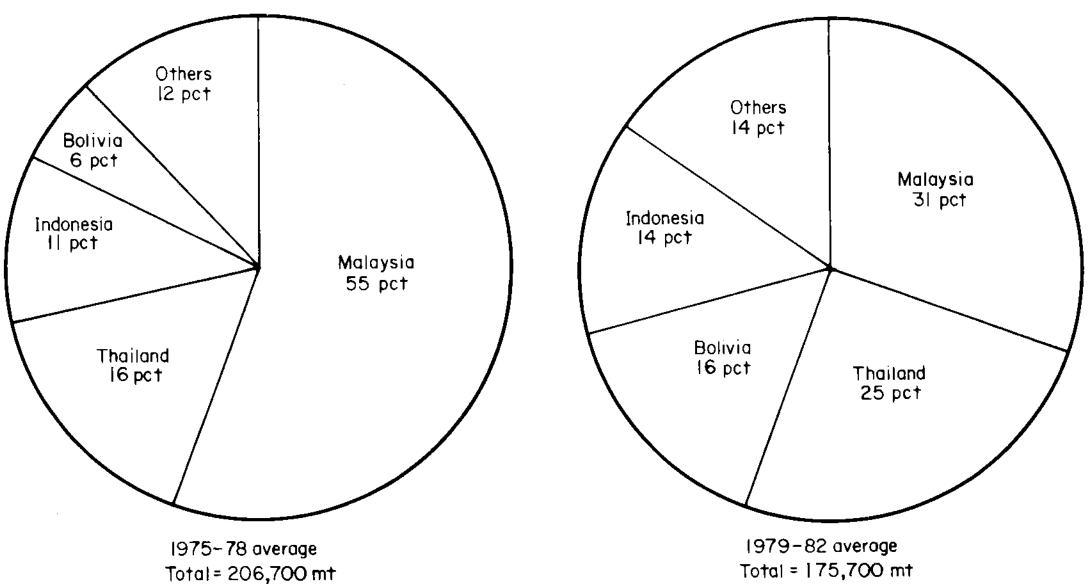


Figure 2.—Primary sources of U.S. tin imports, 1975-78 and 1979-82.

COMMODITY OVERVIEW

Tin was first used approximately 5,000 yr ago as a hardening agent with copper to form bronze. Since that time, tin has become critical to industry as a plating agent because of its ability to protect steel from corrosion and as a component of solder because of its superior adhering properties. Other minor uses for tin include the manufacture of chemicals, pewter, bronze, brass, and alloys for bearings. Research in a new application, as a component in maintenance-free batteries, is ongoing. Market economy tin consumption fell to a 23-yr low in 1982, at just over 157,000 mt, and only rose to about 160,000 mt in 1983. Consumption was expected to increase to 165,000 mt in 1984 (*4*).

Table 3.—Production of tinplate in selected MEC's, 1980-83, thousand metric tons (*5*)

Country	1980	1981	1982	1983
United States	3,699.9	3,273.6	2,714.0	2,568.7
Japan	1,868.8	1,665.8	1,639.1	1,584.8
United Kingdom	597.1	876.2	887.3	882.1
France	914.2	782.0	847.2	771.3
Germany, Federal Republic of	962.5	843.1	818.6	722.3
Netherlands	504.5	513.4	516.6	524.0
Italy	436.1	374.1	413.2	485.4
Spain	389.6	414.2	452.0	432.0
Brazil	594.6	403.2	447.9	391.0
Canada	491.8	365.9	394.7	382.4
Australia	360.0	339.5	330.0	338.0
Belgium	333.5	325.4	276.2	303.3
Others	1,841.4	2,072.9	2,022.1	1,828.7
Total	12,994.0	12,249.3	11,758.9	11,214.0

TINPLATE

Tinplate has traditionally been the largest single use of tin, accounting for approximately 54,000 mt, or 35 to 40 pct of all tin produced. Nearly 90 pct of the tin used for tinplate is used in the packaging industry, for cans and other containers, while most of the remainder is used for the manufacture of gaskets, oil and air filters, and automotive trim (*5*).

Although there are some variations in the manufacture of tinplate, the general process requires passing an electric current through flat-rolled strip steel to produce a cathode. The electrically charged steel is then passed through tin electrolyte and run at high speed between suspended tin anodes. An electrochemical reaction leaves a thin coating of tin deposited on both sides of the steel as tinplate.

Approximately 12 lb (5.4 kg) of tin is required for every metric ton of tinplate produced. Table 3 lists the production of tinplate in selected countries for 1980-83. The United States is the largest producer in the world. Three major U.S. companies produce tinplate: U.S. Steel Corp., Bethlehem Steel, and Weirton Steel Co. Owing to the recession and substitution of the early 1980's of aluminum and tin-free steel for tinplate, the 1983 U.S. tinplate industry operated at about 50 pct of capacity. Production increased in 1984.

Technological progress has allowed a progressive reduction in tin coating weights, which has enabled the tinplate industry to remain competitive with aluminum and plastics as a packaging material. Although there have been a series of reductions in production and permanent closures in the domestic tinplate industry, a new technologically advanced tinplate plant with an annual capacity of 2.9 million mt (of tinplate steel) was being planned by Bethlehem Steel and could be on-line in 1986.

Japan is the world's largest exporter of tinplate and the second largest producer. Japanese tinplate manufacturers produce a somewhat greater tin thickness than producers in other countries, owing to the requirements for the types of foods canned, such as fish, tomatoes, and fruits. In 1982, approximately 190,000 mt, or about 70 pct of China's tinplate needs, was supplied by Japan (*5*).

The European Economic Community (the United Kingdom, France, Federal Republic of Germany, the Netherlands, Italy, and Belgium) as a group is the largest producer of tinplate in the world. Of these countries, the United Kingdom is the single largest producer, and France is the largest exporter.

Five Asian countries, Malaysia, Indonesia, the Philippines, Thailand, and Singapore, have a combined installed annual capacity of about 365,000 mt of tinplate (*5*). Future plans for self-reliance include a 130,000-mt/yr plant in Indonesia due to start full operation in 1986 and a 250,000-mt/yr plant in Malaysia. Both plants will come on-line by 1986. In 1983, however, the five-country region consumed approximately 600,000 mt of tinplate. Despite producing well over half of the MEC's tin, the region is still a net importer of tinplate, but this is expected to change in the near future.

SOLDER

The most widely used alloy of tin is soft solder, which is generally composed of tin and lead in various proportions. In 1982, approximately 49,000 mt, or about 20 pct of all tin consumed, was used as tin in solders. The electronics industry is the largest consumer of solder. Solders have an average tin content of 60 pct, although some specialty solders contain up to 97 pct Sn. Owing to the growth of the electronics industry, moderate growth in demand for solder is expected through 1987. The application of new alunimum soldering techniques could also result in increased consumption. Solders are also used for nonelectric applications such as radiator repair, plumbing, car bodies, and sheet metal. Most of the solders for engineering contain from 2 to 50 pct Sn and use a significant amount of impure and recycled tin (*5*).

TIN CHEMICALS

Tin chemicals account for about 10 pct of total tin consumption. The use of tin in chemicals is expected to continue growing through 1987 (*5*).

Tin is used in plastics, specifically polyvinyl chloride (PVC), to reduce susceptibility to corrosion, light, and heat. Tin is also used in nontoxic biocides, such as pesticides and ship paints. Tin has wide applications as a pigment in glass and ceramics and as a corrosion-resistant additive for primer paints.

SECONDARY TIN

The United States is the world's largest producer of secondary tin. In 1983, about 25 pct of the total tin consumed in the United States originated from secondary material.

There are three primary sources of secondary tin: (1) refined tin from scrap, tinplate scrap, and residues from tinplating, tinning, and detinning; (2) tin contained in alloys; and (3) tin contained in scrap originating from tin fabricators and manufacturers of tin-containing products.

These secondary sources consist of basically two types: tin scrap and tinplate scrap. Tin scrap originates as tin in tin products and tin-rich alloys (bronze, brass, etc.) Tinplate scrap consists of tinplated rejects and leftover trimmings from the manufacture of tinplated containers. It is difficult to acquire accurate statistics regarding the amount of tin derived from secondary sources worldwide because some tin alloys are simply melted and poured to produce new alloy castings. It is possible that between 10 and 20 pct of total world tin production originates from tin scrap. Secondary tin production may increase if tin and steel prices rise or if growing environmental concerns result in more recycling of containers.

WORLD PRODUCTION OF TIN CONCENTRATES

As shown in table 4 and figure 3, production of tin concentrate is dominated by four countries: Malaysia, Indonesia, Bolivia, and Thailand. These four countries accounted for about two-thirds of the 1983 MEC production and, based on preliminary estimates, slightly less than two-thirds of the 1984 MEC production. In 1980, these four countries accounted for over 80 pct of all tin-in-concentrate production. The decrease in market share from 1980 to 1983 resulted primarily from export controls and production cutbacks among members of the ITC, of which three of the four countries are members (Malaysia, Thailand, and Indonesia). The other members, Austrailia, Nigeria, and Zaire, produced only 17 pct of MEC tin-in-concentrate production. Voluntary production and export controls among the six ITC member countries effectively reduced 1983 tin-in-concentrate production by about 55,000 mt. Although there is some variation, most tin concentrates average about 70 pct Sn. A brief discussion of tin concentrate production, by country, follows:

Table 4.—Production of tin concentrate in selected MEC's 1980-84, metric tons (*5-6*)

Country	1980	1981	1982	1983	1984[p]
Malaysia	61,404	59,938	52,342	41,367	38,000
Indonesia	32,527	35,268	33,800	26,554	25,000
Bolivia	27,271	29,830	26,773	24,736	24,000
Thailand	33,685	31,474	26,207	19,942	20,000
Brazil	6,900	8,300	8,200	13,700	17,700
Australia	11,588	12,925	12,615	9,578	9,000
United Kingdom	3,000	3,900	4,200	4,100[e]	4,000
South Africa, Republic of	2,913	2,811	3,035	2,668[e]	2,301
Nigeria	2,569	2,300	1,708	1,450	1,340
Zaire	3,159	3,321	3,144	2,930	4,120
Unspecified origin	7,000	6,000	10,000	16,600[e]	13,000
Others	9,300	9,400	9,400	9,500[e]	10,000
Total	201,316	205,467	191,424	173,125	168,461

[e] Estimated. [p] Preliminary.

MALAYSIA

In 1984, Malaysia produced over 40,000 mt of tin-in-concentrate. It has continually been the world's largest producer of tin since the last century. In 1900, Malaysia produced about 43,000 mt tin-in-concentrate, or about 55 pct of world production (*7*). Although Malaysia's tin industry was greatly affected during the Second World War by the Japanese invasion, it rapidly recovered its position after the war.

The tin mining industry is becoming increasingly Government controlled under the name of the Malaysian Mining Corporation (MMC). MMC has many subsidiaries responsible for individual or regional mining operations and, in recent years, has produced over 35 pct of the country's total tin production. There is little foreign participation in the Malaysian tin industry. In 1984 and 1985, production in Malaysia was more than 30 pct below plant capacity owing to voluntary export controls agreed upon by members of the ITC.

Malaysia's production is primarily from dredges and gravel pumps. Mining operations are discussed more fully later in this report.

INDONESIA

In 1983, Indonesia produced 26,554 mt tin-in-concentrate. Mining activities are situated on or around three islands: Bangka, Belitung, and Singkep. Bangka Island is the major tin producing area. As in Malaysia, Indonesia's tin industry was nearly destroyed by the Japanese invasion, but has recovered to assume the position of the world's second largest producer.

Also in Malaysia, the Indonesian Government is increasing its control over the tin industry. The Government currently produces over 75 pct of the total tin production from the State-controlled company Perusahaan Tambang Timah (PT Tambang Timah Persero). Although there are foreign interests, primarily Australia and the Netherlands, the state does exercise some control as a participating partner. Indonesian production is probably higher than what is reported because of unrecorded stockpiling. Mine capacity is significantly higher than production, but export controls have reduced production by about 40 pct of capacity.

The majority of Indonesia's production comes from gravel pumps, but a significant portion originates from offshore dredges. Offshore dredges are becoming increasingly important because of the discovery of additional resources around Bangka, Belitung, and Singkep Islands.

BOLIVIA

Bolivia produced 24,736 mt of tin-in-concentrate in 1983 and maintained its position as the world's third largest tin concentrate producer, a position held since 1979. From 1969 to 1978, Bolivia was the second largest producer of tin concentrates (*8*). Virtually all of Bolivia's tin production originates from poorly managed, inefficient, underground mining operations. This, combined with political unrest and monetary devaluations, resulted in a decrease of about 20-pct in estimated mine production

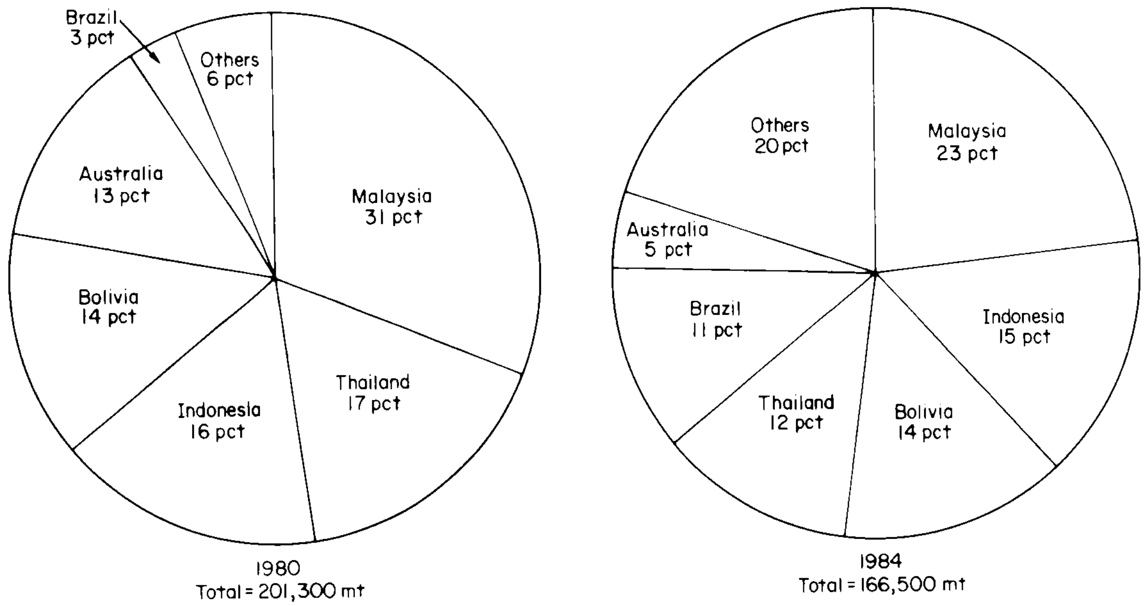


Figure 3.—Estimated tin-in-concentrate production among primary MEC producers, 1980 and 1984.

from 1981 to 1984. Miners have resorted to striking against the Government because of failure to pay overdue royalties.

The tin mining industry is composed of three sectors: the nationalized mining corporation, Corporacion Minera de Bolivia (COMIBOL); the medium-sized mines owned by private companies; and the small mines run by individuals and small partnerships. About 65 pct of Bolivia's total tin production originates from COMIBOL, which produced only about 16,000 mt of tin-in-concentrate in 1983, down from nearly 21,000 mt in 1981. The decline in production in recent years has resulted from falling ore grades, increasingly difficult mining conditions, political unrest, and above-average mining costs. In 1983, tin concentrate and metal valued at $207 million represented nearly 45 pct of Bolivia's total export earnings (60 pct of mineral export earnings) (*8*).

THAILAND

Thailand produced 19,942 mt tin-in-concentrate in 1983 and is currently the world's fourth largest producer. Thailand's tin concentrate production reached a peak in 1979 of 33,962 mt (*5*). Thailand's tin industry is poorly organized in that much of its production is erratic and often unreported.

Illegal mining and smuggling of tin concentrates out of the country are commonplace. Most of the production is from privately owned companies, many of which are Malaysian. The Offshore Mining Organization (OMO), a Government-owned mining group, controls mining areas which are leased to private concerns and allows small suction boats to recover tin, provided they sell through OMO's concentrate buyer. Low prices for concentrates have forced many suction dredge operations out of business and have encouraged additional smuggling to avoid taxes. Overall, about 60 pct of reported tin production originates from gravel pumps and suction dredges. The remaining production originates from open cut, underground, and other generally small operations.

BRAZIL

In 1983, Brazil was the fifth largest producer of tin concentrate in the world, producing an estimated 13,000 mt. Brazil has increased production dramatically since 1982, when an estimated 9,200 mt was produced (*9*). This rate of increase may not be sustainable, owing to the anticipated exhaustion of several mines in the near future. Production in 1984 was expected to approach 17,700 mt of tin-in-concentrate.

Although Brazil contains large resources, major problems impede their development. Most of the known deposits are deep within jungle areas, and therefore mining operations have to be self-sufficient with respect to power, water, etc. In addition, fuel costs are high, and wages must be lucrative to attract workers. Smuggling and theft of concentrates is also a problem in Brazil, where hijacking of concentrates during shipping has been increasing. Brazil's Mining Minister has predicted that the tin mining industry, which is privately operated, will continue to expand through the remainder of the decade (*10*).

The majority of Brazil's tin originates from the Rondonia Province. Most of the country's tin is produced from gravel pump operations.

OTHER COUNTRIES

Approximately 25 pct of the remaining world production originates from Australia, the United Kingdom, Nigeria, Zaire, the Republic of South Africa, Peru, Burma, Rwanda, and other sources. The other sources supply, for the most part, smuggled tin. Of the above-mentioned countries, lode deposits in Australia and the offshore deposits of Burma offer excellent potential for significantly expanded production. From 1969 to 1982, Australia increased its tin concentrate production from 10,035 mt to over 12,000 mt. In 1983, production dropped to just over 9,500 mt; production in 1984 was slightly lower.

Tin production in the United States has historically been small and intermittent. The average total annual domestic tin production for 1980 through 1984 amounted to less than 100 mt tin, about a third of which originated as a byproduct from the Climax Molybdenum Mine in Colorado. Nearly all of the remainder is produced from the Lost River deposit, a small alluvial occurrence in Alaska.

WORLD PRODUCTION OF TIN METAL

Figure 4 and table 5 show the distribution of tin metal production. Appendix B lists tin smelter and refinery facilities by country and provide specific information on plant capacities, processing methods, and products. Over the last 10 yr, there has been a shift in the location of the tin smelting industry. Europe has been steadily losing its share of primary tin metal production to Southeast Asia, and Belgium has essentially ceased tin production. This has resulted from efforts on the part of countries such as Indonesia, Bolivia, and Brazil to realize the higher revenues from value-added products, decrease dependence on imports, train their work forces, and develop technology.

MALAYSIA

Malaysia produces the largest quantity of primary tin in the world. Approximately 53,338 mt of primary tin was produced in 1983 from both domestic and foreign concentrates. Tin concentrates are imported from Indonesia, Thailand, Auatralia, Burma, Laos and Africa.

The two largest tin smelters in the world are located in Malaysia. They are the Datuk Keramat smelter on Penang Island and the Malaysian Smelting Corp. smelter at Butterworth, with annual capacities of 70,000 and 60,000 mt, respectively. The Datuk Keramat plant processes the majority of foreign concentrates.

INDONESIA

Indonesia is the second largest manufacturer of tin metal among the MEC's. In 1983, Indonesia produced approximately 28,396 mt, or 18 pct of total known MEC production. Since 1977, Indonesia has smelted most of its own tin concentrate at a Government-operated facility in the city of Mentok on Bangka Island. The plant has an annual capacity of approximately 38,000 mt/yr of tin metal, using four reverberatory furnaces and three rotary furnaces.

THAILAND

Thailand is the third largest producer of tin metal among the MEC's. In 1983, the country produced 18,467 mt of tin metal, which was far below smelter capacity. Thailand has five smelters with a combined capacity of about 50,000 mt and is planning for future expansion despite voluntary cutbacks. The largest smelter, owned by Thaisarco and located at Phuket, has a capacity of about 35,000 mt. Until 1977, Thaisarco had exclusive rights to smelting all of Thailand's tin concentrates, but the Government recently granted licences to private companies, permitting construction of additional capacity. This change in policy resulted in an additional 14,500 mt of capacity, of which 10,000 mt is at the Thai Pioneer Corp. facility, which was built in 1982. The Thailand Tantalum Industries Corp. is constructing a tin slag treatment plant at Phuket.

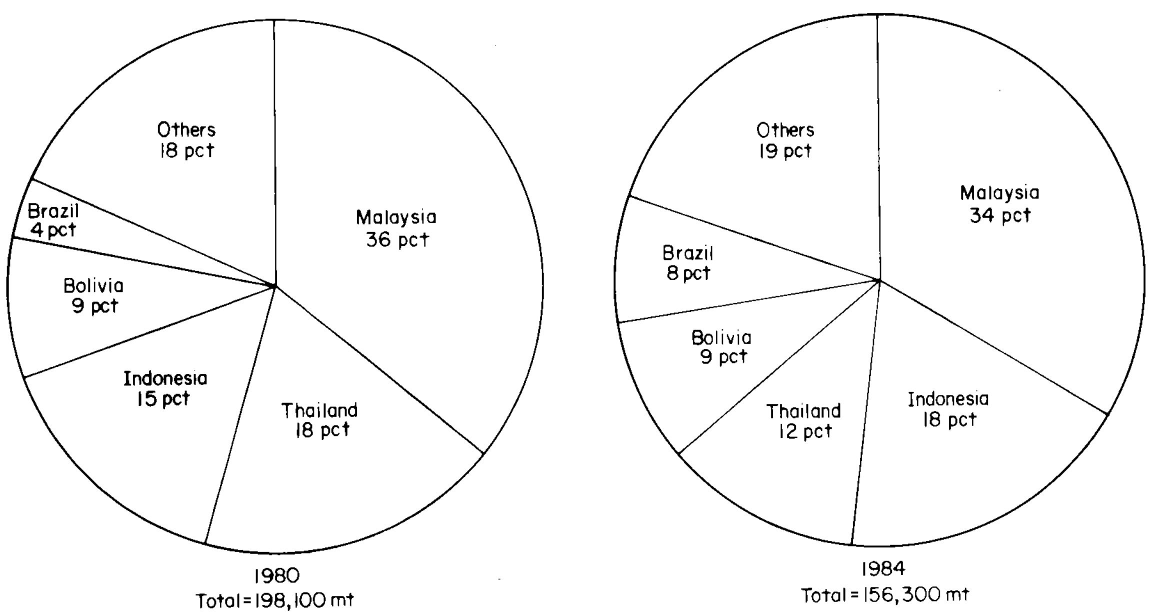


Figure 4.—Distribution of tin metal production among primary MEC producers, 1980 and 1984.

Table 5.—Production of tin metal in selected MEC's, 1980-83, metric tons (*5*)

Country	1980	1981	1982	1983
Malaysia	71,318	70,326	62,836	53,338
Indonesia	30,465	32,519	29,755	28,390
Thailand	34,689	32,636	25,460	18,467
Bolivia	17,648	19,937	18,980	14,164
Brazil	8,796	7,639	9,297	12,560
United Kingdom	5,829	6,863	8,164	6,498
Netherlands	1,148	3,500	2,757	3,650
Australia	4,819	4,286	3,105	2,878
Spain	3,750	3,070	2,750	2,783
United States	3,000	2,087	2,000	2,500
South Africa, Republic of	2,207	2,174	2,197	2,200
Singapore	4,000	4,000	4,000	1,800
Nigeria	2,684	2,489	1,691	1,400
Japan	1,319	1,313	1,296	1,260
Zaire	213	450	352	134
Belgium	2,822	65	0	0
Others	3,405	3,135	3,519	4,231
Total	198,112	196,489	178,159	156,253

BOLIVIA

Bolivia produced 14,164 mt of tin metal in 1983. The tin smelting industry in Bolivia is relatively new. Before 1977, approximately two-thirds of Bolivia's tin was exported as tin-in-concentrate for smelting in the United States and the United Kingdom. Currently, Bolivia has enough smelter capacity to produce about 28,000 mt of tin metal. About 25,000 mt of this capacity is at the Government-owned-and-operated Empresa Nacional de-Fundiciones (ENAF) at Vintos, which accepts about half of COMIBOL's concentrate production. Bolivia also has large fuming plants that recover tin dust from very low-grade concentrates. COMIBOL has expressed considerable discontent with ENAF owing to the low payments it receives for concentrates. The mines claim that more attractive rates are available in the United States and the United Kingdom. Approximately 11,000 mt tin-in-concentrate was exported for processing in 1983. As of late 1984, ENAF was considering adding a processing plant to recover gold, silver, and indium from smelter slags (*11*).

BRAZIL

Brazil produced nearly 12,560 mt of tin metal in 1983, while in 1979 it only produced 9,300 mt. Several smelters were built to treat Brazilian and foreign concentrates, but in 1981, prohibitive taxes and import duties were imposed which have resulted in little or no imports. Prior to 1981, material was received from Bolivia and Singapore. As of 1984, Brazil had at least 10 smelters with a combined capacity of about 38,000 mt/yr (*9*), but was operating significantly under design capacity. Brazil is not a member of the ITC. The fact that the smelters are operating at less than capacity results from slower than anticipated mine development. The two largest smelters are the Mamore smelter owned by Paranapanema at Sao Paulo and the CESBRA smelter at Volta Redonda. They have annual capacities of about 12,000 mt each.

UNITED KINGDOM

The United Kingdom has maintained sixth position among the market economy producers since prior to 1978. In 1983, approximately 6,498 mt of tin was produced. The United Kingdom is a net importer of tin and therefore, has not been required to reduce consumption, as have the other ITC members. In 1983, approximately 65 pct of the country's tin consumption came from domestic sources (*12*).

CENTRALLY PLANNED ECONOMY COUNTRIES

Both China and the U.S.S.R. produce large quantities of tin, although little is exported. Reliable data regarding individual mining operations, concentrate production, and tin manufacturing capabilities are difficult to acquire. Because of this, tin resources of the centrally planned economy (CPE) countries (as listed in footnote 4) are not included in the availability section of this report.

China's tin production has been expanding over the last decade. The 1979 production estimates ranged from 15,000 to 25,000 mt/yr (*13-14*). Production in 1980 was estimated at 14,600 mt (*13*). Most of China's tin production originates from underground mines in the southwest and central regions, and over 80 pct is intended for domestic consumption. China's tin exports peaked in 1978 at 5,486 mt and in 1983 decreased to 3,259 mt (*5*). This downward trend will probably continue as China's industry becomes more vertically integrated and demand exceeds domestic production. Unless the mining industry expands. China could become a net importer. About 60 pct of China's exported tin is purchased by the United States, while Japan and Hong Kong purchase about 16 and 18 pct, respectively (*5*). China has about six existing tin smelters and is planning for additional capacity with construction of a seventh smelter currently underway.

The major tin producing mines in the U.S.S.R. are in Eastern Siberia. Nearly all of the tin is produced from lode deposits using underground mining methods. The Soviet Union is still a net importer of tin despite estimates indicating annual domestic production as high as 35,000 mt (*15*). In 1983, the U.S.S.R. reportedly imported over 16,000 mt of tin metal (*5*). About 69 pct originated from Malaysia, 3 pct from Bolivia, and the remainder from other countries not identified. At least some of the imported tin is purchased from Singapore and probably originates as smuggled tin. During the last 6 yr, U.S.S.R. imports have been relatively stable, ranging from a high of 14,337 mt in 1981 to a low of 12,017 mt in 1982 and averaging about 13,500 mt (*5*).

THE INTERNATIONAL TIN COUNCIL

HISTORY

Attempts to stabilize the production and price of tin can be traced to as early as 1921, when the Bandoeng Pool was formed. This pool was set up by Malaya and the Netherlands East Indies for the purpose of holding accumulated tin stocks off the market in order to maintain the price at an acceptable level. The pool bought almost

20,000 mt of tin in 1921 and did not begin to dispose of it until April 1923. The tin was sold off at the rate of 5 pct per month thereafter until December 1924 (*13*).

Tin prices generally increased during the 1920's, but collapsed with the onset of the Great Depression in 1929. Various tin producers attempted to withhold supply by building inventories, in order to stabilize plummeting tin prices, but the sharp drop in demand made such attempts impossible to maintain. In the early 1930's, Bolivia and Nigeria joined with the two original Bandoeng Pool operators in various control schemes: the First International Tin Agreement of 1931-33, which established the International Tin Committee; followed by two other agreements (1934-36 and 1937-41), which included Siam (Thailand), the Belgian Congo (Zaire) and French Indochina (Southeast Asia).

The general principle of these early agreements was the regulation of production by a system of quotas enforced by Government action. The first agreement did not include any provision for control over stocks. Succeeding tin agreements, however, included the operation of a buffer stock, or tin pool, with the stated objective of preventing rapid price fluctuations. By 1938, a buffer stock with floor and ceiling price levels was adopted to regulate the pool. The ranges of the pool were set to match the London Metal Exchange (LME) quotes. The members of the International Tin Committee contributed to the buffer stock a percentage of their production; the original buffer stock consisted of 10,200 mt of tin.

The first two tin agreements of the 1930's had no provision for representation from consuming countries, and the International Tin Committee was criticized by the consuming nations, particularly the United States, for restraint of trade and operating as a cartel. In reaction to the criticism, the two succeeding tin agreements included invitations to the United States and the United Kingdom to attend and offer their viewpoints at Committee meetings.

The final agreement, the Fourth Control Pack, was terminated in 1946. Although the International Tin Committee began work on framing a fifth agreement intended to come into force in 1947, disagreements between the Committee members prevented its adoption and led to the holding of the International Tin Conference in 1946. The attending nations agreed on little except that the International Tin Committee was defunct and that an International Study Group should be set up to formulate requirements for a new tin agreement.

The International Tin Study Group met in Brussels in April 1947 and continued to operate until 1956, seeking to organize a viable tin organization. Most of the arguments and obstacles to an agreement centered around export controls, the size of the buffer stock, and possible price ranges of the buffer stock. The study group was composed of both producing and consuming nations (*16*), although there was considerable antagonism between the United States, the primary consumer, and the producing countries. Even with demand increasing, owing to U.S. stockpile purchases and the requirements of the Korean War, fears of a new surplus of tin exacerbated the desire of the producing countries to generate a new form of control over the tin market.

The Second U.N. International Tin Conference, held in 1953, led to the First Post-War International Tin Agreement and the formation of the International Tin Council (ITC). There have been six agreements (as of 1984), with each in effect for approximately 5 yr. The current Council consists of six producing and 17 consuming countries, as shown in table 6. All of the producing countries, except Australia (which joined in 1971), have been members since the original 1956 agreement. The member producing countries accounted for over 57 pct of total MEC production in 1983. This percentage would have been over 80 pct had Bolivia and Brazil opted to join the sixth ITC in 1982. The original consuming countries in the ITC were Australia, Belgium, Canada, Denmark, Ecuador, France, India, the Netherlands, Spain, and the United Kingdom. The United States joined the Fifth Agreement in 1976, but did not join the Sixth Agreement in 1982.

Table 6.—Membership and vote distribution of Sixth International Tin Agreement as of July 1983 (*4*)

Member countries	Vote
Producing members:	
Australia	94
Indonesia	247
Malaysia	401
Nigeria	22
Thailand	216
Zaire	20
Total, producing members	1,000
Consuming members:	
Canada	49
European Economic Community (EEC):	
Belgium-Luxembourg	29
Denmark	6
Finland	7
France	104
Germany, Federal Republic of	154
Greece	10
India	31
Ireland	5
Italy	58
Japan	334
Netherlands	61
Norway	10
Poland	42
Sweden	7
Switzerland	13
United Kingdom	80
Total, consuming members	1,000

ORGANIZATIONAL BREAKDOWN

The ITC is divided into two groups, producing and consuming nations; each group has an equal weight of 1,000 votes (table 6). Each of the nations receives five initial votes, plus additional votes in proportion to its tin production or consumption. The input by consuming nations prevents the formation of a cartel, in which only producers set a price. The Council periodically changes the proportion of the votes according to the latest production and consumption statistics.

The consuming nations are permitted to produce tin, which has caused problems by reducing the market for Malaysia, Indonesia, and other producing nations. Canada's development of the East Kemptville property and expansion of the United Kingdom's Cornwall District are expected to result in decreased imports by these nations.

OBJECTIVES

The First International Tin Agreement laid down three goals for all members: (1) to prevent or alleviate widespread unemployment in the tin industry, (2) to stop excessive price fluctuations, and (3) to ensure adequate supplies at reasonable prices. By the fourth agreement (1971-76), the number of basic principles had increased to 10, with a preamble recognizing that such a commodity agreement is in the best interests of both consuming and producing nations. The 10 principles (*16*) were to—

1. Provide for adjustment between world production and consumption and alleviate serious difficulties arising from surpluses or shortages.
2. Prevent excessive price fluctuations.
3. Increase export earnings, thereby providing members with resources for accelerated economic and social growth.
4. Ensure conditions that will help to achieve a dynamic and rising rate of production, which will secure an adequate supply at fair prices and provide a long-term equilibrium between production and consumption.
5. Prevent widespread unemployment.
6. Increase production and distribute supplies fairly in the event of a shortage.
7. Mitigate difficulties producing countries might encounter as a result of a surplus.
8. Review disposals of noncommercial stocks by governments and avoid uncertainties and difficulties that might arise.
9. Review the need for development and exploitation of new deposits and promote the most efficient methods of mining tin ores and smelting concentrates.
10. Continue the work of the previous agreements.

Throughout the history of the postwar tin agreements, the ITC has had the use of two main instruments to pursue its objectives: the control of exports and management of the buffer stock. These instruments have been used with varying degrees of success. Export controls are considered to be the most effective tool to avoid long-term surpluses in the tin industry. The ITC can declare any quarter an export control period, meaning that it can then determine the quantities of tin that may be exported through allocation of country export quotas. The sixth agreement was based on export controls of 36 pct of total production, and this cutback was later increased to 39.6 pct of production. Such an extreme quota on exports was required to mitigate the effects of increased production by non-ITC members, particularly Brazil, a drop in world demand and continued sales from the GSA stockpile. In operating the buffer stock, the buffer stock manager was bound under the following conditions of the sixth agreement (*16,* p. 77):

1. If the market price of tin is equal to or greater than the ceiling price, the maximum agreed-on market price, the manager *must* sell until the market price of tin falls below the ceiling price or the tin at his disposal is exhausted, unless instructed to the contrary by the Council.
2. Within the upper section of the allowable price range, the Manager *may* operate provided he is a net seller of tin.
3. If the market price is in the middle section of the range, the manager may *only* operate with the authority of the Council.
4. If the price is in the lower section of the range, the manager *may* operate, provided he is a net buyer of tin.
5. If the price is equal to or lower than the floor price, the manager *must* buy tin until the price is above the floor price or his funds are *exhausted,* unless instructed to the contrary by the Council.

At the end of June 1984, buffer stock holdings totaled more than 35,000 mt (*4*). Continued production and exports of large quantities of tin from non-ITC countries, primarily Bolivia, Brazil, Peru, and China forced significant additional purchases by the Buffer Stock Manager (*17*).

FORMATION OF THE ASSOCIATION OF TIN PRODUCING COUNTRIES

Although the ITC has been successful in keeping the price of tin at or above the floor price of M$29.15/kg[6] (approximately US$5.65/lb), disagreements among ITC members and nonmembers prompted the formation of a separate organization, the Association of Tin Producing Countries (ATPC). The Association was founded on March 29, 1983, following a meeting of ministers from the tin producing countries of Australia, Bolivia, Indonesia, Malaysia, Nigeria, Thailand, and Zaire. The ATPC's defined aims are to "foster close cooperation among member countries with a view to safeguarding their interests in the tin industry through the maintenance of remunerative and stable prices and intensification of research and development, and marketing to further expand the use of tin" (*18*). The organization was formalized in August 1983 with six founding members: Bolivia, Indonesia, Malaysia, Nigeria, Thailand, and Zaire. Australia joined in November after receiving assurances that the ATPC would not follow policies that would bring the organization into conflict with the operations of the Sixth International Tin Agreement (*4*). The ATPC has made a public commitment to augment and supplement the work of the ITC. It may be a useful organization if expected higher levels of producer financing for the International Tin Research Institute help develop new uses and markets for tin.

In the fall of 1984, members of the ATPC, except for Zaire, met to discuss the stabilization of tin prices. The primary reason for the meeting was to address the problem of some producers not responding to requests for decreased production. The statement was specifically directed towards Brazil (*19*), which is not a member of the ATPC. Although Brazil did not agree to reduce production, the Brazilian mines minister stated that he would not sell tin below stated international tin prices.

SMUGGLING

The ITC estimates that about 16,000 mt of tin-in-concentrate was smuggled out of Southeast Asia in 1983 (*20*). This represents approximately 15 pct of the total production from this region and 10 pct of total accountable MEC production. Smuggling is encouraged by high export taxes, especially in Thailand, as well as voluntary export

[6] M$ denotes Malaysian ringgits.

controls (e.g., a 39.6-pct cutback) by the ITC member nations. Sales quotas have caused marginal producers to sell some of their output on the black market (*20*).

Over the last few years, the Southeast Asian tin producers and other members of the ITC concentrated their efforts to reduce the amount of smuggled tin reaching the market. Smuggled tin has been discovered in fishing boats, trucks, cars, and even in the hollow tubes of bicycle frames (*20*). In 1983, only about 135 mt of tin was seized by Malaysian police, but this is about twice that recovered in 1982 (*21*). The ITC estimates that 12,000 mt of tin will be smuggled in 1984.

One of the major reasons for the availability of smuggled tin on the metals market is the apparent willingness of the smelter operators in Singapore to accept tin concentrates without questioning their origins. The flow of smuggled material received by Singapore is estimated at 5,000 to 6,000 mt/yr of tin-in-concentrate (*22*). This amount could increase without successful preventive measures. From 1972 to 1982, Singapore increased annual exports of tin from 1,000 mt/yr to 11,000 mt/yr (*23*), most of which was believed to have originated from Thailand.

Singapore sells large quantities of tin concentrate despite the fact that it has no domestic tin production. Several attempts have been made by foreign countries to impress upon Singapore the seriousness of the problem. The Netherlands Government requested the Billiton Group, a Netherlands-based company, to stop accepting

Other attempts to control smuggling include providing greater search and seizure power to authorities in tin producing countries, increased penalties for people convicted of smuggling, and requiring much greater documentaton of the source of tin concentrates received for processing in Malaysia (*25*). Although there has been some smuggling of tin in other regions of the world, it is not of the same magnitude as that in southeast Asia.

tin concentrate from Singapore to feed the tin smelter at its Arnhem facility, which has a 2,500-mt/yr capacity (*24*). However, the director of the Billiton plant refused to comply, saying that it is impossible to differentiate between legal and illegal concentrates (*23*). The ITC requested that the LME stop buying Watten and Kimetal ingots which are the marketing brand names for Singapore's tin metal. But the LME declined the request (*21*). Spain and the Soviet Union have also been asked to stop purchasing tin metal and tin concentrates from Singapore (*21-22*). Singapore has been approached directly by the tin producing nations in an attempt to control the production of tin from smuggled sources. However, the Singapore Government has not taken any action since the original appeals for control were made in December 1983.

GEOLOGY AND RESOURCES

This section discusses the geology and resources of tin deposits by country. In some cases, only one deposit was evaluated in a country. Most of the reported tonnage and grade data were gathered by Bureau field offices or contractors. The tonnage and grade data in this report may not conform to the reserve and resource estimate methodologies previously defined by the Bureau or the U.S. Geological Survey (*26*). Table 7 and figure 5 summarize the demonstrated resource information for the 146 MEC tin deposits or regions[7] evaluated in this study. Table 8 lists the MEC deposits and regions by country and name, mining method, ownership, and status. The locations of the evaluated tin deposits and regions are illustrated in figure 6.

Several additional caveats to the above resource estimates must be made to place world tin resources in the proper perspective. These caveats have to do with—

The type of resource data that are reported;

The type of resource occurrence that accounts for production in an individual country; and

The static nature of resource estimates for this type of study.

First, the type of resource data that are reported often vary because of government policies and a reluctance on the part of many mining companies to divulge data on their mining operations. The companies' reluctance is due to a number of factors. Among them is the desire to minimize or avoid taxation in countries that tax the value of unmined mineral resources. Also, most publicly held mining companies are required to report their reserves (as opposed to resources) annually to various institutions. For valid reasons, these annual reported reserves are usually defined as ore that has been developed on at least three sides and assayed as thoroughly as required. These

Table 7.—Tin resources by country

Country	Number of deposits	In situ ore: Amount,[1] 10^6 mt	In situ ore: Av feed grade, pct Sn[2]	Tin,[3] 10^3 mt: Contained	Tin,[3] 10^3 mt: Recoverable
Argentina	1	W	W	W	3
Australia	10	307	0.104	318	185
Bolivia	28	248	.086	211	137
Brazil	18	160	.046	73	67
Burma	2	26	.073	19	9
Canada	1	58	.200	NA	59
Indonesia	7	4,594	.019	865	685
Japan	2	5	.277	14	7
Malaysia	36	15,349	.009	1,315	1,099
Namibia	2	54	.141	76	57
Nigeria	1	147	.015	22	16
Peru	1	W	W	W	34
South Africa, Republic of	3	10	.616	61	29
Thailand	25	2,076	.021	437	270
United Kingdom	6	36	.358	128	87
United States	1	25	.151	38	19
Zaire	1	8	.288	24	19
Zimbabwe	1	13	.209	27	17
Other[4]	([5])	56	.238	135	([5])
Total	146	23,117	.016	3,784	2,799

NA Not available.
W Withheld to avoid disclosing confidential deposit data; included in "Other."
[1] Rounded to nearest million.
[2] Rounded to 3 significant figures.
[3] Rounded to nearest thousand.
[4] Argentina and Peru combined.
[5] Aggregated data for Argentina and Peru.

[7]Some information is aggregated by region because several hundred very small operations may be producing within a distinct region or state. The large number of these small operations precludes any (1) cost-effective method for evaluating each operation, or (2) an efficient method for presenting data. Therefore, large numbers of small tin operations within a distinct region are evaluated and discussed as one region.

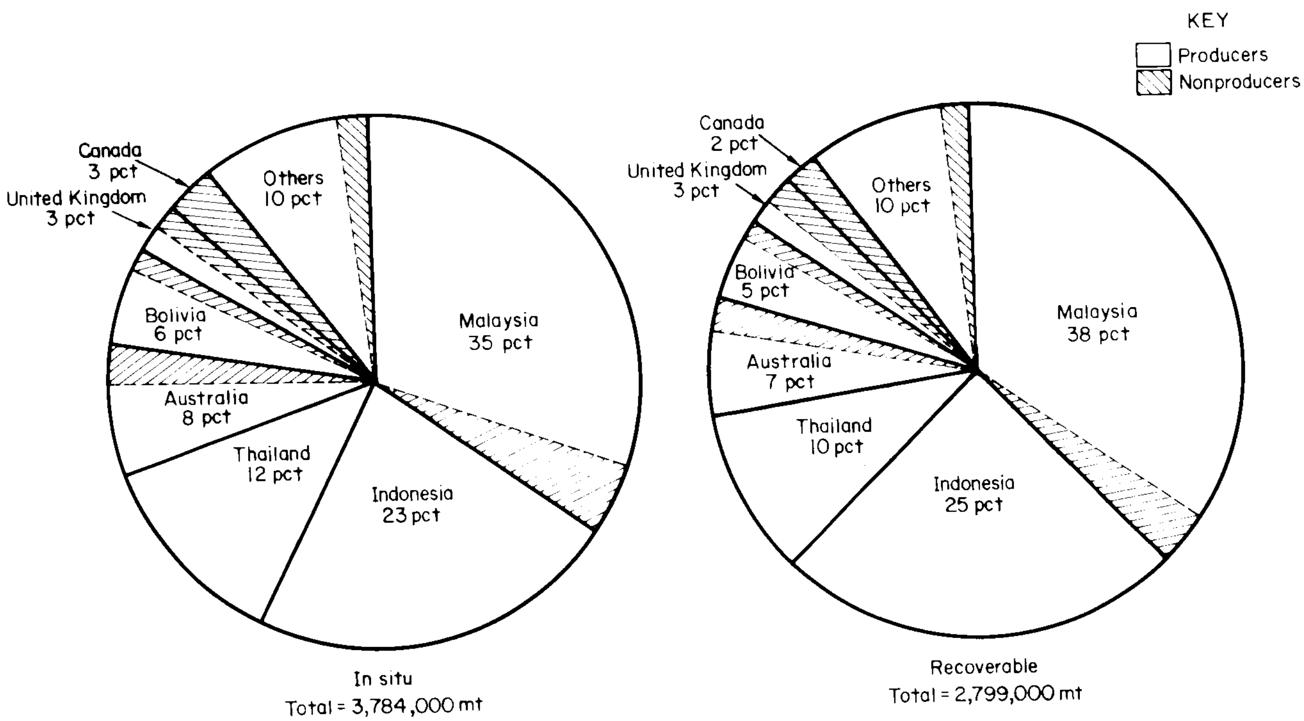


Figure 5.—Distribution of in situ and recoverable tin among evaluated countries.

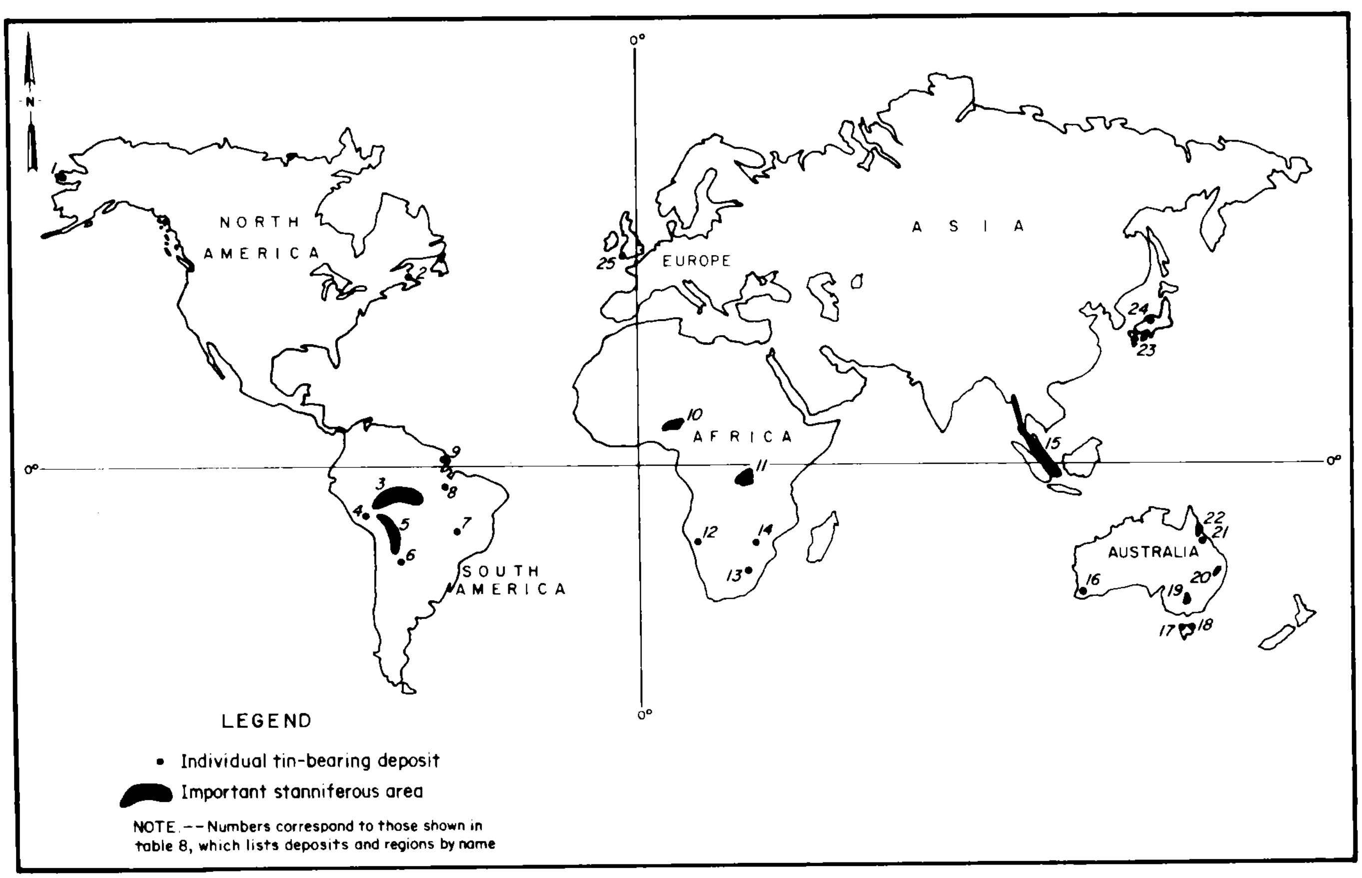


Figure 6.—Locations of evaluated tin deposits and regions.

Table 8.—Market economy country tin deposits, general information

Country and deposit	Owner and/or operator	Mining method	Status[1]	Map location[2]
Argentina: Pirquitas	Sociedad Minera Pirquitas Pichetti y Cia., S.A.	Underground	P	6
Australia:				
Ardlethan	Aberfoyle Ltd.	Open pit	P	19
Baal Gammon	Newmont Holding Pty. Ltd.	.. do	N	22
Cleveland	Aberfoyle Ltd.	Underground	P	17
Greenbushes	Greenbushes Tin NL.	Open pit	P	16
Mt. Bischoff	CRA Exploration Pty. Ltd. (51 pct)	.. do	N	17
Mt. Garnet-Ravenshoe	Oakbridge Ltd.	Dredge	P	22
Pioneer	Triako (45.25 pct), Buka (45.25 pct)	Gravel pump.	P	18
Renison	Renison Goldfields Consolidated Ltd.	Underground	P	17
Ruxton Area	Metals Exploration Ltd.	Open pit	P	21
Taronga	Newmont Holdings Pty., Ltd.	.. do	N	20
Bolivia:				
Atoroma	Empresa Minera Atoroma Ltda.	Underground	P	5
Avicaya	.. do	.. do	P	5
Bolivar	Corporacion Minera de Bolivia (COMIBOL)	.. do	P	5
Carocoles	.. do	.. do	P	5
Cerro Rico	Banco Minero de Bolivia (BAMIN)	.. do	P	5
Chojlla	International Mining Co.	.. do	P	5
Chorolque	COMIBOL	.. do	P	5
Colavi	.. do	.. do	P	5
Colquiri	.. do	.. do	P	5
Comsur	Compañía Minera del Sur S. A. (COMSUR)	Dredge	P	5
El Centenario	COMIBOL	.. do	N	5
Estalsa (gravel pump)	Estalsa Boliviana	Gravel pump	P	5
Estalsa (dredge)	.. do	Dredge	P	5
Huanuni	COMIBOL	Underground	P	5
Japo	.. do	.. do	P	5
Kellguani	Empresa Minera Kellguani	.. do	P	5
La Reyna	Sabino Llave	.. do	P	5
Milluni	COMSUR	.. do	P	
Morococala	COMIBOL	.. do	P	5
Potosi	.. do	.. do	P	5
San Jose de Ayata	Empresa Minera Pabon Ltda.	.. do	P	5
San Juan	Waldo Sarmiento	.. do	P	5
Santa Barbara	Santa Barbara Mining Co.	.. do	P	5
Santa Fe	COMIBOL	.. do	P	5
Suka	Compania Minera Suka Ltda.	.. do	P	5
Totoral	Cia. Minera Orlandini Ltda.	.. do	P	5
Viloco	COMIBOL	.. do	P	5
Yana Mallcu	Empresa Minera Yana Mallcu	.. do	P	5
Brazil:				
Cachoeirinha-Bom Futuro	Moacyrmotta Brumadinho	Dredge	P	3
Candeias-Sao Domingo	Empresas Brumadinho S.A.	.. do	P	3
Ceriumbras	Best Metais e Soldas	.. do	P	3
Cortez	Brascan Recursos Naturais S. A.	.. do	N	3
Duduca	.. do	Gravel pump	N	3
Massangana	Paranapanema S.A. Mineracão, Industria e Construcão, operator; local owner.	.. do	P	3
Mocambo	Mineracão Sao Jose	.. do	N	8
Novo Mundo	Brascan Recursos Naturais S. A.	.. do	P	3
Pitinga	Paranapanema S.A. Mineracão, Industria e Construcão	.. do	P	9
Poco	Brascan Recursos Naturais S.A.	.. do	P	3
Potosi	.. do	.. do	P	3
Potosi Hill	.. do	Open pit	P	3
Rhodia-Espeng	Canopus	Gravel pump	P	8
San Laurenco	Empresas Brumadinho S.A.	.. do	P	8
Sao Francisco	Paranapanema S.A. Mineracão, Industria e Construcão, operator; local owner	.. do	P	3
Sao Raimundo	.. do	Dredge	P	8
Serra Branca	Mineracão Gondwana	Open pit	N	7
Taboquinha	Brascan Recursos Naturais S.A.	Gravel pump	N	3
Burma:				
Mawchi	Burmese Government	Underground	P	15
Tenasserim Valley gravel pump	.. do	Gravel pump	P	15
Canada: East Kemptville	Rio Algom Ltd.	Open pit	N	2
Indonesia:				
Bima dredge	P.T. Riau Tin Mining	Dredge	P	15
Kelapa Kampit	P.T. Broken Hill Pty, Indonesia	Underground	P	15
P.T. Koba Tin	Kajuara Mining Corp. (Pty.) Ltd.	Gravel pump	P	15
P.T. Tambang Timah (Banghah)	P.T. Tambang Timah	Dredge	P	15
Do	.. do	Gravel pump	P	15
P.T. Tambang Timah (Belitung)	.. do	Dredge	P	15
Do	.. do	Gravel pump	P	15
Japan:				
Akenobe	Akenobe Mining Corp. Ltd.	Underground	P	23
Suzuyama Tin	Kyoma Mining Co.	.. do	P	24
Malaysia:				
Austral Amalgamated	Austral Amalgamated Tin Bhd.	Dredge	P	15
Ayer Hitam	Ayer Hitam, Tronoh, MMC	Gravel pump	P	15
Do	.. do	Dredge	P	15
Berjuntai	Malaysian Mining Co.	.. do	P	15
Bidor Malaya	Bidor Malaya Tin Sdn. Bhd.	.. do	P	15
Gopeng Consolidated gravel pumps	Gopeng Consolidated PLC	Gravel pump	P	15
Johor State	Multiple ownership	.. do	P	15
Kedah gravel pump mines	Privately owned	.. do	P	15

[1] P Producer; N Nonproducer or undeveloped.
[2] Numbers correspond to location shown in figure 6.
NOTE.—Other deposits, which were investigated but not evaluated in this study, are listed in appendix A.

Table 8.—Market economy country tin deposits, general information—Continued

Country and deposit	Owner and/or operator	Mining method	Status[1]	Map location[2]
Killinghall	Ramuda Sdn. Bhd. and Straits Trading Co.	.. do	P	15
Kinta Kellas dredge	Kinta Kellas Tin Dredging Bhd.	Dredge	P	15
Kramat dredge	Kramat Tin Dredge Bhd.	.. do	P	15
Kuala Langat	Kumpulan Perangsang Selangor	.. do	N	15
Lower Perak dredge	Lower Perak Tin Dredging Bhd.	.. do	P	15
Malayan dredge	Malaysian Mining Co.	.. do	P	15
Mambang Di-Awan	Gopeng Consolidated, Syarikat Permodalan	.. do	P	15
ML4	Kumpulan Perangsang Selangor	.. do	P	15
Modal Sri Pandan	Pahang Development Corp. (70 pct), Conzinc Riotinto Malaysia (30 pct).	.. do	P	15
Pacific Tin Consol.	Pacific Tin Consolidated Corp. (85 pct)	.. do	P	15
Pahang gravel pump	Multiple ownership	Gravel pump	P	15
Perak State	.. do	.. do	P	15
Perangsang Berjuntai	Permodalan National Bhd. (70 pct), Berjuntai Tin Dredging Bhd. (30 pct).	Dredge	P	15
Petaling	Petaling Tin Bhd.	.. do	P	15
Rahman Hydraulic	Rahman Hydraulic Tin Bhd.	Gravel pump	P	15
Selangor dredge	Selangor Dredging Bhd.	Dredge	P	15
Selangor gravel pumps	Multiple owners	Gravel pump	P	15
Southern Kinta Consolidated	Malaysia Mining Co.	Dredge	P	15
Southern Malayan dredge	.. do	.. do	P	15
Sungei Besi Mines	Sungei Besi Mines Ltd.	Open pit	P	15
Sungei Lembing	Pahang Consolidated PLC.	Underground	P	15
Syarikat Lombong Sebina	Pahang Development Corp. (70 pct), Conzinc Riotinto Malaysia (30 pct).	Dredge	N	15
Timah Dermawan	Malaysian Mining Co. (40 pct), Tronoh (30 pct), Perak State (30 pct).	.. do	P	15
Timah Langsat	Timah Langsat Bhd.	.. do	P	15
Do	.. do	Gravel pump	P	15
Do	.. do	Dredge	P	15
Timah Matang	Malaysia Mining Co.	.. do	P	15
Tronoh Mines Malaysia	.. do	.. do	P	15
Namibia:				
Brandberg West	South West Africa Co., Ltd.	Open pit	N	12
Uis	Industrial Minerals Mining Corp. (Pty.) Ltd.	.. do	P	12
Nigeria: Amalgamated tin mine, Bisichi	Nigerian Mining Corp.	Dredge	P	10
Peru: San Rafael	Minsur, S.A.	Underground	P	4
South Africa, Republic of:				
Rooiberg Mine	Rooilberg Tin Ltd.	.. do	P	13
Union Tin Mines	Union Tin Mines Ltd.	.. do	P	13
Zaaiplaats tin mine	Zimro and Zaaiplaats Tin Mining	.. do	P	13
Thailand:				
Aokam	Aokam Thai Ltd.	Dredge	P	15
Bangrin tin dredge	Fairmont State Ltd.	.. do	P	15
Batun Mine	Phuket Mining Co. Ltd.	Gravel pump	P	15
Bodan dredge	Thai Government (Offshore Mining Organization).	Dredge	P	15
Central Region gravel pump	Multiple local ownership	Gravel pump	P	15
Charintr	Charintr Mining Co.	.. do	P	15
Eurothai Mine	Eurothai Mining Co.	Open pit	P	15
Hok Chong Seng	Hok Chong Seng	Gravel pump	P	15
Hok Chong Seng suction dredge	.. do	Dredge	P	15
Labu Mine	Sawad Wattonayagorn	Open pit	P	15
Narai dredge	Billiton Nederland BV (operator), Thai Government (owner).	Dredge	P	15
Ngan Thawi Brothers Co.	Ngan Thawi Brothers Co.	Gravel pump	P	15
Do	.. do	Dredge	P	15
Nok Hoog Mine	Sombat Co., Lte.	Gravel pump	P	15
Northern Region gravel pumps	Multiple local ownership	.. do	P	15
Phangnga suction boats	Thai Government	Dredge	P	15
Pinyok Mine	Bandit Tantivit	Open pit	P	15
Sethasup Karnrae Co. Ltd.	Sethasap Karnral Co.	Dredge	P	15
Siamese Tin Syndicate Ltd.	Fairmont State Ltd.	.. do	P	15
Sichon Mine	.. do	Underground	P	15
Sierra Mining Co.	Thai Nationals and Pacific Tin	Gravel pump	P	15
Southern Region gravel pumps	Multiple local ownership	.. do	P	15
Tongkah Harbour	Tongkah Harbour Ltd.	Dredge	P	15
Yip In Tsoi—Yala pump	Yip In Tsoi	Gravel pump	P	15
Yip In Tsoi—Haad Yala Ope	.. do	Open pit	P	15
United Kingdom:				
Geevor tin mine	Geevor Tin Mines Ltd. (RTZ Ltd.)	Underground	P	25
Marine Mining	Marine (Cornwall) Mining Ltd. (consortium)	Dredge	N	25
Redmoor	Southwest Minerals Ltd.	Underground	N	25
South Crofty Pendarves district	South Crofty PLC	.. do	P	25
Wheal Concord property	Wheal Concord Ltd.	.. do	P	25
Wheal Jane-Mt. Wellington	Carnon Consolidated Tin Mines Ltd. (RTZ Ltd.).	.. do	P	15
United States: Lost River	Bering Straits Native Corp.	Open pit	N	11
Zaire: Kivu Mine	Sominki	Gravel pump open pit.	P	11
Zimbabwe: Kamativi tin mine	Industrial Development Corp. of Zimbabwe	Underground	P	14

[1] P Producer, N Nonproducer or undeveloped.
[2] Numbers correspond to location shown in figure 6.
NOTE.—Other deposits, which were investigated but not evaluated in this study, are listed in appendix A.

"proven reserves" are defined each year based on production, new development, new assays, changes in prices and costs and, sometimes, changes in technology. Exploration work to delineate resources is a costly and time-consuming endeavor; therefore, it is not done by small operators or poor countries such as Bolivia, or even some large operators that have been in production for a long time. Many mining operations will not estimate below the proven reserve levels.

The larger, more established mining areas generally have the best estimation methodology and reporting. This study, by necessity, deals only with countries and areas where enough basic deposit information is collected and reported that it is possible to estimate demonstrated resources with some reasonable degree of confidence. As a result, over 88 pct of the recoverable resources estimated in this study is contained in producing mines, and all of the undeveloped deposits evaluated are located in established tin producing countries.

Second, the resource tonnage estimates for this study were derived solely from the 146 mines and deposits that were evaluated. Thus, the resource estimates exclude the resources of a number of very small tin producers and producing mines that produce byproduct tin (such as the Climax Mine in Colorado).

Third, the resource estimates for this study reflect demonstrated resource estimates circa 1981-82 minus estimated production from producing mines for the intervening years to January 1984. This implies that no new reserves or demonstrated resources have been added to replace that production, which is doubtful. For all of these reasons, the demonstrated resource estimates presented in this report must be considered conservative.

Several varieties of tin minerals and compounds occur in the Earth's crust (table 9). The most common and economically viable tin mineral is cassiterite (SnO_2). Cassiterite is spatially associated with biotite or biotite-muscovite granites or their extrusive equivalents. Most of the world's producing tin deposits occur in either distinct, rather narrow belts of tin-bearing granites in a larger intrusive complex or in more diffuse belts of younger granites in extensive areas of Precambrian rocks (*27*). The most productive of these regions is a granitic belt that extends from Indonesia through Malaysia and Thailand and into China. Most of this production is from placer-type deposits (*28*). In 1983, Malaysia, Indonesia, and Thailand yielded over 50 pct of the world's primary tin.

Most economic tin deposits occur as residual concentrates or placer deposits in soils, streams, and seabeds. Lateritic weathering of the granites liberated the hard, chemically resistant cassiterite, which concentrated to form these types of tin deposits. The association of tin-bearing granites and tropical weathering conditions around the equatorial regions explains the abundance of placer tin deposits in Southeast Asia and other similar geologic environments and geographic regions.

Sainsbury and Reed (*27*) grouped the major seondary or placer tin deposits into five categories, as follows:

1. Alluvial placers—These constitute the highest grade placers and the largest commercial tin deposits in the world. They are formed near lodes in streams where the current velocity allows for the separation of cassiterite. Alluvial placers occur in both "modern" and "fossil" streambeds, with the tin distribution being dependent on the location of the tin source and the hydraulics of the stream. In Southeast Asia, some stream placers accumulated and were later submerged during Pleistocene eustatic sea level changes. Most alluvial placer deposits are free of deleterious constituents and rarely contain as much as 70 pct Sn.

2. Residual placers—These are in situ deposits formed directly over a bedrock source. They may grade downward into a weathered lode and often contain other economically significant heavy minerals such as columbite-tantalite. Often, residual placers in Indonesia are cemented by iron oxides, creating a "kaksa", which must be crushed to free the cassiterite.

3. Eluvial placers—These are formed by the downslope gravity separation of cassiterite. There may be residual placers upslope and alluvial (stream) placers downslope.

4. Marine placers—Most of these are beach placers or inundated beach placers. They form where a marine shoreline intersects a stream valley containing alluvial cassiterite or a bedrock source of tin. Placers of this type have yielded large amounts of cassiterite at Bangka and Billiton Islands in Indonesia.

5. Fossil placers—Any of the above-mentioned deposits may become fossil placers as a result of burial beneath younger sediments or lava. Uplift and erosion of fossil placers have yielded "second-cycle" alluvial placers such as those in Nigeria. The gravels of some fossil placers have lithified to such an extent that they must be mined as lode deposits.

About one-third of the tin mined in the world is from lode deposits. Lode deposits, as outlined by Sainsbury and Reed (*28*), include the following types:

1. Pegmatite deposits—These deposits are generally associated with granitic rocks and may contain significant byproducts such as columbite-tantalite, beryl, and spodumene. The most productive tin-bearing pegmatites occur in Precambrian-age rocks such as the Manono deposit in Zaire and the Minas Gerais districts in Brazil. The tin content is rarely greater than 0.3 pct in pegmatite deposits (*28*).

2. Pneumatolytic-hydrothermal deposits—Most of the major lode tin deposits of the world (except in Bolivia), including those at Cornwall and in the U.S.S.R., are this type (*27, 28*). They are in or near biotite or biotite-muscovite granites and form replacement, fissure-filling, or greisen deposits in many types of country rock. These deposits vary widely in mineralogy and contain cassiterite, topaz, wolframite, silver, stannite, and base-metal sulfides.

3. Subvolcanic or tin-silver deposits—These are exemplified by the mineralogically complex deposits of Bolivia. Individual mines in such deposits have produced enormous amounts of tin, e.g., Bolivia's past producer, the Llallagua deposit, which produced over 500,000 mt during its life (*28*). Porphyry tin deposits associated with subvolcanic tin lodes contain large amounts of low-grade tin.

4. Disseminated deposits—Small amounts of cassiterite are widely disseminated throughout altered granites in these deposits. Although none of these deposits has been mined commercially, erosion of such granites has resulted in vast, economically important alluvial deposits such as those in Southeast Asia (*27*).

Table 9.—Varieties of tin minerals (*27*)

Mineral	Formula	Location
Arandisite	Complex tin silicate	Namibia.
Argyrodite	Ag_8GeSn_6	Do.
Berndtite	$\beta\text{-}SnS_2$	Do.
Canfieldite	Ag_8SnS_6	Bolivia, Tasmania.
Cassiterite	SnO_2	Worldwide; occurs in most tin deposits.
Cylindrite	$Pb_3Sn_4Sb_2S_{14}$	Do.
Franckeite	$Pb_5Sn_3Sb_2S_{14}$	Bolivia, Malaysia.
Herzenbergite	SnS	Bolivia.
Hochschildite	$PbSnO_3{\cdot}nH_2O$	Do.
Hulsite	$12(Fe,Mg)O2Fe_2O_3SnO_23B_2O_32H_2O$	United States, Canada.
Malayaite	$CaSnSiO_5$	Malaysia, England.
Mawsonite	$Cu_{44}{\cdot}5Fe_{12}5Sn_{10}{\cdot}4S_{33}$	Tasmania.
Native tin	Sn	Australia.
Nigerite	Complex tin silicate	Namibia.
Nordenskioldine	$Ca, Sn(BO3)_2$	Norway, Namibia.
Ottemannite	Sn_2S_3	Bolivia.
Stannite	$Cu_{12}FeSnS_4$	Worldwide; occurs in most tin deposits.
Stokeite	$Ca, Sn(SiO_9)2H_2O$	United Kingdom.
Teallite	$PbSnS_2$	Bolivia, Malaysia.
Thoreaulith	$SnTa_2O_7$	Zaire.

5. Contact-metamorphic deposits—These deposits, which generally grade less than 0.5 pct Sn, contain many important associated minerals: magnetite, garnet, fluorite, tourmaline, and sulfide and beryllium minerals. The Lost River lode deposit in Alaska is an example of this type of occurrence (*27, 29*). Skarn and tactite are other terms for an igneous intrusion that has altered carbonaceous country rock to create a mineralized zone.

6. Fumerole deposits—These are small but widespread fracture-fillings in Tertiary laves. Placers derived from the erosion of such veins have been mined in Argentina, Mexico, and the United States.

Tungsten, tantalum, copper, lead, zinc, silver, gold, indium, ilmenite, fluorine, arsenic, heryllium, antimony, bismuth, iron, and some rare-earth elements may be genetically associated with lode tin deposits. Some of these metals, especially tantalum, are recoverable as byproducts from placer tin deposits. Because of the diverse mineralogy of many lode tin deposits and the accumulation of metals in placer tin deposits, associated byproducts and coproducts can be expected to play a major role in the reserve status of some tin deposits throughout the world.

SOUTHEAST ASIA

The four countries evaluated in Southeast Asia account for over 22 billion mt of demonstrated tin resources, or 95 pct of the MEC's demonstrated resources. They have over 80 pct of the recoverable tin evaluated in this study. They are located in a tin-rich belt of lode and alluvial deposits that extends from Belitung Island in Indonesia north to the Mawchi tin district in Burma and into China (fig. 7).

Malaysia

Malaysia is the world's leading producer of tin. Although most of the country's tin is recovered in placer operations, one lode deposit (Sungei Lembing) is currently producing tin. Malaysia's estimated demonstrated resource of tin ore is over 15 billion mt, or approximately 66 pct of the evaluated MEC demonstrated resources. Almost 65 pct of Malaysian resources are in Perak State (fig. 8). The average in situ grade for producing tin mines is 0.0086 pct Sn; the average in situ grade among the undeveloped deposits and regions is 0.0080 pct Sn.

Most of the primary and secondary tin mineralization of Malaysia is closely associated with the north-south-trending Main Range granite of western Malaysia and a similarly trending granite range on the east coast. Primary and secondary tin and related minerals are derived from these late Carboniferous through Cretaceous age granites. Many of the Main Range granites are Triassic and are associated with numerous vein swarms, pegmatites, and lodes (*30*).

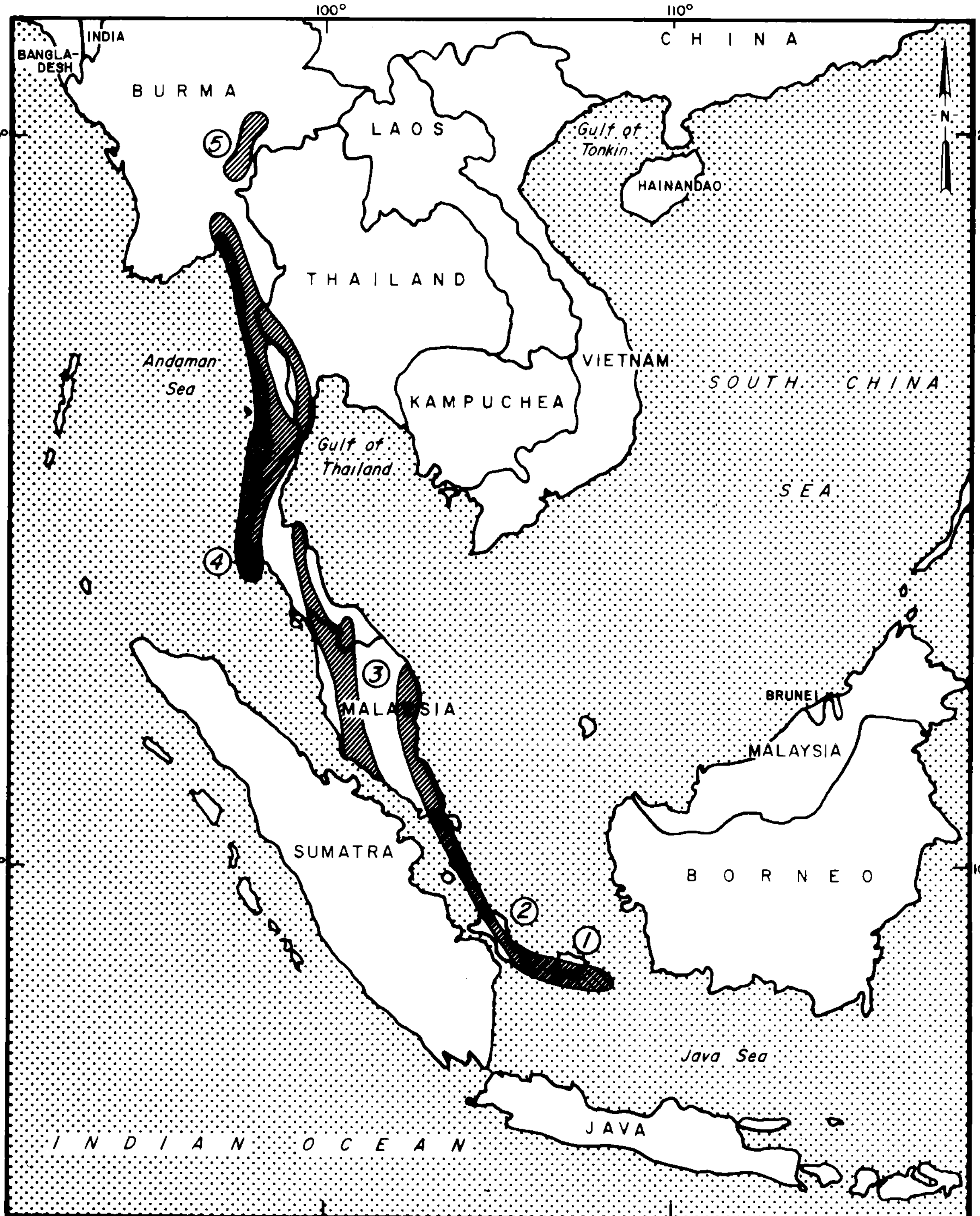
The Kinta Valley of Perak State is believed to be the world's richest tin field. Current demonstrated resources in Perak State are over 30 pct of the demonstrated resources in the evaluated MEC's. Both lode and alluvial deposits are found in this valley, although only the alluvial deposits are mined. The Main Range granite and an associated granite range to the west are sources of tin in the Devonian age carbonates of the valley. The trough and pinnacle topography of the limestone valley and associated solution channels have formed a series of natural riffles for concentrating heavy minerals.

Indonesia

Tin production in Indonesia is primarily from onshore and offshore placer deposits at Bangka, Belitung, and Singkep Islands (fig. 7). These islands have been intruded by gabbroic to granitic rocks. Most primary ore deposits are associated with biotite granite. The placers of Bangka and Belitung Islands are widespread and extend seaward from the present shoreline. The Sanda Shelf had extensive drainage systems developed by erosion. Much of the deposited placer material has been cemented by iron hydroxides forming "kaksa," cassiterite cemented between coarse quartz and sandstone fragments. Including the Kellapa Kampit underground tin mine, Indonesia has over 4.5 billion mt of demonstrated tin resources at an average in situ grade of 0.019 pct Sn.

Thailand

Geologically, Thailand is composed of several north-south-trending granite mountain ranges varying in age from pre-Carboniferous through Cretaceous (*31*). The Triassic granites are a source of cassiterite in northern and southern Thailand (fig. 7).



LEGEND

1 Billiton (Belitung) Island, Indonesia
2 Bangka Island, Indonesia
3 Malaysia
4 Phuket Island, Thailand
5 Mawchi area, Burma

Tin-bearing fields

0 500 1,000
Scale, km

Figure 7.—Tin-bearing areas in Southeast Asia.

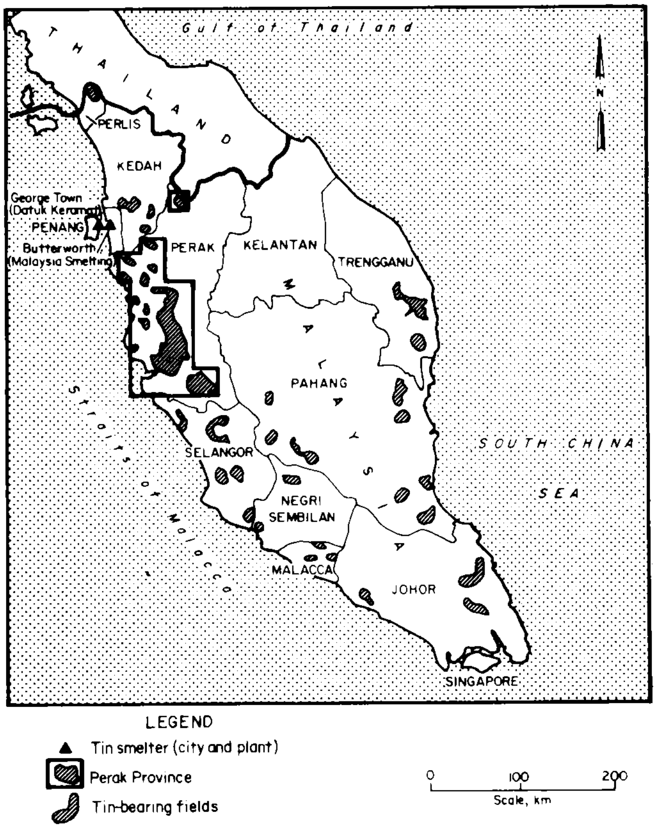


Figure 8.—Tin-bearing areas and major smelter complexes in Malaysia.

Over 97 pct of Thailand's demonstrated recoverable tin is contained in placer deposits. These placers are derived from the weathering of tin lodes and are mainly found along the western side of Thailand adjacent to a bordering granitic range. Thailand has a demonstrated resource of approximately 2 billion mt with an in situ grade of 0.021 pct Sn among producing deposits.

The main offshore deposits are derived from residual tin concentrations rather than transported deposits (*31*). The Bodan dredge operation is located offshore in the structural troughs of a series of folds. The coarse granular nature of the cassiterite recovered from offshore deposits indicates a partial in situ shedding of material from the submerged granite ridges (*27*).

Hydrothermal lodes and greisens are the most common lode deposits. Most tin-bearing quartz veins are shallow, extending to depths of 10 to 30 m. Three of the evaluated lode deposits of the Yala Province occur on the contact of Late Paleozoic sediments and a Cretaceous granite. Deposition is almost entirely in the sedimentary rocks with minor veining occuring into the granite.

Minerals associated with cassiterite in the lode deposits are wolframite, rhodochrosite, fluorite, and sulfides, of copper, lead, mercury, silver, bismuth, and zinc. Tin bearing pegmatites are generally found in all granites. Columbium and tantalum minerals and rare-earth minerals are often associated with the pegmatites.

Burma

The tin deposits of Burma lie along the Thai-Burmese border and form the northern extension of the mineralized belt that runs through Southeast Asia (fig. 7). Of the MEC deposits evaluated, Burma accounts for over 26 million mt of demonstrated resources with an estimated in situ grade of 0.073 pct Sn.

The Mawchi tin-tungsten mine consists of veins that intersect a tourmalized biotite granite. The veins contain cassiterite, wolframite, and scheelite, and, in small amounts, galena, arsenopyrite, molybdenite, bismuthinite, and other sulfide minerals. Although placer deposits probably exist throughout this region, the lack of flat-lying valleys or washes precludes the accumulation of many large alluvial deposits (*27*).

OTHER PACIFIC COUNTRIES

Australia

Most of the major Australian tin deposits are located along the tectonic belt that follows the eastern margin of the continent (figure 6, locations 19-22). The northernmost tin-rich portion of this belt is known as the Herberton mining district. Tin deposits are associated with biotite granites that have intruded into metamorphic and sedimentary rocks (*27*).

The Mt. Garnet-Ravenshoe deposit is the largest tin producer in the Herberton district. Most of the tin produced is from alluvial deposits, although lode deposits were worked prior to 1938. The ore deposits occur in four mappable zones related to the Upper Paleozoic Elizabeth Creek granite. An inner tungsten zone, mainly confined to the Elizabeth Creek granite, passes progressively into tin, copper, and lead zones. Cassiterite is the main ore mineral in the tin zone of the granite. In addition to tin, lodes in this district have produced tungsten, copper, silver, and in minor amounts, bismuth, antimony, molybdenum, zinc, gold, fluorite, calcite, and mica. The Kangaroo Hill province, believed to be metallorgenically associated with the Herberton district, produces tin from Quaternary-age basal gravels at the Ruxton placer deposit.

One of the world's largest underground tin mines, Renison Mine, is located in western Tasmania (figure 6, location 17). Mineralization in this ore body consists of fine-grained cassiterite in massive pyrrhotite and occasional pyrite. "Modern" placers and older "deep leads" have also been produced in northern Tasmania (figure 6, location 17) (*27*).

Tin and tantalum are recovered from the Greenbushes Pegmatite in Western Australia (figure 6, location 16). The main producing ore body is composed of a series of discontinuous and structurally complex pegmatite veins. The ore body and the country rock, which have been regionally metamorphosed to the lower amphibolite facies, contain associated columbium and boron (*32*).

All but one of the producing tin deposits evaluated in Australia are mined from lodes. The producing deposits evaluated in Australia contain demonstrated resources of 260 million mt with an average in situ grade of 0.087 pct Sn. Although the in situ grade of the undeveloped deposits is much greater, at 0.197 pct Sn (for over 46 million mt of demonstrated resources), these deposits have yet to undergo any substantial development.

Japan

Lode deposits in Japan occur primarily as pegmatites and quartz veins associated with biotite granite (figure 6, locations 23-24). The veins, which cut both diorite and gabbro of the Yakumo complex, are in the late Permian age Maizuru Group. The Maizuru Group is composed of slate, igneous extrusives, and phyllites. The principal ore minerals of the evaluated deposits are cassiterite, stannite, and stanniferous tetrahedrite. The Akenobe deposit, one of the most widely studied high-temperature, low-pressure ore deposits in the world, produces copper, zinc, gold, and silver, in addition to tin.

The two evaluated mines, Akenobe and Suzuyama, have recoverable resources sufficient for 40 and 20 yr, of production, respectively, at current rates. Akenobe produces about 350 mt/yr tin-in-concentrate with byproduct copper and zinc. Suzuyama mined 8,000 mt of 1.0-pct Sn in 1983 (*33*).

SOUTH AMERICA

Bolivia

Currently, most Bolivian tin is mined from lode deposits. The lodes lie within the East Andean orogenic zone, a belt that extends from Peru through Bolivia and into Argentina, a distance of 800 km (figure 6, location 5). These subvolcanic-type deposits are associated with thick marine Paleozoic sediments intruded by stocks of biotite granite, granodiorite, and quartz monzonite. The igneous activity ranges in age from Late Triassic through Pliocene. In the northern part of the region, erosion has exposed the underlying granites, while stocks remain unexposed to the south. This relationship has resulted in exposure of different zones of ore deposition yielding a variety of mineral suites (*27, 34*).

Primary mineralization along the orogenic belt occurs as quartz-cassiterite-wolframite veins. Several tin associations, tin-silver, tin-tungsten, and tin-zinc-silver, as well as complex sulfosalts, occur throughout the mineralized zones. Other metals persent in the tin zones are lead, gold, iron, arsenic, copper, and bismuth (*34*).

At the Potosi mines, tin is produced from a dacite stock, that contains a tin-rich en echelon vein system. The veins are strongly zoned and contain complex tin and silver minerals, bismuthinite, and wolframite. At the Uncia mine in the Llallagua district, 6 pct Sn was mined from some of the veins (*27*). Very few placer tin deposits had been exploited through the late 1960's.

Only 25 pct of the approximately 248 million mt of demonstrated resources evaluated in Bolivia comes from producing deposits. The producing underground deposits have an average in situ grade of 1.114 pct Sn, which is more than 13 times higher than the average in situ grade of all demonstrated resources in Bolivia. Of all the producing deposits, 75 pct of the recoverable resources is from dredging and gravel pump operations. Tin from these operations has an average in situ grade of 0.022 pct.

Over 270 million mt of waste and tailings tin resources is estimated to be contained in 22 of the Bolivian deposits evaluated. Grades range from a low of 0.02 to over 2.0 pct Sn.

Brazil

The producing deposits evaluated in Brazil contain an estimated 160 million mt of demonstrated resources at an average in situ grade of 0.040 pct Sn. Almost 25 pct of this resource occurs in nonproducing deposits with an average in situ grade of 0.064 pct Sn.

Brazilian tin is produced from both placer and lode deposits (figure 6, locations 3 and 7-9). The granitic source rocks intrude metamorphic rocks and older igneous ring complexes of the Precambrian Brazilian Shield and Lower Paleozoic rocks. Cassiterite, the primary tin mineral, occurs within altered and greisenized rocks generally within the north-south-trending granites. The potentially mineralized area extends into eastern Bolivia (*28*) (figure 6, location 3).

The Rhondonia district, discovered in the early 1950's, covers almost 200,000 km^2 in the drainage basin of the Rio Madeira. Its tin deposits are composed of lodes in granites and tin placers. Most lodes consist of cassiterite locally associated with wolframite in topaz greisen (*27*). Of lesser importance are tin, columbium-tantalum, beryllium, and boron mineralized zones associated with pegmatitic quartz-rich veins (*27*). Recent exploration has uncovered tin deposits in Goias State in central-eastern Brazil which were not evaluated in this study. Additional resources from Goias State and other regions which were not evaluated, plus increased production, have raised Brazil to the level of one of the world's major tin producers.

Argentina

Argentina's Pirquitas tin mine is developed on several veins in metamorphosed shale and sandstone. It is at the southernmost tip of the Bolivian tin belt (figure 6, location 6). The vein system, which contains individual veins grading up to 3.5 pct Sn, consists of cassiterite, sphalerite, galena, stannite, pyrargyrite, proustite, polybasite, andorite, and marcasite (*27*). The Pirquitas deposit produces about 7,000 mt of ore per month grading 1.3 pct Sn. Byproduct silver and various base metal sulfides are expected to be recovered if this region develops more deposits (*34*).

Peru

The San Rafael tin deposit consists of steeply dipping mineralized veins within a sequence of extrusive rocks (figure 6, location 4). The veins vary in thickness between 0.3 and 1.5 m. The principal vein minerals, cassiterite and chalcopyrite, produce tin and copper. The deposits are progressively enriched in tin and depleted in copper with depth.

AFRICA

Republic of South Africa

The Republic of South Africa's tin deposits are found mainly in or near granites or granophyres of the Precambrian Bushveld Complex. These intrusions extend for approximately 240 by 140 km with an overall east-northeast trend (figure 6, location 13). Mineralization occurs in pipeform deposits, fissure veins, vein replacements, and zones of disseminated cassiterite, in flat, sheetlike deposits. The pipes are vertically and horizontally zoned and generally terminate on a tourmalized granite (*35*). The main Bushveld granite is a crudely stratiform sheet, 2,800 m thick, intruded by stocks of miarolitic granite (*35*).

The tin-bearing lodes of the Union tin mine region form an irregular stockwork along fissures in or near the Union Tin Formation, a shale unit located in a thick sequence of Rooiberg felsites. Mineralization at the Rooiberg mine occurs in a complex series of replacement and fracture lodes in a quartzite near the tip of the Magaliesberg Formation. The source of the tin for both of these deposits was probably the Bushveld granite.

The deposits evaluated in the Republic of South Africa comprise almost 10 million mt of demonstrated resources and have an average in situ grade of 0.616 pct Sn.

Zaire

Tin at the Kivu Mine in Zaire (figure 6, location 11) is produced from both alluvial and lode deposits. Lode deposits at the Kivu Mine are tin-bearing pegmatites, greisens, and quartz veins. Basement rocks in this region consist of Precambrian-age quartzites, schists, and gneisses locally intruded by mafic rocks and a younger biotite granite. After injection of the granite, several systems of veins and dikes formed in the following sequence: (1) aplite-pegmatite, (2) quartz veins containing columbite and tantalite, (3) greisen containing columbite-tantalite, and (4) greisen containing wolframite and cassiterite (*27*). The tin deposits are genetically related to a biotite granite. Wolframite and columbite-tantalite are associated with cassiterite. The mineralized areas throughout the granite massif are zoned. The zoning allows for differential weathering and accumulation of tin and associated minerals as placers (*27*). Approximately 8 million mt of 0.288-pct-Sn in situ resources has been demonstrated at Kivu.

Nigeria

Most tin in Nigeria (figure 6, location 10) is produced from placer deposits from the Jos Plateau. The plateau is intruded by 50 to 60 Jurassic-age ring complexes comprised of rhyolite, tuff, agglomerate, explosion breccia, syenite, and biotite and riebeckite granite and dikes (*35*). Most of Nigeria's tin deposits are associated with the biotite granites. The lode deposits consist principally of mineralized stockworks and quartz-topaz mica greisens. In addition to cassiterite, the tin lodes contain wolframite, columbite, chalcopyrite, bornite, arsenopyrite, sphalerite, and molybdenite (*27, 35*).

The high-grade placers of the Jos Plateau were formed largely as a result of erosion of the basement rocks. Rising water levels in streams buried the placers beneath clay and alluvium. Subsequent extensive lavas further buried the stream gravels. Tin-bearing drainage systems formed later on the newer surfaces, revealing these ancient placers. Although most current production is from modern placers, additional resources exist in the ancient deposits (*27*). Demonstrated in situ resources for the Amalgamated tin mine are 147 million mt at 0.015 pct Sn.

Zimbabwe

Tin is recovered from pegmatites in a northeast-trending schist belt located in the Precambrian orogenic shield of southern Zimbabwe. The pegmatites, which are primarily produced at the Kamativi Mine (figure 6, location 14), contain tin and may contain tantalum, columbium, beryllium, and lithium (*35*). The lithium-poor pegmatites are rich in tin and contain recoverable amounts of columbite-tantalite. Albitized parts of the tin-bearing pegmatites are enriched in columbite-tantalite (*27*). The Precambrian schist system has been intruded by biotite granite, but there is no spatial relationship between the granite and the tin deposits. The estimated demonstated resources at Kamativi are 13 million mt at an in situ grade of 0.209 pct Sn.

Namibia

The two major tin producing mines in Namibia, Brandburg West and Uis (figure 6, location 10), contain about 53 million mt of ore at an average grade of 0.143 pct Sn. The Uis tin mine is situated within a regional graben feature bounded by steeply dipping fault planes. It is located at the northeastern extremity of a 30- by 125-km pegmatite schist belt. There are more than 100 individual pegmatite bodies at the mine, some exceeding 30 m in thickness. Veins of iron and manganese oxides are often found, and in such areas, there is an increase in tantalum and columbium values.

EUROPE: UNITED KINGDOM

The Cornwall lode deposits (figure 6, location 25) are related to several outcropping stocks of biotite granite and occur in granite and surrounding altered sediments. These late Paleozoic granites trend north-northeast intermittantly for about 210 km (*35*). The fissure-filling and replacement mineralization is dominated by cassiterite and includes quartz, tourmaline, topaz, arsenopyrite, wolframite, chalcopyrite, galena, sphalerite, and locally, sulfosalt minerals (*27*).

Some mines produced principally copper ores, while some produced lead-zinc ores, and others produced tin (*27*). The Dalcoath Mine was one of the world's most productive lode tin mines. It produced 80,000 mt of tin and 350,000 mt of copper over its life (*29*).

Of the 36 million mt of demonstrated in situ tin resources in the deposits evaluated in the United Kingdom, only 17 pct occurs in producing deposits. The average in situ grade of these producing mines is 0.739 pct Sn, while the nonproducing deposits grade about 0.279 pct Sn.

NORTH AMERICA

Canada

The East Kemptville tin deposit in Nova Scotia (figure 6, location 2) is an example of large tonnage, low grade, greissen-hosted mineralization. It is situated in granitic rocks of the South Mountain Pluton, immediately underlying the metasediments of the Meguma Group. Tin mineralization occurs in a stockwork of tin-bearing greisen alteration zones. These zones are well developed to a depth of about 100 m. Associated with cassiterite in these deposits are pyrite, pyrrhotite, sphalerite, chalcopyrite, and some wolframite (*37*).

Published resources of 38 million mt grading 0.2 pct Sn at a 0.1-pct cutoff grade, have been defined for East Kemptville. The mine there was scheduled to go into operation at the end of 1985. The mining rate when the ultimate pit is constructed is projected to be 21,000 mt/d of 0.165-pct Sn. The mine plan calls for 17 yr of production, about 12 yr of which is expected to be at capacity (*39-38*).

United States

The Climax molybdenum mine in Colorado is the only tin producing mine in the conterminous United States; however, it was not evaluated since tin is only a minor byproduct. The only domestic tin property evaluated for this study was the Lost River deposit, Seward Peninsula, AK (figure 6, location 1). Tin would be produced as a coproduct along with fluorite, tungsten, and beryllium in a proposed open pit operation. The bulk of the bedrock in the Lost River valley consists of the Ordovician Port Clarence limestone. A rhyolitic porphyry dike known as the Cassiterite Dike and an unexposed tin granite intrude the limestone. The mineralized skarn was produced by felsic igneous intrusions followed by greisenization along with contact metamorphism of the intruded limestone. The main ore minerals derived from the Lost River deposit are cassiterite, fluorite, wolframite, beryl, and chrysoberyl. Other metallic minerals associated with the tin-tungsten ores include stannite, arsenopyrite, pyrite, galena, chalcopyrite, ferroan sphalerite, molybdenite, stibnite, and bismuthinite (*39*). Estimated demonstrated resources for this deposit are 25 million mt at an in situ grade of 0.151 pct Sn.

Demonstrated resources of domestic tin have been defined for five other deposits in the United States, all located in Alaska. Almost 30 million mt of in situ demonstrated resources has been defined for these deposits, with over 20,000 mt of recoverable tin. These deposits were not included in the evaluation for this study.

MINE AND BENEFICIATION TECHNOLOGY

The geologic nature of tin occurrences dictates the mining method utilized. Tin is recovered by essentially four types of mining methods: dredging, gravel pumping (hydraulicking), open pit, and underground. Tin recovered from dulong washers accounted for about 5 pct of the total tin produced in Malaysia in 1982. "Dulong" is a Malayan term for a hardwood pan (resembling a gold pan) used by women to concentrate tin from placer deposits. Tin produced from dulong washers was not evaluated. Figure 9 illustrates the distribution of recoverable tin with respect to the mining methods evaluated.

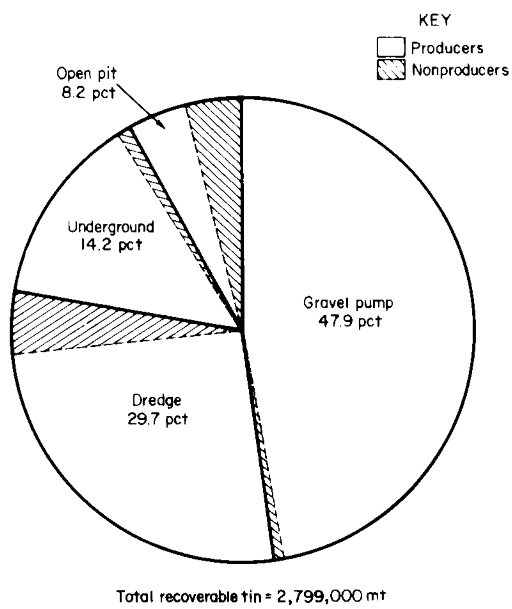


Figure 9.—Distribution of recoverable tin in MEC's by mining method.

GRAVEL PUMPS

Gravel pumps have been an important tin mining method for at least 70 yr, and more than 30 pct of the world's tin is currently recovered using gravel pumps. Nearly half of the evaluated recoverable tin resource is potentially available from gravel pump operations, most of which reside in already-producing operations. Approximately half of Malaysia's and Indonesia's tin production, one-third of Thailand's, and most of Brazil's tin production originates from gravel pump operations (*40*). There are over 400 active gravel pump operations in Malaysia.

Gravel pumps have several advantages over dredging methods: (1) topography is relatively unimportant, (2) selective mining can be practiced, (3) capital cost is low, (4) complete extraction of the material is possible, and (5) ground at various depths can be worked with the same equipment (*41*).

A gravel pump generally consists of three primary sections: monitors (high pressure water nozzles), pumping stations, and a concentrating section. A simplified flow diagram of a gravel pump operation is illustrated in figure 10. Gravel pump monitors are designed to excavate exposed faces of virgin ground, tailings, and previously dredged ground, especially around exposed limestone pinnacles. Exposed faces can range in thickness from 1 to over 60 m. High-pressure water, directed through the nozzles of the monitor, serves to break up the tin-bearing ground. The monitors are generally placed about 35 m from the exposed face. The resulting slurry flows through channels to the pumping station.

The pumping station consists of an excavation or sump which is designed to receive the slurry. The sump serves to separate driftwood, stones, clay, and other undesirable materials from the gravel. The gravel is pumped from the bottom of the sump to a trommel. (A trommel is a revolving, generally cylindrical screen that separates out the oversized material.) The screened material is then directed to the palongs, which are long (up to 50 or 60 m), inclined sluices lined with riffles. Fine-grained material requires a longer palong in order to allow time for the fines to settle out. The riffles capture fragments of cassiterite as well as other accompanying heavy minerals such as zircon, apatite, monazite, and rutile. The flow of slurry is periodically stopped so the material collected in the riffles can be emptied. The collected material (tin concentrate) is then dewatered and fed to a jig plant. (A jig is a mechanical device designed to utilize gravity for the separation of tin—essentially a box

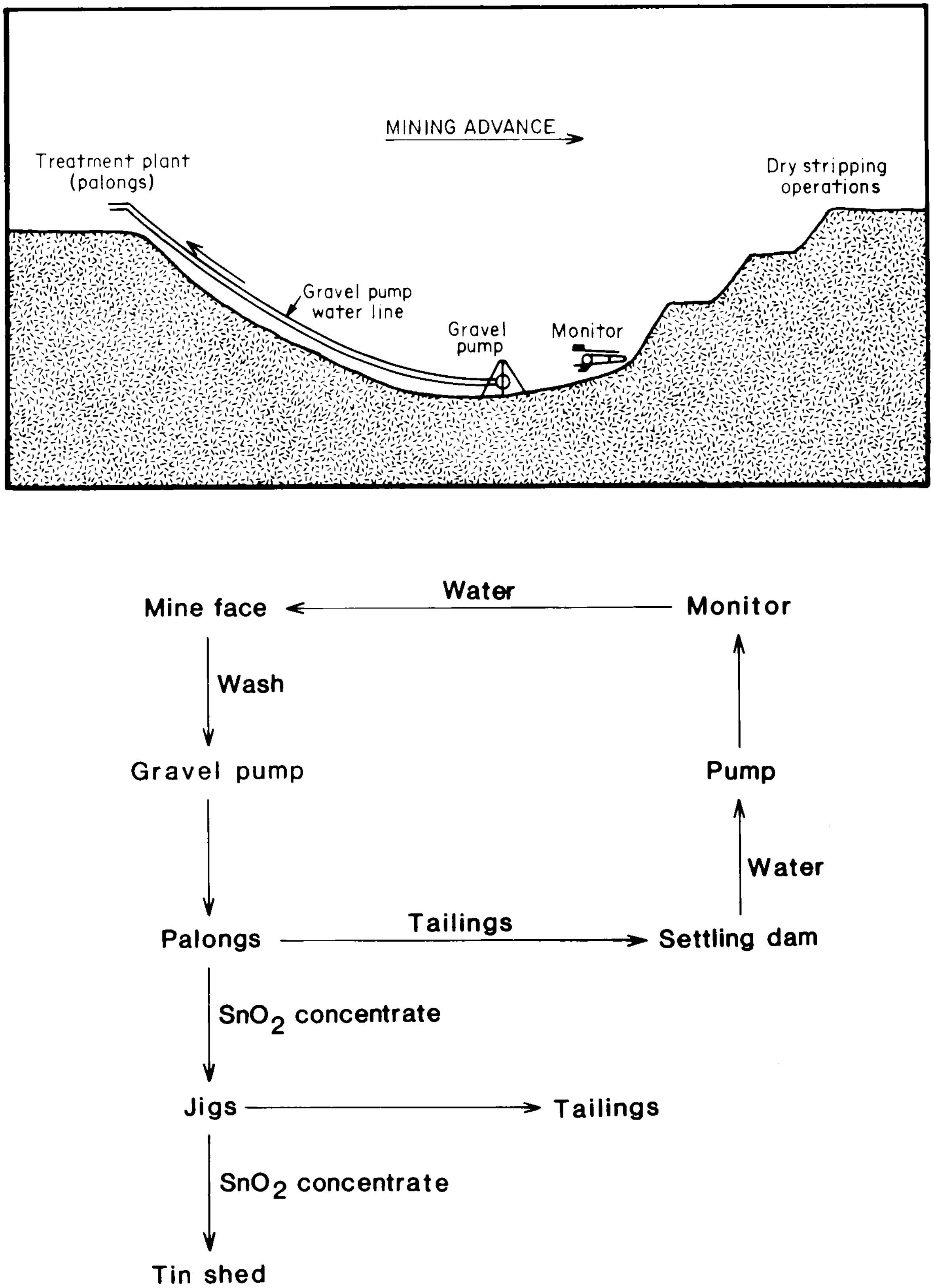


Figure 10.—Typical gravel pump operation.

with a screen bottom by which the action of water currents agitates the tin concentrate, leaving the most dense material at the bottom of the box.) The waste material is returned to the mine site to be used as landfill. The concentrates are then directed to the tin shed. (See "Tin Shed" section.)

Other than grade, the primary factor in the cost per recovered unit of tin is the nature of the ground being mined. Sandy clay requires much less energy to break than clays. Clays though, are less expensive to process than clean sands because the clay content increases the density of the water, which produces a more effective medium for pumping the tin-bearing material.

DREDGING

Thirty pct of the evaluated recoverable tin from the deposits evaluated is potentially available from dredging operations, and nearly 85 pct of this tin is from producing deposits. Onshore dredges have been used to recover tin from alluvial deposits since the turn of the century. In 1984, more than 30 dredges were operating in Malaysia (*42*). A dredge's basic function is to serve as a self-contained, floating excavating machine on which is mounted a screening and jigging plant. There are basically two types of dredges in common use: bucket-line dredges and suction dredges. Both types require slight modifications to mine offshore.

The bucket-line dredge (fig. 11), is the most common type of dredge. It is an efficient mining machine with a low operating cost, owing to its high bucket capacity, speed, and its ability to operate for a relatively long time without maintenance. The dredge consists of a hull, generally constructed of pontoons, upon which is mounted the digging mechanism and on-board concentrator plant.

The digging mechanism on a bucket-line dredge consists of a series of buckets connected to a chain mounted on a ladderlike structure. As the buckets rotate around the ladder in a ferris-wheel-type fashion, material is excavated and dropped into a distribution chute. At times the dredge is used to remove overburden in order to reach the "pay zone." The removal of material ahead of the dredge produces a pond for the dredge to advance on. The dredge's heading is guided by an on-board cable attached to a land anchor. Most dredges are operated by electricity (supplied by cable), but in remote areas, diesel-electric generators or, more rarely, steam-driven generators are used.

Most modern tin dredges have a capacity ranging from 1.5 to nearly 2.5 million mt per month and have an average digging depth of about 21 m, with maximum depths of up to 50 m. Since the 1930's, the average digging depth of dredges has increased from 15 m to nearly 21 m. This has resulted from improved design of dredge equipment and the need for higher capacities to reduce unit costs. Lower unit costs allow dredging of lower grade ore. When dredges encounter difficult mining conditions, such as high boulder content or uneven bedrock surfaces, dredging may be abandoned and replaced with a gravel pump operation.

Offshore dredges started operating off the coast of Thailand in about 1907. The success of the operation encouraged the construction and use of offshore dredges in Indonesia. Offshore dredges differ from onshore dredges in that they are designed to be wave resistant. Despite the modification, offshore dredges have difficulty operating year round. An attractive aspect of offshore dredging is that much of the overburden has been winnowed out by wave and tidal action, leaving behind heavier alluvial sands and gravels. However, bad weather, tidal currents, and wave action cause offshore dredges to mine at substantially lower efficiencies than their onshore counterparts, resulting in higher unit costs.

Suction dredges are much less common than bucket-line dredges. Large suction dredges find their greatest application in relatively shallow waters. A suction hose surrounded by high-pressure water jets or cutter heads delivers material to the surface as the high-pressure water or cutters dislodges the material. Among the disadvantages of suction dredging is the high amount of slimes produced and occasional clogging of the cutters and suction pipe by debris.

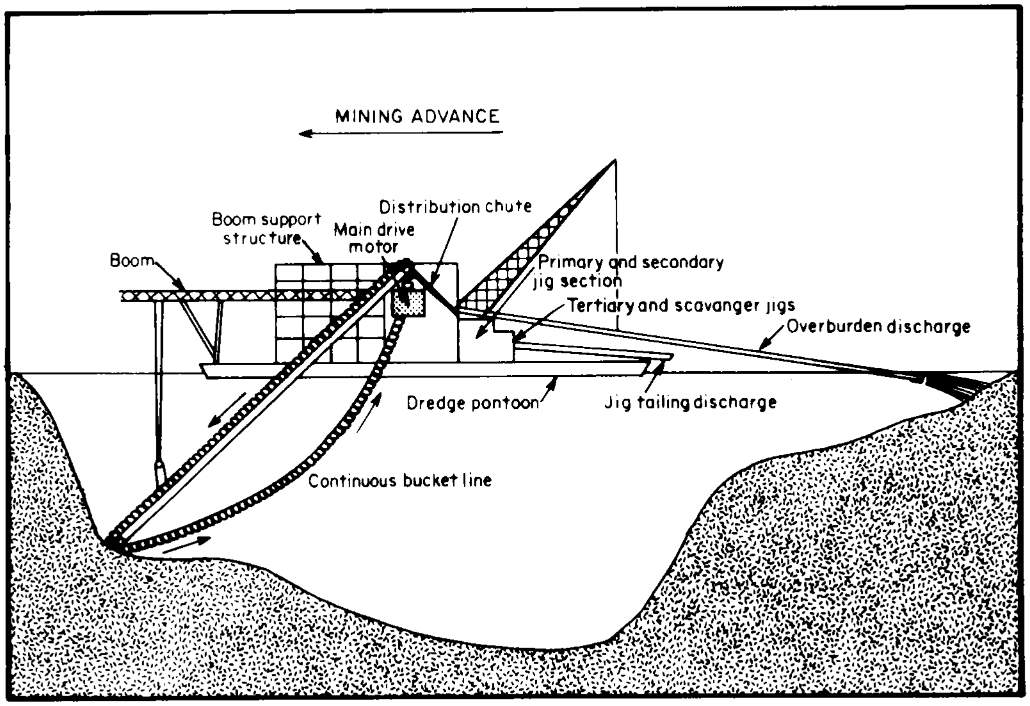
Approximately 1,000 privately owned small suction boats, which employ a total of about 60,000 people, operate in waters offshore from Thailand. The boats operate on a seasonal basis, and each recovers only about 15 kg/d of cassiterite concentrate, but collectively they are responsible for a large portion of total Thai tin prouction. The operations generally employ a diver who directs the suction hose to the pay zone. As in gravel pump operations, recovery of tin from gravels and sands on dredges is accomplished by utilizing gravity methods (fig. 11). When the ore is dumped on board, it is delivered to a series of screens which serve to remove the larger rocks and debris. After screening, the material is sprayed by high-pressure hoses to break up clay balls and other loosely aggregated material. The material is rescreened, and the undersize material is sent to a series of jigs. The final tin concentrate generally assays between 20 to 30 pct and yields about a 95-pct Sn recovery. The concentrate is further processed at a land-based tin shed.

TIN SHED

The tin shed is a centrally located treatment plant designed to further upgrade tin concentrates recovered from alluvial deposits to about 70 to 75 pct Sn (90 to 95 pct cassiterite). The plant consists of a relatively simple series of gravity methods, including the use of jigs and tables (fig. 12). In some cases (especially if the tin shed is owned by a large company), a tin shed can be relatively complicated (fig. 12), using acid leaching to remove carbonates, flotation to remove sulfides (most commonly pyrite and arsenopyrite), and magnetic or electrostatic methods to remove iron minerals, zircon, ilmenite, columbite, and monazite. Some of these minerals have economic value but are not generally sold on a regular basis. After upgrading, the concentrate is usually dried and then shipped to the smelter.

MINING OF LODE DEPOSITS

Most tin lode deposits are mined by underground methods, although there are a few significant open pit operations. Tin potentially available from underground mines accounts for about 14 pct of total recoverable tin among the evaluated deposits. Of the recoverable tin potentially available from underground mines, 92 pct is in producing deposits. Open pit mines generally employ standard open pit mining practices using power shovels



Bucket feed

↓

Trommel	**Overburden chute (used when stripping)**
↓	↓
Primary jigs	**Tailings**
↓	
Secondary jigs	
↓	
Tertiary jigs	
↓	
Scavanger jigs	
↓	
SnO_2 concentrate	
↓	
Tin shed	

Figure 11.—Typical bucket-line dredge and outboard concentrating plant.

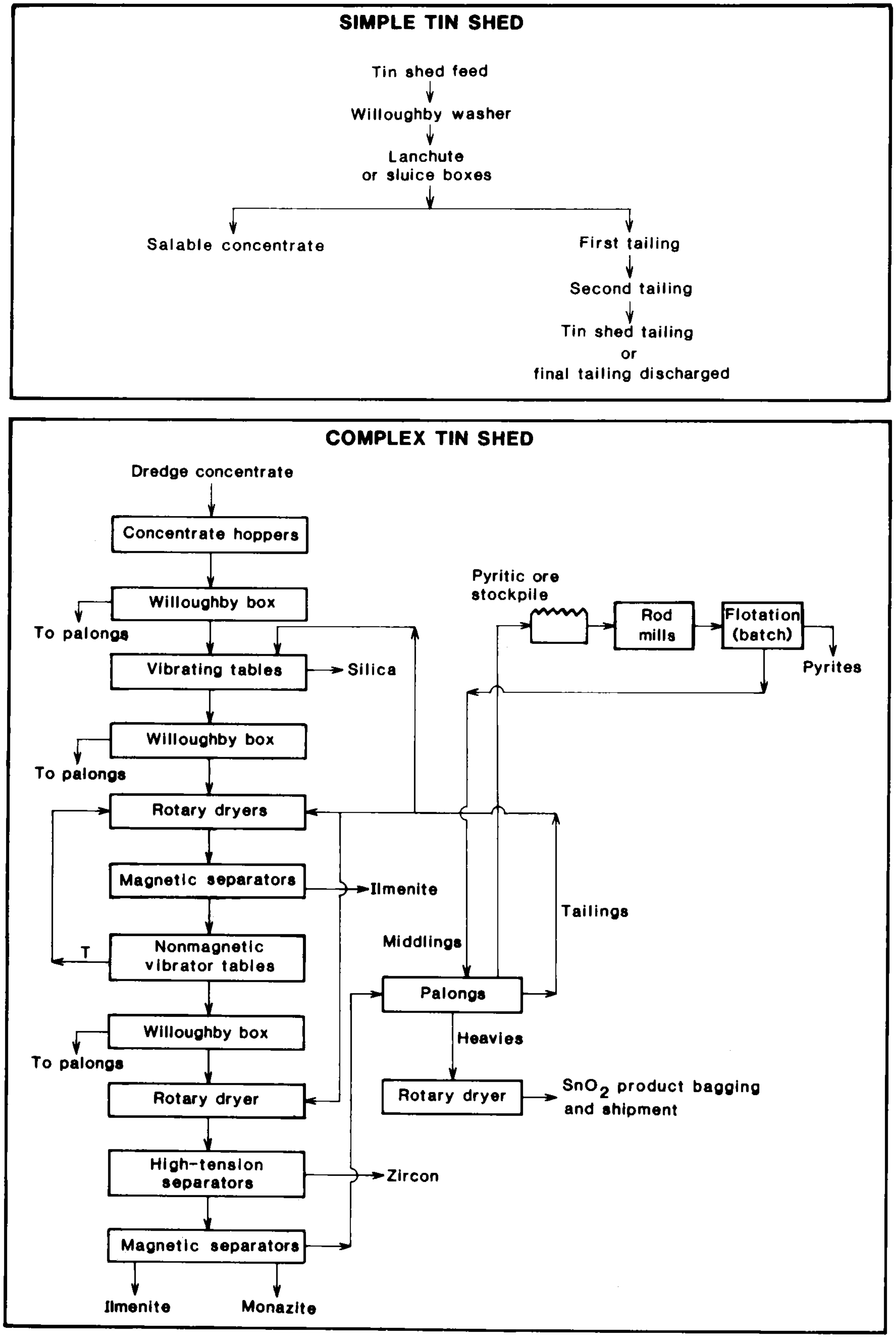


Figure 12.—Flowsheets for typical simple and complex tin shed plants.

and trucks. These operations represent only 8 pct of the total evaluated recoverable tin resources, and producers account for about 40 pct of that total.

Bolivia has more underground tin mines than any other country evaluated in this study. Underground mines represent virtually all of the country's current tin production. The Bolivian mines use high-cost selective stoping methods, and achieve poor productivity rates.

The Cornwall district of England uses combined stoping methods but has somewhat higher productivity rates than Bolivia because of more mechanization and better mine planning.

One of the world's largest underground tin mines, Renison Bell in Australia, uses highly mechanized room-and-pillar mining methods and inclined truck haulage. Ore production is approximately 850,000 mt/yr.

Ores associated with lode deposits are mineralogically more complex than alluvial deposits. Lode deposits are often associated with pyrite, pyrrhotite, arsenopyrite, and various silicate minerals. Additional minerals, such as wolframite, scheelite, chalcopyrite, galena, sphalerite, stibnite, bismuthinite, gold, and sliver, may occur in sufficient quantities to warrant recovery as a coproduct or byproduct. In nearly all cases, gravity methods are used to recover the tin. However, a flotation circuit may also be part of the beneficiation circuit if the ore is complex. As in most beneficiation plants, the ore is first crushed. After crushing, a high-speed concentrate may be isolated by handsorting for direct shipment to a smelter. Handsorting is practiced at some mines in Bolivia and Southeast Asia. More typically, the ore is sent through a complex series of heavy-mineral-separation steps, including jigs, tabling, and hydroclassifiers. Depending on the complexity of the ore, several grades and compositions of concentrates may be produced.

FUMING, SMELTING, AND REFINING

Three major postbeneficiation steps are generally used to produce marketable tin metal: fuming, smelting, or refining. However, the fuming step is not always used. Several criteria regarding the tin concentrate chemistry are used to select the correct type of processing. Tin grade is the most important criterion, but iron and impurity content are also considered.

FUMING OF CONCENTRATES

Over the past few years, direct fuming of low-grade tin concentrates has become an important addition to tin smelting technology. Fuming is performed when the tin grade is between 5 and 25 pct. Fuming does not require a roasting step. The fuming process converts the tin-in-concentrate to a gaseous stage, from which a tin oxide dust is recovered. COMIBOL (of Bolivia) is considering a loan of $400 to $500 million from the Soviet Union for construction of a 400-mt/d fuming plant (*43*). Chemically, the tin in cassiterite reacts with sulfur present in pyrite and other sulfides) to form stannous sulfide (SnS), which, in the presence of air, oxidizes back into a stannous oxide (SnO_2), or "fume." The recovered fume (tin dust) yields a 45- to 60-pct Sn concentrate. The fume is converted to metallic tin in a conventional smelting and refining complex.

Some mining operations, especially in Bolivia, are constructing on-site fuming plants. Fuming is especially important for Bolivia, where tin in low-grade concentrates and tailings may be recoverable by fuming. The tailings can be upgraded to a low-grade concentrate that assays 1 to 3 pct Sn and could be upgraded further by fuming to a relatively high-grade tin product. Refining would then follow.

In the smelter, fuming improves tin recovery and, in conventional smelting, also eliminate the need for a second stage. As shown in the top flowsheet in figure 13, the fuming process uses a furnace in which a sulfur source, such as pyrite, is added to the molten slag. The reaction of the tin (in an oxide phase) with the sulfur results in a stannous sulfide gas. The sulfide vapor is then burned off in the presence of oxygen to produce a fine stannous oxide powder, which is directed to the smelting furnace.

SMELTING

Conventional smelting of medium-grade tin concentrates (30 to 50 pct Sn) usually includes roasting. Roasting is necessary to remove arsenic and sulfur, which are contained in arsenopyrite and pyrite. Medium-grade concentrates usually originate from lode deposits that include large amounts of impurities. Smelting results in two products: a crude tin metal which is poured off and sent to the refiner and large volumes of slag.

Losses of tin in slag have replaced stack losses as the single largest source of tin loss because methods of recovering tin from offgasses during smelting have been improved. The large volumes of tin lost in slag have promoted research to maximize tin recovery from slags using fuming. The addition of a fuming or volatization step has improved the recovery of tin.

Conventional smelting of high-grade tin concentrate is generally carried out in two stages (figure 13, bottom flowsheet). Smelting can be carried out in reverberatory, rotary, or electric smelter furnaces. The choice is generally dictated by economic rather than technical factors. For example, most Malaysian smelters use oil-fired reverberatory or rotary plants rather than electric smelters owing to the ready availability of oil. In some African countries, electricity is used because of the availability of inexpensive hydroelectric power.

The first smelting step consists of heating a concentrate to the point where it becomes molten. At this point, an iron-rich slag and a crude tin metal can be separated. The impure tin, which generally assays over 90 pct Sn, is directed to the refinery. The iron-rich slag is directed to a smelting furnace where higher temperatures and a reducing (oxygen-deficient) environment are produced. These conditions result in separation of the melt into a reject slag and "hardhead," a tin-iron alloy. The hardhead is then returned to the initial smelting furnace, and the process is repeated. Hardhead usually assays about 60 to

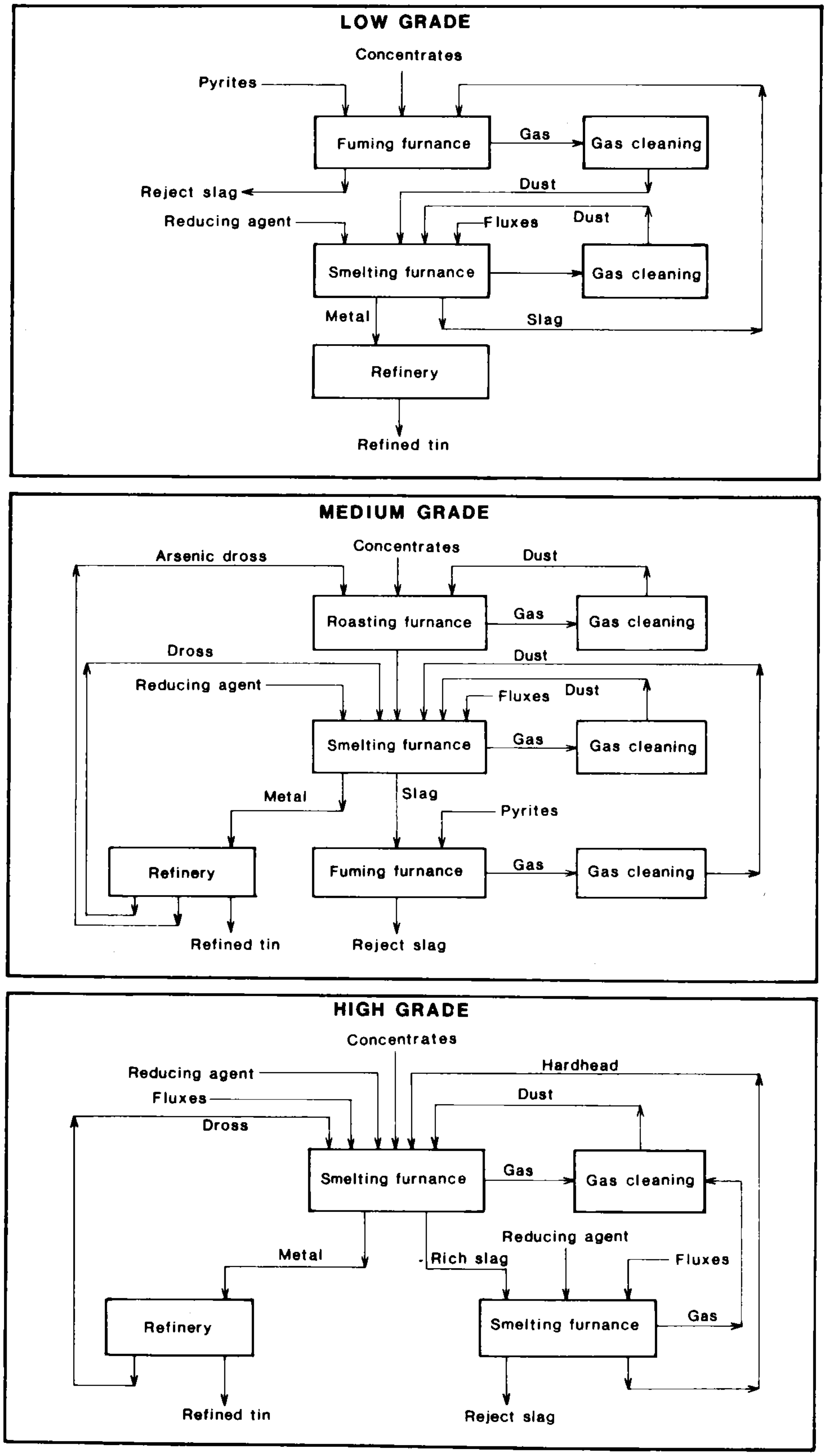


Figure 13.—Typical smelter flowsheets for low-, medium-, and high-grade tin concentrates.

70 pct Sn and 25 to 40 pct Fe. The discarded reject slag assays only 0.5 to 0.8 pct Sn and 8 to 12 pct Fe.

REFINING

Tin produced from the smelting of tin concentrates contains minor amounts of impurities, most importantly, iron, lead, copper, bismuth, arsenic, antimony, cobalt, nickel, zinc, and cadmium. In order to attain a purity of 99.8 pct Sn, virtually all of the impurities must be removed by the refining process. The refining of tin is performed by either pyrometallurgical or by electrolytic processes.

Pyrometallurgy

Pyrometallurgical treatment, the more common of the two primary methods, generally consists of one of two processes: liquation or boiling. In some cases, both methods may be used.

To remove iron, either process can be used. In liquation, the impure tin is heated to just above tin's melting point (232° C). At this temperature, an iron-tin phase remains as a solid when the relatively pure tin is poured off. The remaining iron-tin material (dross), is returned to the smelter complex. This step is repeated until separation of the solids is nearly complete. At some refineries, a centrifuge is used to concentrate the iron into an isolated crystalline phase containing some tin. The iron-rich solids are also returned to the smelter, where heating (to 237° C) causes the tin to melt. Air is blown through the molten material, which has the effect of forming an iron-rich scum on the surface. The recovered scum is then liquated.

Copper is relatively simple to remove from molten tin. The process involves the addition of sulfur to the tin mixture. Since copper has a higher affinity for sulfur than it has for tin, the resulting copper sulfide (which is less dense than molten tin) can be removed as a scum from the surface of the melt.

Arsenic, antimony, nickel, cobalt, plus any residual copper or iron, can be removed through the addition of aluminum. The resulting aluminum complexes can also be removed as a scum.

Lead is generally present in tin in relatively small quantities and can be removed from the tin melt through the addition of chlorine. The resulting reaction forms lead chloride, which is also removed as a scum.

Bismuth is usually eliminated in the roasting steps; however, if bismuth remains in significant amounts, it can be removed by using sodium or calcium in conjunction with magnesium to form scum.

Vacuum distillation is a relatively new development in pyrometallurgical tin refining. The process requires that molten tin be contained in a vessel of dense graphite at high temperatures (1,100 to 1,300° C) and subjected to a vacuum. Using this process, impurities can be selectively distilled by application of specific temperatures and lengths of time. The vacuum distillation process is likely to replace some electrolytic plants.

Electrolytic Refining

Removal of impurities can also be accomplished by electrolytic refining. Electrolytic refining is generally classified into two general types, using either acid or alkaline electrolytes.

Both processes consist of immersing impure tin anodes and pure tin cathodes in a bath of electrolytes. The passage of a direct electric current through the tank or cell causes the anode tin to dissolve and deposit on the cathode. Anode impurities must be removed from time to time to maintain the effectiveness of the electrolyte. A major disadvantage in electrorefining is the large amount of tin that is locked up in the electrolytes (25 to 50 mt) for every metric ton of recovered tin.

BYPRODUCTS OF TIN SMELTING AND REFINING

The smelting and refining processes are capable of isolating several salable byproducts. Some facilities in Bolivia, Malaysia, the United Kingdom, and the United States recover lead, bismuth, antimony, copper, and tungsten. An important byproduct of tin processing is tantalum, either contained in slag or as a pentoxide. Tantalum-rich slags are produced in Australia, Indonesia, Malaysia, Nigeria, Rwanda, Singapore, Thailand, Zaire, and Zimbabwe. The slag is sold to companies that recover the tantalum for use in steel alloys. No credit is paid to the mines for the tantalum content in concentrate, owing to its low assay levels; also, nearly all of the tantalum is recovered from the smelter slag. Therefore, although the tin industry is an important source of tantalum to the industrial world, tantalum does not make any significant contribution to the success or failure of the tin industry.

The largest known established resources of tantalum are located in Thailand and are based mostly on tantalum potentially recoverable from tin slags, which assay up to 15 pct tantalum pentoxide (Ta_2O_5). Tantalum from tin slags in Thailand may account for as much as 30 pct of total world tantalum production (*44*). Based on evaluated tin-tantalum resources in Thailand, approximately 5 million lb of tantalum is potentially recoverable from slags. This does not include tantalum contained in slag dumps. A West German firm has agreed to provide Thailand with the technology to construct a plant for processing tantalum-bearing tin slag. The plant was scheduled for production in 1986 and was expected to cost about U.S.$ 90 million (*45*). The planned capacity is about 1 million lb of tantalum pentoxide, with production to be derived from Thai as well as Malaysian tin slags.

Malaysia has also shown an active interest in the recovery of tantalum from slags. Over 1 million mt of potentially recoverable tantalum exists in the evaluated resource; however, tin slags in Malaysia have significantly lower assays than Thailand. The high-grade slags assay less than 8 pct tantalum pentoxide (*46*).

OPERATING AND CAPITAL COSTS

Operating costs (in January 1984 U.S. dollars) and associated capital costs were estimated for each deposit or mining region evaluated in this study. Cost data were gathered during site visits, through contacts with company officials, and from published materials. Where unavailable, capital and operating costs were estimated by standard costing techniques. Costs were either calculated or determined for mining, milling, smelting, refining, transportation (f.o.b. refinery), taxes, and royalties.

Capital costs for undeveloped deposits reflect the total investment required to develop a deposit and bring it into production. These costs include acquisition, exploration, development, mine and mill plant, equipment costs, and infrastructure. Capital costs for most producing deposits and regions are not presented because they have been in existence for so long that initial investments have been depreciated.

All costs and investments were aggregated by country, mining method, and mining status, in order to determine their relative importance in the MEC tin industry. The operating costs presented are weighted averages calculated over the life of the deposit or region.

OPERATING COSTS

Operating costs include labor, materials, energy, administration, and transportation. All estimated costs are presented in dollars per metric ton of ore ($/mt ore) for mining and beneficiation and dollars per pound of refined tin ($/lb Sn) for mining and beneficiation plus the other companies that contribute to total operating costs. Operating costs are presented in tabular form in the following sections of this report. These costs are aggregated by producing and undeveloped operations and by four specific mining methods: gravel pump, dredge, underground, and open pit[8]. Individual deposit costs vary depending on the size of an operation, mining method, deposit location, grade and characteristics of the ore body, byproducts, and country tax structure.

Costs Aggregated by Producing and Undeveloped Deposits and Regions

Of the 146 operations evaluated, 130 were in production at the time of this study. The estimated costs for these operations were aggregated for producing and undeveloped operations and are shown in table 10. Costs for producing operations are disaggregated by country; undeveloped operations were not disaggregated owing to their small number.

The weighted-average mining and beneficiation cost for producing tin mines was $1.10/mt ore. This cost encompassed almost 1.1 billion mt of average annual ore capacity (based on the 1984 estimated average capacities of the deposits and regions evaluated) at a weighted-average grade of 0.015 pct Sn. Almost 80 pct of the recoverable tin metal among evaluated producing deposits is recovered from gravel pump and dredge operations. These operations produce tin from low-grade deposits such as those in Malaysia's Perak State, where dredged deposits average 0.008 pct Sn. Over 90 pct of the total average annual capacity was from Malaysia, Thailand, and Indonesia. The weighted-average mining and beneficiation costs estimated for producing deposits in these three countries was the lowest in the study, at $1.30/mt ore or less.

The highest weighted-average mining and beneficiation cost estimated for producing mines was $47.50/mt ore for the high-grade (0.722 pct Sn) underground mines of the United Kingdom. Weighted-average mining and beneficiation costs for South African and Bolivian tin mines were also high, at $28.50 and $11.40/mt ore, respectively. Most of the relatively high-grade producing tin deposits in these two countries (with average grades of 0.586 and 0.245 pct Sn, respectively) are mined by underground methods.

The average estimated potential mining and beneficiation cost among the 16 undeveloped deposits and regions was $1.80/mt ore at a weighted-average grade of 0.029 pct Sn. This value was weighted heavily by Malaysia's Kuala Langat deposit, which was scheduled to go on-line in the mid- to late 1980's. When this multiple dredge operation reaches its projected full capacity in the 1990's, it is expected that it will be the largest tin producer in Malaysia.

Mining and beneficiation costs and the remaining costs that contribute to an operation's total production cost are discussed in the following text and presented in table 11. These costs are presented in dollars per pound of refined tin ($/lb Sn) in order to demonstrate the effect of grade on total operating costs. The tin price was $5.69/lb in January 1984.

Table 10.—Estimated average feed grade and mining and beneficiation costs for producing and undeveloped deposits[1]

Status and country	Number of mines or deposits	Av feed grade, pct Sn[2]	Cost, $/mt ore		
			Mining	Beneficiation	Total
Producing mines:					
Australia	7	0.072	4.10	2.90	7.00
Bolivia	27	.245	8.40	3.00	11.40
Brazil	13	.040	1.50	.60	2.10
Indonesia	7	.019	.70	.50	1.20
Malaysia	34	.009	.70	.10	.80
South Africa, Republic of	3	.586	15.80	12.70	28.50
Thailand	25	.021	.80	.50	1.30
United Kingdom	4	.702	32.60	14.90	47.50
Others:					
Namibia, Nigeria, Zaire, and Zimbabwe	4	.058	2.30	1.20	3.50
Argentina, Burma, Japan, and Peru	6	.218	7.30	2.30	9.60
Total or weighted av.	130	.015	.80	.30	1.10
Undeveloped deposits[3]	16	.029	1.00	.80	1.80
Grand total or weighted av	146	.016	.80	.40	1.20

[1] Based on 1982 data. Costs were updated tin Jan. 1984 U.S. dollars.
[2] Rounded to 3 significant figures.
[3] Includes properties in the United States, Australia, Bolivia, Brazil, Canada, Malaysia, Namibia, and the United Kingdom.

[8]To maintain the proprietary nature of certain data, several deposits were aggregated in "Others" entries in the tables and are not specifically identified in the text.

Table 11.—Estimated operating costs and byproduct credits for producing and undeveloped deposits, dollars per pound of refined tin[1]

Status and country	Number of mines or deposits	Cost: Mining	Cost: Beneficiation	Cost: Smelter-refinery[2]	Cost: Taxes[3]	Cost: Total[4]	Byproduct credits	Net cost[5]	Total costs: 0-pct DCFROR	Total costs: 15-pct DCFROR
Producing mines:										
Australia	7	3.50	2.50	0.60	0.10	6.80	1.20	5.60	6.10	7.20
Bolivia	27	2.50	.90	1.20	1.60	6.10	1.10	5.00	5.50	6.20
Brazil	13	1.70	.70	.20	.70	3.40	0	3.40	4.00	4.50
Indonesia	7	1.90	1.30	.20	.20	3.60	0	3.60	4.20	4.80
Malaysia	34	4.30	.80	.10	.10	5.30	0	5.30	5.50	6.00
South Africa, Republic of	3	2.30	1.90	.10	[6]0	4.30	[6]0	4.30	4.60	5.40
Thailand	25	2.50	1.50	.10	1.80	6.00	.10	5.90	6.20	6.80
United Kingdom	4	2.50	1.10	1.00	.20	4.80	1.20	3.70	4.50	5.70
Other:										
Namibia, Nigeria, Zaire, and Zimbabwe	4	2.30	1.20	.30	.10	4.00	.20	3.80	4.40	5.00
Argentina, Burma, Japan, and Peru	6	1.90	.60	2.40	.10	5.10	2.30	2.80	3.30	3.90
Total or weighted av	130	3.00	1.20	.30	.40	4.90	.20	4.70	5.10	5.70
Undeveloped deposits[7]	16	2.30	1.90	.90	.40	5.50	1.20	4.30	6.00	10.50
Grand total or weighted av	146	2.90	1.30	.40	.40	5.00	.30	4.60	5.20	6.20

[1] Based on 1982 data. Costs were updated to 1984 U.S. dollars.
[2] Includes all transportation costs f.o.b. refinery.
[3] Includes Federal, State, property, and severance taxes plus royalties.
[4] Summation of mine, mill, and smelter-refinery costs and taxes. Data may not add to totals shown because of independent rounding.
[5] Total cost minus byproduct credit.
[6] Rounding to the nearest $0.10 makes this value appear as 0.
[7] Includes properties in the United States, Australia, Bolivia, Brazil, Canada, Malaysia, Namibia, and United Kingdom.

The average mining and beneficiation cost among producing deposits was $4.20/lb of refined tin. Although Indonesia and Malaysia had the two lowest mining and beneficiation costs on a per-metric-ton basis, Brazil's cost and the combined costs of Argentina, Burma, Japan, and Peru were the lowest per pound of tin. Brazil's costs are low because it produces tin from relatively high-grade gravel pump and dredge operations. Brazil's feed grade in these operations ranges from two to five times higher than average feed grades for similar gravel pump operations in Southeast Asia. Mining and beneficiation costs in Argentina, Burma, Japan, and Peru are associated primarily with underground mines; the aggregated cost was weighted heavily by Peru's high-grade San Rafael Mine and Japan's Akenobe Mine.

Australia had the highest mining and beneficiation cost per pound of refined tin. The low feed grade and high capacity of the Mt. Garnet-Ravenshoe dredging operation and the relatively low feed grade and associated high costs of the Renison underground mine weigh heavily in the aggregated mining and beneficiation costs for Australia. These two deposits have a combined recoverable tin metal content of over 9,900 mt/yr.

The average cost among producing mines for smelting and refining tin concentrates was $0.30/lb Sn. The highest smelter-refinery cost, $2.40/lb Sn, was the aggregated cost for concentrates from Argentina, Burma, Japan, and Peru. This cost was offset by a $2.30/lb-Sn average byproduct credit. Like the average mining and beneficiation cost, the average smelter-refinery cost and byproduct credit were weighted heavily by Peru and Japan's underground tin mines, which accounted for over 90 pct of the recoverable tin in these four countries. The smelter-refinery cost for Argentina, Burma, Japan, and Peru was higher than the average because of penalties from impurities associated with lode deposits and relatively high transportation costs. Byproduct credits were generated from tin production in Bolivia ($1.10/lb) and the United Kingdom and Australia ($1.20/lb), and these credits helped offset high production costs in these countries.

Smelter-refinery costs for Bolivia and the United Kingdom were also high. Bolivian law requires that most Bolivian concentrates must be treated at Government-run smelter-refinery complexes. These complexes have treatment charges almost five times higher than those charged by the Southeast Asian smelters and refineries. Similar charges exist at Capper Pass, where the United Kingdom's concentrates are treated. Additional costs are incurred for the smelting and refining of byproduct zinc and copper produced from some of the United Kingdom's tin deposits.

Bolivia and Thailand had the highest estimated taxes, at $1.60 and $1.80/lb of refined tin, respectively. Bolivian mines paid royalties to the government on all revenues received from the sale of concentrate to the state-owned smelter after a deduction (determined by the Government) of about $3.80/lb Sn for mining costs. The royalty was 53 pct of the gross revenues after the allowable operating cost deduction. In addition, there was a 1.1-pct tax on the value of the concentrates (f.o.b. mine) for state-funded mining research and development. In Thailand, all tin companies registered on the Thai stock exchange were levied a 40-pct income tax (except for two that paid a 30-pct income tax). They also paid royalties of 30 pct, based on the Penang price of tin metal credited at the smelter. In contrast, Malaysian mines paid no severance taxes or royalties, but paid an effective income tax of 50 pct; however, Malaysia imposed a sliding-scale export tax on tin which increased as the Penang price increased. Indonesia had no severance taxes, but levied a royalty of $210/mt of contained tin in concentrate. The cost in dollars per pound of refined tin varies, depending on mill concentrate grades and smelter-refinery recoveries.

The estimated weighted-average total cost among producing mines (at a 0-pct DCFROR), including all operating costs, taxes, byproduct credits, and recovery of capital, was $5.10/lb Sn. The highest cost mines were in Thailand and Australia, where costs were over $6.00/lb Sn; while Brazil's and the combined weighted-average cost for Argentina, Peru, Japan, and Burma were the lowest, at $4.00/lb Sn or less. Total costs at a 15-pct DCFROR among producing mines were $5.70/lb Sn.

The estimated mining and beneficiation cost for the 16 undeveloped deposits evaluated was about $4.20/lb of refined tin, which was equal to the cost for producing mines. Projected smelter-refinery costs among undeveloped deposits, at $0.90/lb, were three times greater than producers' smelter-refinery costs. This is because costs for producing operations were weighted heavily by alluvial deposit operations, whereas costs for undeveloped operations included many lode deposits, which have more associated impurities and byproducts that are removed at the smelter. Many of the undeveloped deposits could recover byproducts with credits estimated at $1.20/lb Sn, approximately $1.00/lb higher than the average credit for producing mines. This credit brought the weighted-average total cost (at a 0-pct DCFROR) for undeveloped deposits to $6.00/lb Sn, or $0.90/lb higher than for producing deposits. At a 15-pct DCFROR, the total cost for undeveloped operations was $10.50/lb Sn, or $4.80/lb higher than for producing mines. This value ($10.50/lb) represents the tin price that would be required to generate revenues to provide a 15-pct DCFROR on investments for the undeveloped operations. Such a high total cost indicates the very large capital outlays projected to develop these operations and bring them into production. Among the undeveloped operations evaluated, the East Kemptville deposit in Canada and the Kuala Langat operation in Malaysia are the most likely to begin producing within the next few years.

Costs Aggregated by Mining Method

All producing deposits were aggregated by mining method with weighted-average operating costs determined for each method. Costs for gravel pump, dredge, underground, and open pit operations are presented in tabular form and discussed in the following sections.

Mining and beneficiation costs were combined for gravel pump and dredge operations. Since most of these operations are vertically integrated through the beneficiation stage, a breakdown in costs between mining and beneficiation was not performed. Underground and open pit mining and beneficiation costs were isolated within each operation and are discussed separately.

Gravel Pumps

Almost 1.3 million mt of refined tin metal was estimated to be recoverable from the producing tin gravel pump operations evaluated in this study. This amounted to over 50 pct of the recoverable tin available from all producing deposits. At the time of this analysis, 37 producing gravel pump operations were evaluated in 8 countries. Average gravel pump costs are largely influenced by the tin production of Perak State, Malaysia. At the time of this study, these operations accounted for almost 40 pct of the recoverable tin metal among producing gravel pump operations and over 20 pct of the recoverable tin metal from the evaluated producing mines.

The average mining and beneficiation cost was $1.10/mt ore at a weighted-average feed grade of 0.012 pct Sn (table 12). Mining and beneficiation costs ranged from $0.90/mt in the very low-grade Malaysian deposits to $4.70/mt in the high-grade deposits of Australia, Bolivia, Burma, and Zaire (table 12, "Others" entry under "Gravel pump").

Direct costs are generally about 70 pct of total mining and beneficiation costs. Power constitutes the largest percentage of direct costs in gravel pump operations. In Southeast Asia, power comprises about 40 pct of the direct operating costs, with labor constituting about 25 pct. The remaining 35 pct is accounted for by materials and miscellaneous costs. High electricity costs for pumping water and gravel, relative to fuel costs for tractors and bulldozers, has brought about a greater reliance on mechanized stripping methods over the traditional monitor-and-gravel-pump methods of stripping.

The second-largest source of tin in Malaysia is from the Selangor State gravel pump operations with over 140,000 mt of recoverable tin, or almost 15 pct of the recoverable tin estimated for Malaysia. Annual capacity from Selangor State gravel pumps is over 90 million mt ore. In 1978, the total labor force employed in gravel pump mining in Selangor State was 6,032 out of a countrywide total of 26,795 laborers in tin mining. Labor accounted for almost 30 pct of the mining and beneficiation cost or approximately $0.30/mt ore, for the State's gravel pump operations.

The average mining and beneficiation cost per pound of refined tin for gravel pumps was about $5/lb Sn, with Brazil having the lowest cost, $2.50/lb Sn, owing to its higher grade placer deposits. With an average tin feed grade of 0.009 pct Sn, Malaysia has the lowest feed grade of any of the evaluated countries producing tin by gravel-pump methods and the highest mining and beneficiation cost on a per-pound-of-tin basis, at $5.40. In Australia, Bolivia, Burma, and Zaire (table 13, "Others" entry under "Gravel pump"), the average tin feed grade is the highest among all gravel pump operations evaluated, and the mining and benficiation cost is one of the lower costs, at $3.50/lb Sn.

The only byproduct credits associated with gravel pumps evaluated in this study were from the Northern Region gravel pumps of Thailand, where tungsten yielded a credit of $0.20/lb. Although byproduct tantalum is also recovered with tin in Indonesia, Malaysia, and Thailand, smelter contracts do not generally provide credit for byproducts. Assays are rarely performed for anything other than tin and selected impurities.

The total cost at a 0-pct DCFROR for all producing gravel pumps was about $5.70/lb Sn (table 13). The highest cost operations were in Thailand, at $7.20/lb Sn. Thailand's total cost was higher, relative to the other countries' total cost, because of a large tax burden. At $2/lb of refined tin, Thailand's average tax was almost 15 times higher than the average tax imposed on other Southeast Asian countries. Brazil's cost of $4/lb Sn was the lowest of any country evaluated in this study. The largest portion of total costs (at 0-pct DCFROR) was in mining and beneficiation.

Dredges

Dredging accounts for almost 30 pct of the recoverable tin resources in producing MEC deposits. It was the lowest cost tin mining method evaluated in this study and had an

Table 12.—Estimated capacities, feed grade, and mining and beneficiation costs for producing mines, by mining method[1]

Mining method and country	Total ore capacity[2] 10^6 mt	Av feed grade, pct Sn[3]	Cost, $/mt ore: Mining	Cost, $/mt ore: Beneficiation
Underground:				
Bolivia	18.0	0.804	$28.60	$10.40
South Africa, Republic of	9.4	.586	15.80	12.70
United Kingdom	6.7	.702	32.60	14.90
Southeast Asia: Burma, Indonesia, Malaysia, and Thailand	5.6	1.080	38.00	12.60
Others: Argentina, Australia, Japan, Peru, and Zimbabwe	34.0	.622	19.80	12.40
Total or weighted av	73.7	.704	24.00	12.10
Open pit:				
Australia	47.5	.059	11.60	6.30
Thailand	3.8	.541	8.80	3.20
Others: Brazil, Malaysia, and Namibia	61.4	.133	4.40	3.10
Total or weighted av	112.7	.116	7.80	4.50
Dredge:				
Indonesia	2,603.0	.015	1.00	(4)
Malaysia	2,669.0	.007	.50	(4)
Thailand	939.0	.012	.80	(4)
Others: Australia, Bolivia, Brazil, and Nigeria	407.3	.012	1.10	(4)
Total or weighted av	6,619.2	.012	.70	
Gravel pump:				
Brazil	85.5	.041	2.30	(4)
Indonesia	1,298.9	.023	1.70	(4)
Malaysia	10,873.4	.009	.90	(4)
Thailand	886.6	.020	1.70	(4)
Others: Australia, Bolivia, Burma, and Zaire	52.8	.078	4.70	(4)
Total or weighted av	13,197.2	.012	1.10	(4)

[1] Based on 1982 data. Costs were updated to Jan. 1984 U.S. dollars.
[2] Estimated, based on production over the life of each deposit.
[3] Rounded to 3 significant figures.
[4] Mining and beneficiation costs are combined in the mining cost column because most dredge and gravel pump operations were vertically integrated through the beneficiation stage.

annual capacity of over 480,000 mt ore. Operating costs for dredges vary from site to site due to the characteristics of the ore body and the depth and type of overburden. Offshore dredging costs are slightly higher. Although offshore overburden has generally been removed by the action of waves and currents, the ore-rich zone may also be reduced, thereby reducing the throughput of dredged material (*47*).

Due to prolonged monsoon seasons, offshore dredges operate only about 9 months out of the year. The delays inherent in such an operation cause the overall efficiency to drop and operating costs to rise.

Mining and beneficiation costs per metric ton of ore averaged $0.70/mt for dredging operations (table 12). Mining and beneficiation costs per pound of refined tin averaged about $3.10/lb Sn, or about $1.90/lb less than for gravel pump operations (table 13). Australia, Bolivia, Brazil, Nigeria, and Malaysia had the highest mine and beneficiation costs, at $4.50 and $4.10/lb ore, respectively, while Thailand and Indonesia had the lowest costs, at $2.90 and $3.10/lb ore, respectively.

Indonesian deposits contained the largest amount of recoverable tin metal among all the MEC dredge operations evaluated—over 365,000 mt of refined tin metal at an annual capacity of 12,000 mt ore. Indonesia's P.T. Tambang Timah is the largest integrated tin producer in the world, accounting for over 20 pct of the world's estimated recoverable tin metal. The total cost (at a 0-pct DCFROR) for dredges in Indonesia was about $4.10/lb Sn.

In Malaysia, dredges had the largest per unit output of any of the mining methods used. In 1979, the average output per dredge was 369 mt Sn, compared to 44 mt for gravel pumps, 136 mt for open pit mines, and 58 mt for underground mines. Berjuntai Tin Dredging Sdn Berhad, Malaysia, is one of the largest alluvial mining companies in the world (*48*) and also one of the lowest cost tin producers evaluated, containing at the time of the study over 26,000 mt of recoverable tin metal at a mining and beneficiation cost of about $0.40/mt ore. The average breakdown of mining and beneficiation costs for Malaysian dredges was 88 pct for dredging and 12 pct for the tin shed. About 74 pct of the dredging cost pertained to the actual mining and 26 pct to the onboard beneficiation.

The average dredge operation can produce tin metal at a total cost (at a 0-pct DCFROR) of about $4.20/lb. Of the 41 producing dredge operations evaluated in 7 MEC's, Malaysia's dredges had the lowest weighted-average total cost, at $3.50/lb Sn. The weighted-average cost for Australia, Bolivia, Brazil, and Nigeria (table 13, "Others" entry under "Dredges") were the highest at $5.70/lb Sn. Thailand's large tax burden relative to the other Southeast Asian dredge operations resulted in a high total cost of $5.00/lb Sn.

Underground Mines

Underground mining methods and operating costs are dependant on the depth, size, type, and geometry of the ore body. Unlike surface mining operations which produce tin primarily from relatively unconsolidated and easily accessible placer deposits, underground mines require shaft sinking, drifting, and roof support, which are generally labor-intensive procedures. Therefore, underground mining has the highest mining and beneficiation costs per metric ton of ore of all the tin mining methods.

Among the 42 producing MEC underground mines evaluated, the weighted-average mining and beneficiation cost was about $36.10/mt ore; however, the average tin grade from underground mines was much higher than all

Table 13.—Estimated production costs and byproduct credits for producing mines, by mining method, dollars per pound of refined tin[1]

Mining method and country	Number of mines	Total av capacity, 10^3 mt/yr of refined tin	Cost: Mining	Cost: Beneficiation	Cost: Smelter-refinery[2]	Cost: Taxes[3]	Cost: Total[4]	Byproduct credits	Net costs[5]	Total costs: 0-pct DCFROR	Total costs: 15-pct DCFROR
Underground:											
Bolivia	24	14.0	2.60	0.90	1.20	1.60	6.40	1.20	5.20	5.70	6.40
South Africa, Republic of	3	2.0	2.30	1.90	.10	0	4.30	0	4.30	4.60	5.40
United Kingdom	4	6.0	2.50	1.10	1.00	.20	4.80	1.20	3.70	4.50	5.70
Southeast Asia: Burma, Indonesia, Malaysia, and Thailand	4	3.0	1.90	.60	.50	.30	3.30	.10	3.20	5.10	5.90
Others: Argentina, Australia, Japan, Peru, and Zimbabwe	7	13.0	2.00	1.20	1.30	.20	4.60	.90	3.70	4.20	4.90
Total or weighted av	42	38.0	2.20	1.10	1.00	.50	4.90	.80	4.10	4.80	5.50
Open pit:											
Australia	3	2.0	10.60	5.80	.60	.10	17.00	6.90	10.10	11.40	15.10
Thailand	4	.5	2.40	.90	.30	1.40	4.90	.20	4.70	5.20	5.60
Others: Brazil, Malaysia, and Namibia	3	2.0	2.00	1.40	.10	0	3.50	0	3.50	3.80	4.10
Total or weighted av	10	4.5	4.30	2.50	.30	.20	7.20	1.90	5.30	5.90	7.00
Dredge:											
Indonesia	3	12.0	3.10	(6)	.20	.20	3.50	0	3.50	4.10	4.90
Malaysia	22	15.0	3.10	(6)	.10	.10	3.40	0	3.40	3.50	3.90
Thailand	10	12.0	2.90	(6)	.10	1.60	4.60	0	4.60	5.00	5.80
Others: Australia, Bolivia, Brazil, and Nigeria	6	4.0	4.50	(6)	.30	.30	5.20	0	5.20	5.70	5.70
Total or weighted av	41	43.0	3.10	(6)	.20	.40	3.80	0	3.80	4.20	4.90
Gravel pump:											
Brazil	10	6.0	2.50	(6)	.20	.70	3.50	0	3.50	4.00	4.50
Indonesia	3	11.9	3.60	(6)	.20	.10	3.90	0	3.90	4.10	4.60
Malaysia	10	31.0	5.40	(6)	.10	.10	5.60	0	5.60	5.90	6.40
Thailand	10	17.0	5.10	(6)	.10	2.00	7.20	0	7.00	7.20	7.60
Others: Australia, Bolivia, Burma, and Zaire	4	3.0	3.50	(6)	.30	.30	4.00	0	4.00	4.80	5.50
Total or weighted av	37	68.9	5.00	(6)	.10	.40	5.40	.02	5.40	5.70	6.20

[1] Based on 1982 data. Costs were updated to Jan. 1984 dollars.
[2] Includes all transportation costs f.o.b. refinery.
[3] Includes Federal, State, property, and severance taxes plus royalties.
[4] Summation of mine, mill, and smelter-refinery costs and taxes. Data may not add to totals shown because of independent rounding.
[5] Total cost minus byproduct revenues.
[6] Mining and beneficiation costs are combined in the mining costs column because most dredge and gravel pump operations were vertically integrated through the beneficiation stage.

other producing tin deposits, yielding more tin per metric ton of ore mined. This resulted in a very low total cost (at a 0-pct DCFROR) of $4.80/lb Sn (table 13). The average total cost for all underground operations was weighted heavily by Bolivian production. (Bolivia's underground mines accounted for 37 pct of the annual MEC tin metal production.) Bolivia's total cost (0-pct DCFROR) of $5.70/lb Sn appears comparable to other underground operations in U.S. dollar terms, but is unrealistically low because of the tremendous devaluation of Bolivian currency. See the "Total Availability" section for a further discussion of Bolivia's currency.

Underground mining and beneficiation costs per pound of refined Sn ranged from $2.50/lb Sn in the Southeast Asian countries to $4.20/lb in the Republic of South Africa. The four Southeast Asian operations produce tin from much higher grade deposits than those mined by the South African operations.

A large portion of total underground costs is the combined smelter and refinery operating costs. The weighted-average smelter-refinery cost for producing underground MEC deposits was about $1.00/lb Sn compared to $0.10/lb and $0.20/lb Sn, respectively, for concentrates from gravel pump and dredge operations. This difference was due largely to the high cost of smelting concentrates from underground mines in Bolivia, Japan, Peru, and the United Kingdom (table 13). Bolivia has high treatment charges imposed on tin concentrates by its state-controlled smelters and refineries. Japan has high treatment charges in addition to charges imposed because of impurities (some recoverable as byproducts) in the concentrates. The United Kingdom and Peru both have their concentrates treated by the high cost Capper Pass facilities, in England. Concentrates from the United Kingdom have impurities which are removed at the smelter, and Peru's concentrates are transported a great distance. Both of these factors impact the smelter-refinery costs. The average byproduct credit for underground tin operations was $0.80/lb, compared to almost no byproduct revenues generated in gravel pump or dredge operations.

Bolivia was estimated to have the highest total cost for underground deposits, at about $5.70/lb Sn (0-pct DCFROR). The major difference between Bolivia's total costs and those of other producing underground mines was taxes. Bolivian producers were levied $1.60/lb of refined tin. This value was effectively a royalty of 53 pct of gross revenues minus an allowable operating cost deduction determined by the Government.

The lowest total cost (0-pct DCFROR) for producing underground mines was $4.50/lb Sn in the United Kingdom. The United Kingdom's 4 producing underground mines contain almost 40,000 mt Sn, or over 10 pct of the total recoverable tin among the 42 underground deposits evaluated.

A small Bolivian mine had one of the lowest total costs. Its feed grade was over 3.4 pct Sn, and its total cost was less than $2.00/lb Sn (0-pct DCFROR). The Sichon Mine in Thailand had one of the highest costs among underground producers, with a mining and beneficiation cost of $30.00/mt ore and a total cost over $10.00/lb Sn (0-pct DCFROR). This mine had one of the lowest feed grades of any of the evaluated underground mines, at 0.25 pct Sn. Comparison of the Sichon Mine's total cost with the high-grade Bolivian mine's total cost illustrates the direct correlation between grade and total cost for underground deposits.

One of the largest underground tin mines in the world is Australia's Renison Mine. At the time of the study, it contained over 25 pct of the 365,000 mt of recoverable tin estimated for producing underground deposits and had a capacity of about 850,000 mt/yr ore. Its mining and beneficiation cost of $42.00/mt ore and low total cost of less than $4.00/lb Sn (0-pct DCFROR) contrasted with most of Australia's other tin mines, which are primarily lower grade open pit operations and thus have higher total costs.

Although mining and beneficiation costs per metric ton of ore are higher for underground mining than for any other tin mining method, lower mining and beneficiation costs per pound of refined tin in underground mining are the direct result of higher grade deposits. Byproduct revenues realized by several of the underground operations also reduce operating costs.

Open Pit Mines

The 10 producing open pit mines evaluated in this study accounted for less than 5 pct of the recoverable tin in MEC's, with production of over 400,000 mt/yr ore, yielding over 4,500 mt/yr Sn metal. The major portion of their average total cost of $5.90/lb Sn (0-pct DCFROR) was mining. The Australian open pit operations had an average mining cost of $10.60/lb Sn. The cost was weighted heavily by the Greenbushes tin mine, which accounted for over 40 pct of the available tin ore from open pit operations. Greenbushes produces tin and tantalum primarily from an open pit operation and a smaller capacity underground operation. The mining method used there has varied over the last few years in order to enhance the recovery of byproduct tantalum, an important revenue producer. The $6.90/lb Sn byproduct credit for Australian mines is due primarily to byproduct tantalum recovered at Greenbushes.

The largest producing open pit mine evaluated in this study was Namibia's Uis tin mine. The burden of the total cost for this mine was in mining and beneficiation. With one of the longest projected production lives of any of the deposits evaluated in this study, and operating at a relatively low total cost (0-pct DCFROR), Uis is expected to continue to be a major open pit tin producer.

Summary

Total operating costs (at a 0-pct DCFROR) for producing tin mines averaged about $5.10/lb Sn (table 11). They ranged from a low of $3.30/lb Sn, the aggregated total cost for Argentina, Peru, Japan, and Burma, to a high of $6.20/lb Sn in Thailand. Total costs were weighted heavily by countries producing tin from alluvial deposits, such as Malaysia, which accounted for almost 40 pct of the recoverable tin metal and 30 pct of the annual production among evaluated tin producing countries.

The largest portion of total costs was mining and beneficiation of the ore. The most significant factor affecting mining and beneficiation costs on a cost-per-pound-of-tin basis was the feed grade. A comparison of costs between underground and dredging operations (table 13) indicated that, although underground mining and beneficiation costs were more than 50 times higher per metric ton of ore, the total cost per pound of refined tin was only 14 pct greater because of much higher grade deposits. Feed grades for underground mines are often 100 times greater than for surface mines. Berjuntai, a typical dredging operation in Malaysia, had a feed grade 100 times lower than the 0.704-pct-Sn average feed grade for all underground deposits. Extremely high mining and beneficiation costs per metric ton of ore among underground mines and very low mining and beneficiation costs among dredging operations yield comparable mining and beneficiation costs per pound of refined Sn.

CAPITAL COSTS

Capital costs include exploration, land acquisition, development, mine and mill plant and equipment costs, and infrastructure. Reinvestments for maintenance and equipment replacement are required over the mine's life. Since most of the producing tin operations evaluated in this study have been producing for many years, initial investments were depreciated. For this reason, projected investment data for underground operations and one producing deposit were used in this analysis.

The largest single tin producing region in the world is Perak State in Malaysia, where most of the tin produced is from gravel pumps. Based on projected capital investments necessary to develop tin deposits, Malaysian gravel pumps require the least amount of capital. The costs presented in table 14 are for a hypothetical gravel pump operation in Malaysia. The proposed operation utilizes mechanical means for overburden stripping to a depth of 16 m in a 9.3-m-thick ore zone with a grade of 0.011 pct tin oxide. Assuming an average ore production of 540,000 mt/yr (or approximately 48 mt/yr of refined tin), and an average gravel pump operation life of 24 yr, total production from this deposit was projected to be over 1,000 mt tin metal. The capital investment necessary to bring this tin deposit on-line as a gravel pumping operation was determined to be $1.435 million. This amount does not include investments necessary to acquire the mineral rights, undertake exploration, or pay for infrastructure.

Table 14.—Capital investments for a hypothetical 540,000-mt/yr-tin-ore gravel pump operation

	Cost, 1982 U.S. dollars
Gravel pump mining:	
Gravel pump	88,000
Water pumps	79,000
Tailing pump	65,000
Auxiliary pump	67,000
Jig plant	13,000
Palong and trommel	33,000
Gravel pipings	61,000
Monitors, water pipings, water valves	23,000
Miscellaneous mining equipment	9,000
750 kV•A electrical installation and fittings	25,000
Living quarters (kongsi) and tin shed	13,000
Gravel pump shed, tailing pump shed, water pumps shed, other installations	9,000
0.75-m^3 backhoe and bulldozer	98,000
Miscellaneous contract work wages	4,000
Total	587,000
Overburden stripping:	
2 backhoe units, 1.3 m^3	196,000
12 haulage trucks	241,000
Bulldozer	31,000
Total	468,000
Preproduction development:	
Overburden dry stripping to a depth of 13.7 m (344,050 m^3)	100,000
Gravel pump mining from stripping depth to ore horizon (229,370 m^3)	280,000
Total	380,000
Grand total	1,435,000

Table 15.—Capital investments for underground tin mines

	Cost, 1982 U.S. dollars
Hypothetical (Thai) mine with 21,000-mt/yr-tin-ore capacity:	
Exploration	130,000
Development	180,000
Mine equipment	375,000
Millsurface	400,000
Mill plant	600,000
Infrastructure	450,000
Miscellaneous	65,000
Total	2,200,000
Wheal Concord Mine, 250,000-mt/yr-tin-ore capacity:	
Exploration	2,000,000
Mine capital	3,000,000
Surface capital	4,000,000
Mill plant and equipment	9,000,000
Infrastructure	1,500,000
Miscellaneous	500,000
Total	20,000,000

Of the 16 undeveloped operations evaluated, only 3 were potential gravel pump operations. Their estimated total recoverable tin metal ranged from 660 to almost 80,000 mt, with capital costs from $1.9 to $13.4 million. The capital investment required for the hypothetical operation was lower than the evaluated undeveloped gravel pump operations because investments for acquisition, development, and infrastructure were not included in the hypothetical operation.

For dredge operations, one of the larger capital investments is the dredge itself. An offshore dredge designed for Tongkah Harbor in Thailand, with a proposed output of 1,186 mt/yr of tin concentrates, cost $23 million (in 1982 U.S. dollars) (*49*). Assuming a grade of 0.024 pct Sn and a mill concentrate grade of 75 pct (based on averages for producing Thai operations), this operation would produce about 3.7 million mt/yr ore (approximately 2.3 million m^3/yr). The No. 9 dredge built for Petaling Tin in Malaysia is expected to dredge to a depth of 40 m when it goes on-line. This dredge has a life expectancy of 8 to 10 yr and should process almost 2 million m^3/yr ore. Its cost was about $16 million (in 1982 U.S. dollars) (*49*).

Average capital costs for Indonesian dredge operations were allocated among four major categories: 22 pct was for exploration and development, 25 pct for equipment, 43 pct for infrastructure, and the remaining 10 pct was for other costs.

Capital costs were also estimated for a small hypothetical underground mine in Thailand and for the Wheal Concord underground deposit in the United Kingdom. The hypothetical Thai mine was a 21,000-mt/yr-ore (150-mt/yr-Sn-metal) operation, with capital cost estimates based on other underground Thai properties with similar capacities. Its costs are presented in table 15.

The Wheal Concord deposit is a 250,000 mt/yr-ore operation with a tin metal production capacity over ten times larger than that of the Thai property. Its estimated costs are also presented in table 15.

Depending on the size, type, mineralogy, and depth of an ore body, capital costs for the development of underground deposits may vary greatly.

TIN AVAILABILITY

An economic evaluation was performed on each of the 146 mines and deposits included in the study to determine the average total cost of tin production over the producing life of each mine or deposit. Some of the mines evaluated are actually mining regions, such as Johor and Perak States in Malaysia, which contain large numbers of small family-owned gravel pump or dredging operations that are too small to be evaluated individually but as an aggregate are significant producers.

The evaluation used DCFROR techniques to determine the constant-dollar long-run average total cost of tin production. (DCFROR's are discussed in the "Methodology" section.) This average total cost is equivalent to the tin price each operation would require over the long run for the discounted sum of total revenues from the sale of tin and associated byproducts (if any) to be sufficient to equal the discounted sum of all costs of production over the life of the operation. Annual cash flows were discounted at prespecified rates of return at both 0- and 15-pct DCFROR's.

One producing mine was determined to have a zero long-term total cost associated with tin production at both a 0- and 15-pct DCFROR. This means there would be no costs remaining to be covered by tin production after allowance for byproduct credits.

For government-owned operations, the profit motive may be subservient to other government objectives, such as employment, the need for foreign exchange, or other national development programs. Since most of the large tin mining companies are either government-owned or government-controlled, this study emphasized the total cost of production at a 0-pct DCFROR, since a 15-pct DCFROR, in many cases, is not particularly relevant to the development of new tin deposits.

An implicit assumption in each evaluation is that each deposit represents a separate corporate entity. The life of each property was determined by assuming the property would operate at 100 pct of mine capacity. The mine life covers only the demonstrated resource level, which, for tin, tends to be a very conservative estimate owing to the added expense of blocking out new reserves in countries such as Bolivia, or government philosophies of exploration which, in the past, did not actively seek out new sources of tin as long as existing resources were considered adequate, as in countries such as Malaysia. Recent reductions of sales by 40 pct of capacity in ITC countries and the existence of significant quantities of tin not yet defined as demonstrated resources can be expected to extend mine lives beyond those given in this report.

All capital investments incurred 15 or more years before the cost date of the analysis (January 1984) were treated as sunk costs. For investments incurred during the prior 15 yr, undepreciated balances were entered as 1984 capital investments. All subsequent investments, reinvestments, operating costs and transportation costs are expressed in constant (unescalated) January 1984 dollars. The resource and cost data evaluated were based on January 1982 data updated to January 1984 values. Additions to demonstrated resources, if any, between January 1982 and January 1984 were not accounted for.

Investment and operating schedules were determined as much as possible from published data or plans announced by the companies involved. For explored deposits for which no plans to initiate production had been announced, a development plan was assumed. The assumed preproduction period for these explored deposits allowed for only the minimum engineering and development time necessary to initiate production. Additional time lags and potential costs that might result from filing environmental impact statements, receiving required permits, arranging financing, etc., were not accounted for in the analyses, although such delays and costs may be quite significant.

The potential tonnage and average total cost determined over the estimated producing life of each mine and deposit evaluated were aggregated into availability curves which illustrate the potential availability of tin at different cost levels. Availability curves are constructed as aggregations of the total amount of tin potentially available from each mine and deposit, ordered from those having the lowest average total cost to those having the highest. An availability curve provides a concise, easy-to-read, graphic analysis of the comparative costs associated with any given level of potential output and provides an estimate of what the average long-run tin price (in January 1984 dollars, in this study), would likely have to be in order for a given tonnage to be potentially available to the marketplace. Two types of curves were generated: (1) total availability curves and (2) annual curves at selected total production costs. Annual curves are simply a disaggregation of the total curve to show annual tin availability at various costs of production.

TOTAL AVAILABILITY

The 146 tin mines and deposits (130 producing mines and 16 deposits that were either explored or under development) evaluated in 18 MEC's represented a demonstrated in situ tonnage of 23.1 billion mt ore containing 2.8 million mt of potentially recoverable tin metal. Producing mines accounted for 2.5 million mt of recoverable tin (88.5 pct of the total), and undeveloped deposits account for 321,000 mt (11.5 pct of the total).

The relative shares of recoverable tin, by country, from producing mines and undeveloped deposits are illustrated in figure 14. The two charts in figure 14 illustrate the dominance of the Southeast Asian countries in the world tin industry. About 73 pct of the recoverable tin resource evaluated in MEC's was in Malaysia, Indonesia, and Thailand (fig. 5). The share of recoverable

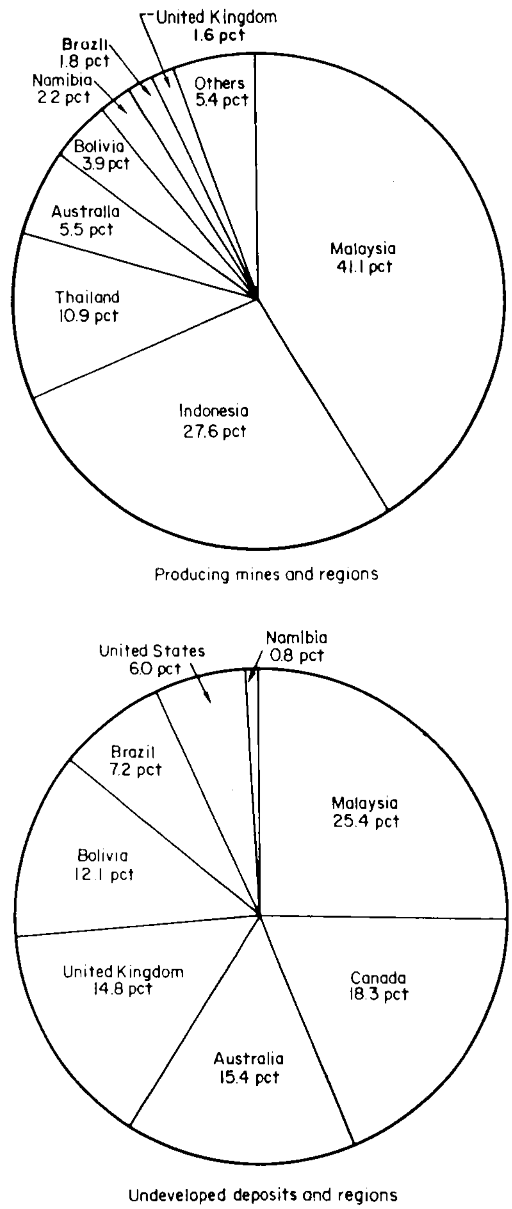


Figure 14.—Distribution of potentially recoverable tin from producing and undeveloped mines and regions in MEC's, by country.

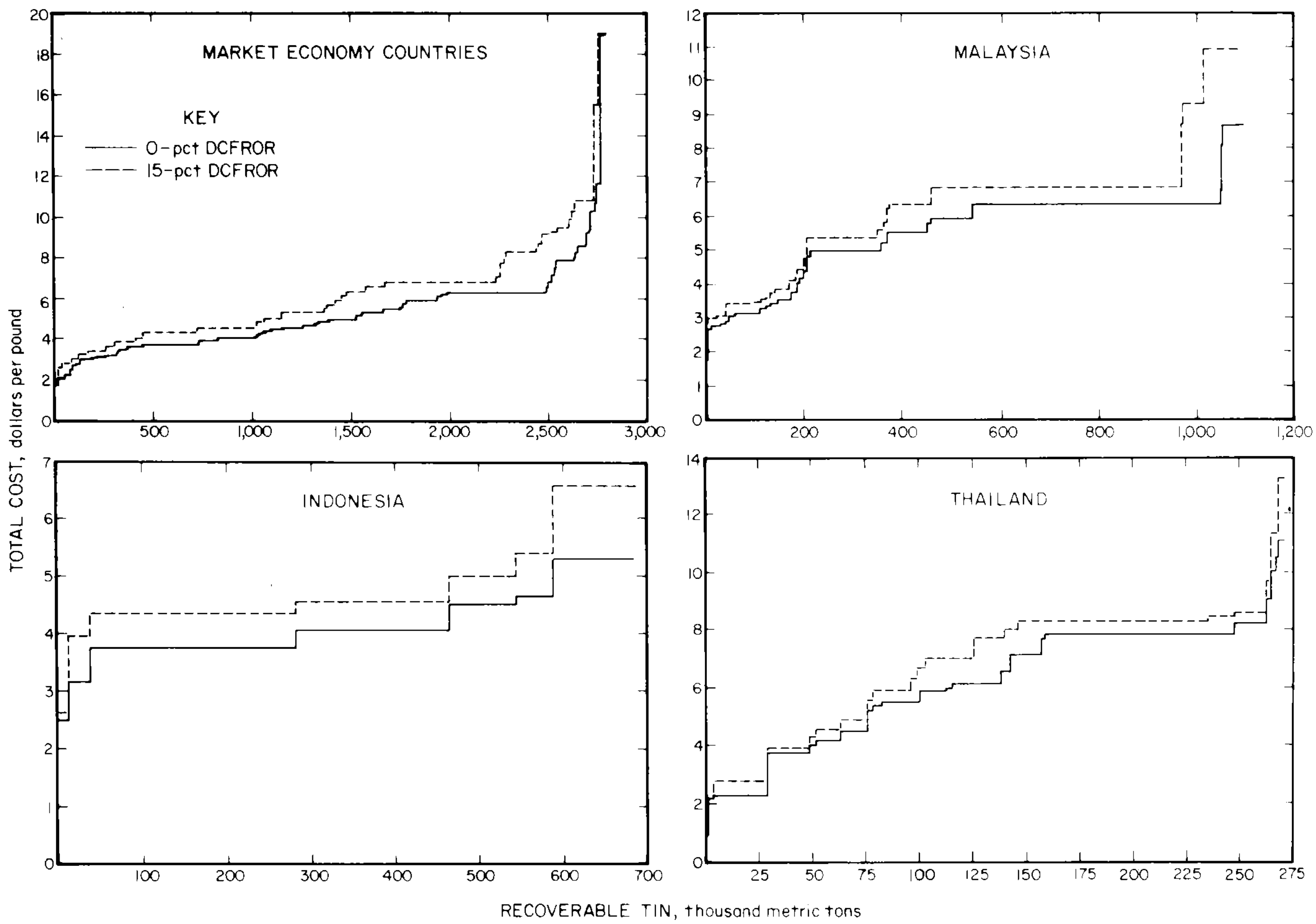


Figure 15.—Total recoverable tin from producing mines and undeveloped deposits in all evaluated countries and in Malaysia, Indonesia, and Thailand at both a 0- and 15-pct DCFROR in January 1984 U.S. dollars.

tin from producing mines in these three countries constituted almost 80 pct of the total from producing mines. Since most of the demonstrated tin resources of Southeast Asia were under exploitation, the region's share of recoverable tin from undeveloped deposits was much smaller, consisting of undeveloped Malaysian deposits which accounted for 25.4 pct of the total.

Figure 15 shows total availability curves for all MEC's and individual curves for Indonesia, Malaysia, and Thailand at both 0- and 15-pct DCFROR's. About 2.8 million mt of tin was estimated to be recoverable at total production costs ranging from $0 to $19.00/lb at a 0-pct DCFROR and from $0 to $31.80/lb at a 15-pct DCFROR. (Properties with estimated average total costs greater than $20/lb were not included on the curves.) On the 0-pct DCFROR curve, approximately 138,000 mt of tin was potentially recoverable at costs ranging up to $3.00/lb, 824,000 mt was recoverable at costs ranging up to $4.00/lb, 1.5 million mt was recoverable at costs up to $5.00/lb, and 2.5 million mt was available at costs ranging up to $7.00/lb. Ninety pct of the recoverable tin was potentially recoverable at costs under $7.00/lb at a 0-pct DCFROR. The 15-pct-DCFROR curve shows that approximately 94,000 mt of tin was potentially recoverable at costs ranging from up to $3.00/lb, 430,000 mt was recoverable at costs ranging up to $4.00/lb, 1.1 million mt was recoverable at costs up to $5.00/lb, and 2.2 million mt was recoverable at costs ranging up to $7.00/lb. Almost 80 pct of the recoverable tin was potentially recoverable at costs under $7.00/lb at a 15-pct DCFROR. These estimated costs were determined assuming full-capacity production; current production costs for mine operating at less than full capacity in countries under ITC production quotas could be slightly higher. Recently, some operations were operating at less than capacity, others were temporarily shut down, and others were operating at capacity but stockpiling up to 40 pct of their production.

The following discussions of tin availability, by country, provide estimates of potential tin availability at different ranges of estimated average total production costs. In interpreting the availability data presented, the reader should keep in mind that the market price for tin in January 1984 was $5.69/lb and the weighted average price for tin in 1984 was $5.96/lb. Given recent price trends (table 2), the average price for tin over the long run (in January 1984 dollars) may be below the 1984 price data, indicating that the tin industry could likely become even more competitive than it is now.

The curve for Malaysia (fig. 15) shows 1.1 million mt tin potentially recoverable from 36 mines and deposits (or regions) at costs ranging from $1.80 to $8.60/lb at a 0-pct DCFROR (and from $2.00 to $10.80/lb at a 15-pct DCFROR). At a 0-pct DCFROR, about 47,000 mt tin was potentially available at total production costs under

$3.00/lb, 191,000 mt was available at costs ranging up to $4.00/lb, 359,000 mt was available at costs under $5.00/lb, and slightly less than 1.1 million mt was available at costs ranging up to $7.00/lb. Only 46,000 mt would have an estimated production cost above $7.00/lb. At a 15-pct DCFROR, potential availability was 24,000 mt tin at total production costs under $3.00/lb, 171,000 mt at costs ranging up to $4.00/lb, 210,000 mt at costs under $5.00/lb, and 972,000 mt at costs up to $7.00/lb. An additional 127,000 mt tin would have an estimated potential production cost of over $7.00/lb.

The curve for Indonesia (fig. 15) shows 685,000 mt of tin potentially recoverable from 7 mines (or regions) at costs ranging from $2.50 to $5.30/lb at a 0-pct DCFROR (and from $2.60 to $6.60/lb at a 15-pct DCFROR). Almost 590,000 mt of this tin was estimated to have a total production cost of under $5.00/lb at a 0-pct DCFROR, and 465,000 mt was estimated to have a total cost under $5.00/lb at a 15-pct DCFROR.

The curve for Thailand (fig. 15) shows 270,000 mt of tin potentially recoverable from 25 mines with total production costs ranging from $0.90 to $11.20/lb at a 0-pct DCFROR ($1.10 to $13.40/lb at a 15-pct DCFROR). At a 0-pct DCFROR, slightly over 29,000 mt of tin was potentially recoverable at production costs ranging up to $3.00/lb, 49,000 mt was recoverable at costs under $4.00/lb, 76,000 mt was recoverable at costs under $5.00/lb, and 143,000 mt was recoverable at costs ranging up to $7.00/lb. An additional 128,000 mt of tin was potentially recoverable at total production costs over $7.00/lb. Thailand had the highest weighted-average total cost of the Southeast Asian producers ($6.20/mt at a 0-pct DCFROR), largely owing to its export tax, which was approximately $1.60/lb higher than Malaysia's or Indonesia's export tax. Avoidance of this tax burden is one of the main reasons that most of the smuggled tin in Southeast Asia comes out of Thailand.

Figure 16 compares potential production from producing mines and undeveloped deposits at both a 0- and 15-pct DCFROR. These curves show that most (88.5 pct) of the demonstrated tin resources was from producing mines, and also show the effect of the cost of capital at a 15-pct DCFROR. The average cost difference at the 0- and 15-pct DCFROR's was much less for producing mines ($0.60/lb) than it was for new operations ($4.50/lb) since many producing tin mines are not extremely capital intensive and much of the original capital investment was depreciated.

The data from the curves were disaggregated as shown in table 16, to show the potential production and weighted-average total costs, by country, for producing mines and undeveloped deposits. Potential production and weighted-average total costs at both 0- and 15-pct DCFROR are shown. To determine the weighted-average costs shown in table 16, the mines and deposits were evaluated using 1982 production costs, which were then

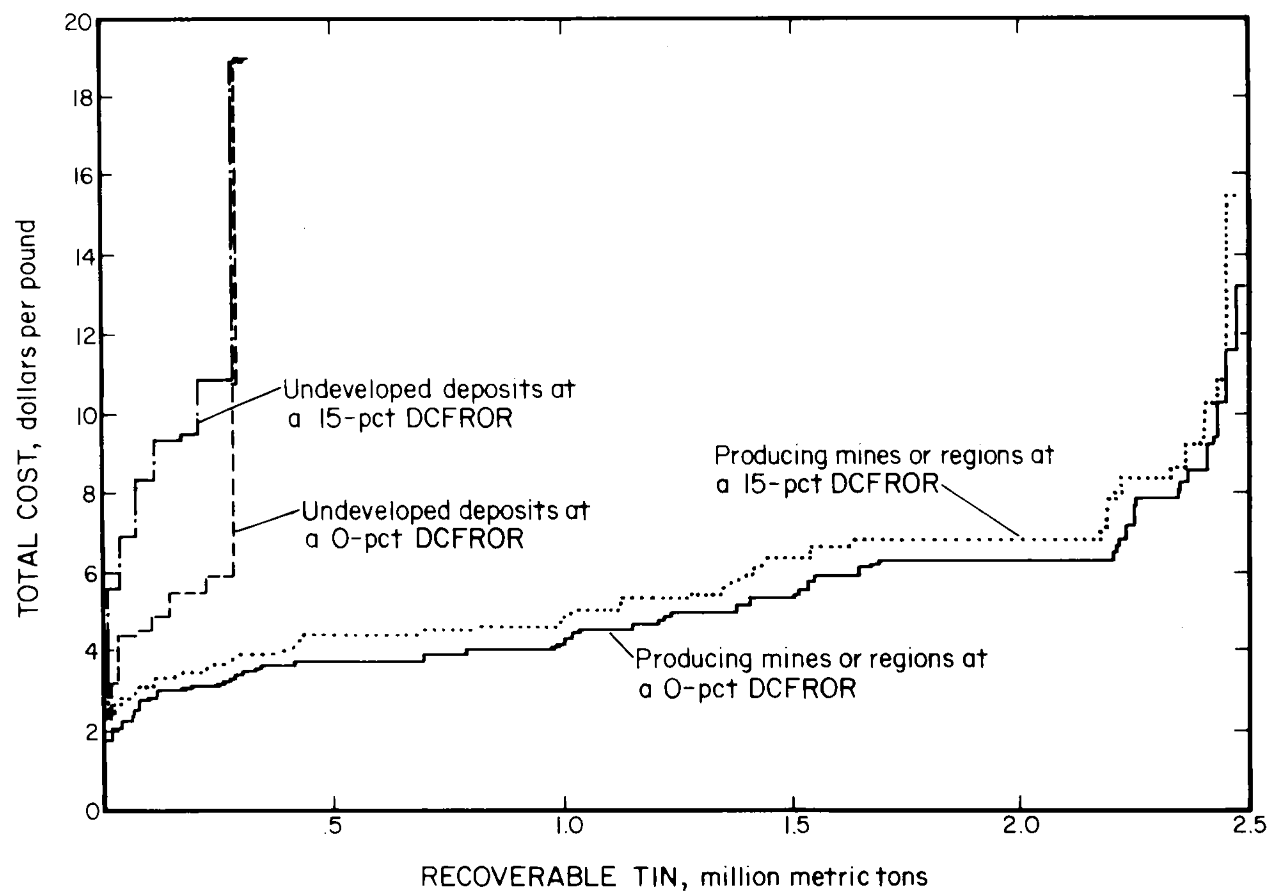


Figure 16.—Comparison of total recoverable tin from producing mines and undeveloped deposits in MEC's at both a 0- and 15-pct DCFROR in January 1984 U.S. dollars.

Table 16.—Comparison of estimated long-run average total costs of potential tin production from producing mines and undeveloped deposits at a 0- and 15-pct DCFROR in January 1984 U.S. dollars

Country	Producing mines: Potential production, 10^3 mt	Producing mines: Weighted-av total cost, $/lb Sn, 0-pct DCFROR	Producing mines: Weighted-av total cost, $/lb Sn, 15-pct DCFROR	Undeveloped deposits: Potential production, 10^3 mt	Undeveloped deposits: Weighted-av total cost, $/lb Sn, 0-pct DCFROR	Undeveloped deposits: Weighted-av total cost, $/lb Sn, 15-pct DCFROR
Argentina	2.9	W	W	NAp	NAp	NAp
Australia	135.3	6.10	7.20	49.6	6.40	10.70
Bolivia	97.8	5.50	6.20	38.7	W	W
Brazil	43.9	4.00	4.50	23.0	2.80	3.70
Burma	9.3	1.60	2.	NAp	NAp	NAp
Canada	NAp	NAp	NAp	58.8	W	W
Indonesia	685.1	4.20	4.80	NAp	NAp	NAp
Japan	7.0	7.70	10.10	NAp	NAp	NAp
Malaysia	1,017.7	5.50	6.00	81.4	5.50	10.70
Namibia	54.2	W	W	2.6	W	W
Nigeria	16.0	W	W	NAp	NAp	NAp
Peru	34.4	W	W	NAp	NAp	NAp
South Africa, Republic of	29.1	4.60	5.40	NAp	NAp	NAp
Thailand	270.3	6.20	6.80	NAp	NAp	NAp
United Kingdom	39.4	4.50	5.70	47.5	4.00	6.50
United States	NAp	NAp	NAp	19.2	W	W
Zaire	19.4	W	W	NAp	NAp	NAp
Zimbabwe	16.8	W	W	NAp	NAp	NAp
Total[1] or weighted av	2,478.7	5.10	5.70	320.7	6.00	10.50

NAp Not applicable. W Withheld; company proprietary data.
[1] Data may not add to totals shown because of independent rounding.

Table 17.—Comparison of estimated long-run average total costs of potential tin production from producing mines and undeveloped deposits at a 0- and 15-pct DCFROR in January 1984 U.S. dollars

Country	Producing mines: Potential production, 10^3 mt	Producing mines: Weighted-av total cost, $/lb Sn, 0-pct DCFROR	Producing mines: Weighted-av total cost, $/lb Sn, 15-pct DCFROR	Undeveloped deposits: Potential production, 10^3 mt	Undeveloped deposits: Weighted-av total cost, $/lb Sn, 0-pct DCFROR	Undeveloped deposits: Weighted-av total cost, $/lb Sn, 15-pct DCFROR
Argentina	4.1	W	W	NAp	NAp	NAp
Australia	155.7	5.90	7.20	49.6	6.50	10.80
Bolivia	135.3	9.40	10.20	38.7	W	W
Brazil	58.8	5.20	6.00	23.0	3.80	5.00
Burma	11.0	1.70	2.20	NAp	NAp	NAp
Canada	NAp	NAp	NAp	58.8	W	W
Indonesia	735.1	5.30	6.00	NAp	NAp	NAp
Japan	7.9	8.90	10.20	NAp	NAp	NAp
Malaysia	1,122.0	5.20	5.60	81.4	5.50	10.70
Namibia	55.8	W	W	2.6	W	W
Nigeria	20.0	W	W	NAp	NAp	NAp
Peru	39.8	W	W	NAp	NAp	NAp
South Africa, Republic of	34.3	4.60	5.50	NAp	NAp	NAp
Thailand	335.6	5.70	6.50	NAp	NAp	NAp
United Kingdom	48.8	5.40	6.80	47.5	4.60	7.30
United States	NAp	NAp	NAp	19.2	W	W
Zaire	24.0	W	W	NAp	NAp	NAp
Zimbabwe	19.8	W	W	NAp	NAp	NAp
Total[1] or weighted av	2,807.9	5.50	6.10	320.7	6.10	10.40

NAp Not applicable. W Withheld; company proprietary data.
[1] Data may not add to totals shown because of independent rounding.

Table 18.—Estimated potential 1984 production capacities for producing mines, with costs derived at a 0-pct DCFROR, metric tons[1]

Country	Tin cost, $/lb: 0-3.00	Tin cost, $/lb: 3.01-4.00	Tin cost, $/lb: 4.01-5.00	Tin cost, $/lb: 5.01-7.00	Tin cost, $/lb: Over 7.00	Total[2]
Argentina	610	0	0	0	0	610
Australia	0	6,010	0	1,660	1,960	9,630
Bolivia	1,330	6,230	4,430	1,390	3,400	16,770
Brazil	780	4,080	2,000	2,010	140	9,010
Burma	890	0	0	0	0	890
Indonesia	4,380	8,930	8,570	3,520	0	25,410
Japan	0	0	0	0	390	390
Malaysia	4,460	12,220	13,110	20,290	2,070	52,150
Namibia	0	790	0	0	0	790
Nigeria	1,990	0	0	0	0	1,990
Peru	0	3,730	0	0	0	3,730
South Africa, Republic of	0	0	2,020	370	190	2,580
Thailand	1,470	610	1,780	12,800	16,970	33,630
United Kingdom	0	0	1,730	2,930	0	4,660
Zaire	0	0	0	2,300	0	2,300
Zimbabwe	0	0	0	1,500	0	1,500
Total[2]	15,910	42,590	33,640	48,780	25,100	166,020

[1] Costs are in Jan. 1984 U.S. dollars. Capacities are based on 1982 data.
[2] Data may not add to totals shown because of independent rounding.

updated to January 1984 dollars using the Bureau's Mining Cost Indexation System. Countries whose currencies had devalued by more than their domestic inflation rates relative to the U.S. dollar show U.S.-dollar-based January 1984 costs that are lower than the costs were in January 1982. The major tin producing countries most affected by this foreign-exchange bias were Bolivia, Brazil, and Indonesia. Bolivia, in particular, had undergone an extremely rapid devaluation of the Peso Boliviano since late 1981. The Bolivian inflation rate was approaching 1,000 pct per year; not only creating economic chaos within that country, but also making any attempt to measure actual costs in U.S. dollar terms extremely tenuous.

The data from table 16 is presented in table 17 using January 1982 dollars for comparison purposes. The estimated tonnage of total recoverable tin from producing mines in 1984 was based on 1982 resource data minus 2 yr of estimated production, at full capacity. Therefore, the tonnage figures on table 18 are larger than the tonnage figures on table 16. The comparison between 1982 and 1984 dollar costs also includes the differential of byproduct prices between 1982 and 1984. In general, commodity prices were lower in 1984 than they were in 1982, meaning they would have had less impact toward lowering the total cost of tin production than they did in 1982. The effect of exchange rates on dollar-based total cost estimates was, therefore, even more significant for countries whose estimated total cost of tin production was lower in 1984 dollars than in 1982 dollars

Of the major tin producing countries shown in tables 16 and 17, estimated total production costs in dollar terms actually declined in Bolivia, Brazil, Burma, Indonesia, Japan, the Republic of South Africa, and the United

Kingdom. All of these countries had currencies that devalued relative to the U.S. dollar at a faster rate than their domestic inflation rates. The most dramatic change occurred in Bolivia, where the Peso Boliviano was devalued from $b24.51 to the U.S. dollar at the beginning of 1982 to $b230 to the dollar at the beginning of 1984 (and stood at $b2,000 to the dollar in September 1984). Bolivia showed a weighted-average total production cost of $5.50/lb in 1984 dollars at a 0-pct DCFROR, compared to $9.40/lb in 1982 dollars. The $9.40/lb cost of tin was probably a more accurate reflection of the total cost of Bolivian tin production in real terms than the much lower $5.50/lb cost in 1984 dollars. Any cost savings to Bolivia in this situation would have come from the decrease in real income of the Bolivian miners, which fell dramatically over the last few years. This plunge in real income was probably responsible for a spate of work stoppages at several COMIBOL mines in 1984. Such occurrences tend to have an adverse effect on profitability and would contribute to a total cost picture that is probably higher than the $5.50/lb estimate in 1984 dollars (at a 0-pct DCFROR).

Only Australia, Malaysia, and Thailand showed actual increases in production costs from 1982 to 1984 in U.S.-dollar terms. All three of these countries had domestic inflation rates relative to the U.S. inflation rate that were higher than any devaluations that occurred between 1982 and 1984. The exchange rate for the Malaysian Ringgit fluctuated around M$2.33 per U.S. dollar, while the value of the Australian dollar declined from $1.14 to $0.90 during the same period. The value of the Thai Baht was pegged at B23 per U.S. dollar during this period. Further devaluations may have occurred since the study was concluded.

ANNUAL AVAILABILITY

Another method of illustrating tin availability is to disaggregate the total resource availability curve and show potential availability on an annual basis. For analysis, separate annual availability curves were constructed for producing mines and proposed (undeveloped) operations in MEC's. Although no accurate development schedule could be proposed for all of the undeveloped deposits, the potential annual availability curves for these deposits were useful for indicating estimated potential capacity and estimated cost levels of future tin production.

The annual curves are valuable in that they graphically illustrate annual production potential at different cost levels. The curves are not intended as projections of actual production during the years shown, but they do illustrate annual production potential at estimated capacity rates.

Producing Mines and Regions

Potential annual production of tin from producing mines (and regions) in MEC's at a 0- and 15-pct DCFROR, from 1984 to 1995, is shown in figures 17 and 18. The curves reflect the production capacity of existing mines, including planned expansions when known. It was assumed that all operations produce at full (100 pct) capacity over the life of the mine. The curves could not take into account ITC sales quotas, production cutbacks mandated by market conditions, or smuggled tin, since these factors are likely to vary on an annual basis and would be difficult to project. Since actual production was at less than capacity levels at the time of the study (at least on a countrywide basis among ITC members), it is not likely that potential annual production will decline to the extent shown in the curves, since much production potential was being deferred. Furthermore, since this study is based on a static 1982 resource estimate, these curves do not reflect the fact that mineral resource estimates historically have increased over time or remained relatively constant owing to ongoing exploration programs in existing mines and the discovery of new ore bodies. This is particularly important in countries such as Bolivia, where underground mines tend to maintain resource estimates which often exceed no more than 3-5 yr of production at current mining levels. This is partially due to the nature and complexity of the ore bodies, and partially due to the added cost of blocking out reserves further ahead of current production. The Bolivians possess millions of tons of old tailings (some of which are now being treated) which have high enough tin grades to eventually become economic when and if the need arises to exploit these resources.

Figures 17 and 18 show a gradual decline in production capacity among producing mines, from 166 million mt in 1984 to 72.3 million mt in 1995, as the demonstrated resources of a number of mines become exhausted. As mentioned above, such a decline is unlikely for some producers, but there is concern among low-cost producers such as Malaysia that new capacity from existing mines will be more expensive to develop than currently available capacity since ore grades at dredging operations have been declining. In order to expand future tin production, the Malaysians will likely have to resort to even more costly underground lode mining in mountainous areas of Malaysia which are currently under exploration.

The data presented in figures 17 and 18 are shown in tabular form in tables 18 through 21. These tables show the estimated annual production capacities for producing mines in each producing country at different cost levels, in 1984 and 1995 and at both a 0- and 15-pct DCFROR. For each country, these tables provide a detailed breakdown of the different cost levels of production from producing mines.

The historic prices of tin from 1975 to 1984 (table 2), showed a trend of declining tin prices from 1979 to 1984. The 1984 low level of tin prices obviously had an adverse impact on profitability. As shown in table 18, if tin prices dropped to as low as $5.00/lb and stayed at that level in real terms, less than 56 pct (92,100 mt) of the 1984 production capacity of 166,020 mt would provide for at least a 0-pct DCFROR. Only 44 pct of this production capacity (73,240 mt) could be sold at $5.00/lb and return a 15-pct DCFROR. At the January 1984 tin price of $5.69/lb, approximately 103,000 mt of the 1984 tin capacity (62 pct) could be produced and return at least a 0-pct DCFROR; at the same price, 94,000 mt (57 pct) could be produced and earn at least a 15-pct DCFROR. Slightly over 60 pct of the 1984 tin capacity that could be produced for under $5.00/lb at a 0-pct DCFROR (58 pct at a 15-pct DCFROR) is in Southeast Asia.

In 1995, approximately 46,000 mt of tin capacity could potentially be produced for under $5.00/lb and return at least a 0-pct DCFROR. Of this amount, slightly under 36,000 mt (78 pct) would be from Southeast Asia. Southeast Asia would account for 74 pct (20,000 mt) of the

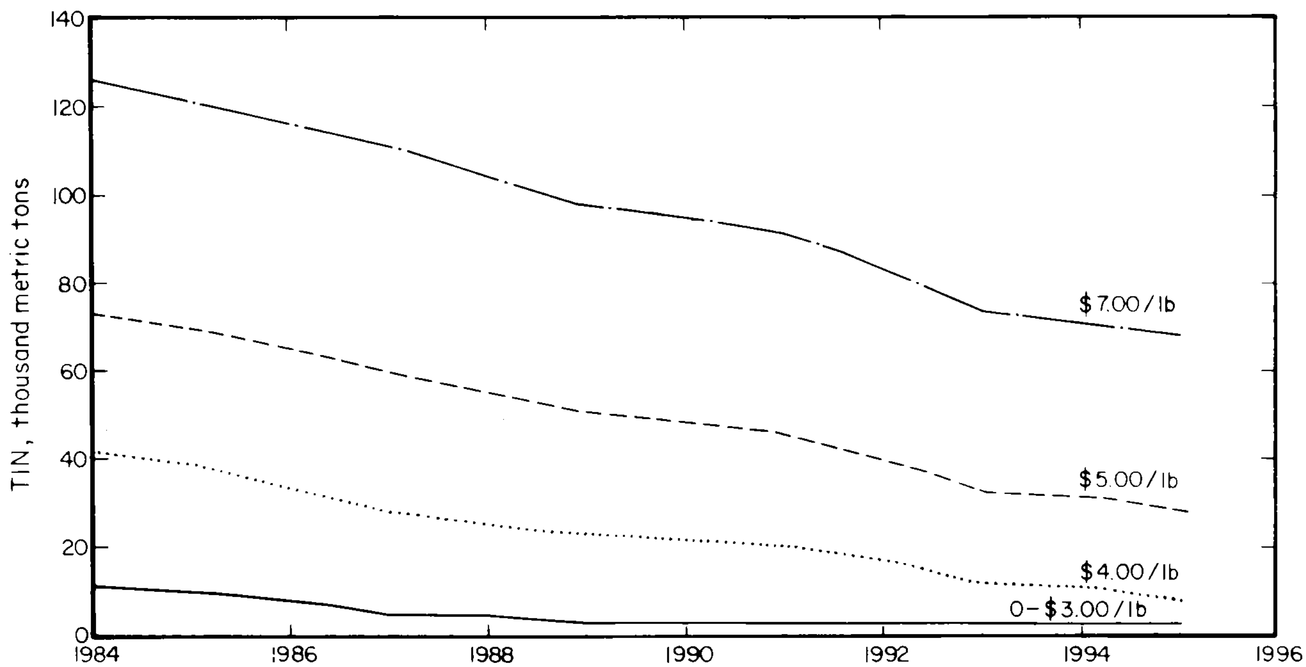


Figure 17.—Annual availability of tin from producing mines and regions in MEC's at various cost levels including a 0-pct DCFROR in January 1984 U.S. dollars.

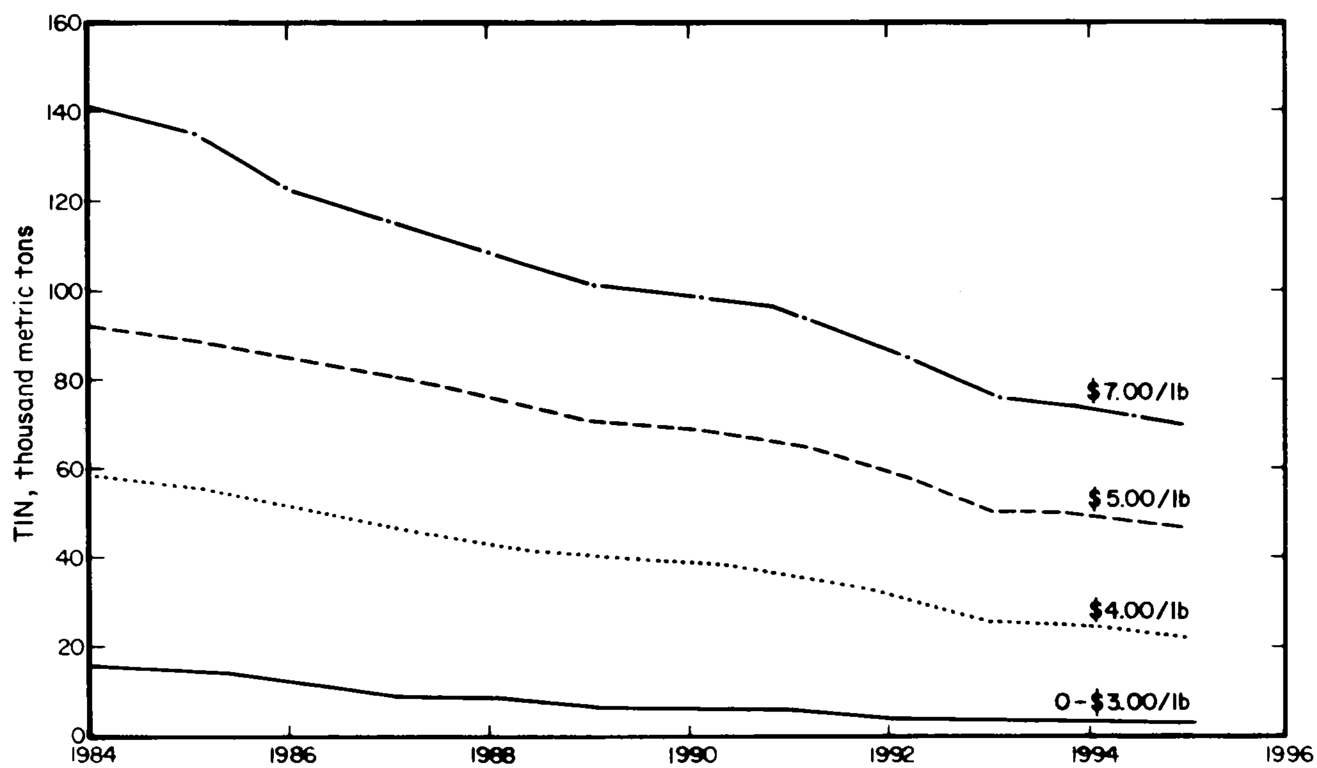


Figure 18.—Annual availability of tin from producing mines and regions in MEC's at various cost levels including a 15-pct DCFROR in January 1984 U.S. dollars.

Table 19.—Estimated potential 1984 production capacities for producing mines, with costs derived at a 15-pct DCFROR, metric tons[1]

Country	Tin cost, $/lb					Total[2]
	0-3.00	3.01-4.00	4.01-5.00	5.01-7.00	Over 7.00	
Argentina	610	0	0	0	0	610
Australia	0	300	5,710	1,660	1,960	9,630
Bolivia	1,330	5,430	4,570	1,130	4,310	16,770
Brazil	780	2,850	2,090	3,160	140	9,010
Burma	890	0	0	0	0	890
Indonesia	4,380	2,030	12,090	6,900	0	25,410
Japan	0	0	0	0	390	390
Malaysia	2,000	12,720	5,110	29,890	2,430	52,150
Namibia	0	790	0	0	0	790
Nigeria	0	1,990	0	0	0	1,990
Peru	0	3,730	0	0	0	3,730
South Africa, Republic of	0	0	0	2,020	560	2,580
Thailand	1,470	610	1,780	1,400	28,360	33,630
United Kingdom	0	0	0	4,660	0	4,660
Zaire	0	0	0	2,300	0	2,300
Zimbabwe	0	0	0	0	1,500	1,500
Total[2]	11,450	30,440	31,350	53,130	39,640	166,020

[1] Costs are in Jan. 1984 dollars; capacities are based on 1982 data.
[2] Data may not add to totals shown because of independent rounding.

Table 20.—Estimated potential 1995 production capacities for producing mines, with costs derived at a 0-pct DCFROR, metric tons[1]

Country	Tin cost, $/lb					Total[2]
	0-3.00	3.01-4.00	4.01-5.00	5.01-7.00	Over 7.00	
Australia	0	5,710	0	0	1,400	7,100
Bolivia	0	320	330	230	0	880
Burma	650	0	0	0	0	650
Indonesia	0	7,410	10,690	3,520	0	21,620
Japan	0	0	0	0	390	390
Malaysia	1,860	2,740	9,960	17,380	1,240	33,180
Namibia	0	790	0	0	0	790
South Africa, Republic of	0	0	2,020	0	0	2,020
Thailand	1,060	610	1,510	1,620	700	5,500
Zimbabwe	0	0	0	240	0	240
Total[2]	3,580	17,570	24,520	23,000	3,720	72,370

[1] Costs are in January 1984 dollars; capacities are based on 1982 data.
[2] Data may not add to totals shown because of independent rounding.

Table 21.—Estimated potential 1995 production capacities for producing mines, with costs derived at a 15-pct DCFROR, metric tons[1]

Country	Tin cost, $/lb					Total[2]
	0-3.00	3.01-4.00	4.01-5.00	5.01-7.00	Over 7.00	
Australia	0	0	5,710	0	1,400	7,100
Bolivia	0	0	0	880	0	880
Burma	650	0	0	0	0	650
Indonesia	0	500	12,090	9,030	0	21,620
Japan	0	0	0	0	390	390
Malaysia	970	2,670	950	27,350	1,240	33,180
Namibia	0	790	0	0	0	790
South Africa, Republic of	0	0	0	2,020	0	2,020
Thailand	1,060	610	1,510	540	1,770	5,500
Zimbabwe	0	0	0	0	240	240
Total[2]	2,680	4,580	20,260	39,820	5,040	72,370

[1] Costs are in January 1984 dollars; capacities are based on 1982 data.
[2] Data may not add to totals shown because of independent rounding.

27,500 mt of tin capacity that could be produced in 1995 for under $5.00/lb and earn at least a 15-pct DCFROR.

Undeveloped Deposits

The potential annual availability curves for all 16 of the evaluated undeveloped deposits in MEC's at a 0- and 15-pct DCFROR are shown in figures 19 and 20. Since no definite startup date was known or available for most of these deposits, it was assumed that preproduction began in a base year (N). Production could not be established in an actual year since development of these deposits was not expected in the near future. However, the annual curves for the undeveloped deposits do show the required lead times before production can begin and therefore are important in that they show the potential production costs and potential annual capacities of future mines.

In constructing these curves, all undeveloped deposits were assumed to begin preproduction development at the same time, and thus production from some could begin in the year N + 2. The sharp increase in production during the next several years is the result of all deposits coming on-line at the same time. The assumption of concomitant development of all 16 of these deposits overstates the tonnage available in a given year since the deposits would not be likely to begin preproduction simultaneously. Given the depressed situation of the tin industry with its associated production quotas from producing mines, it is doubtful than many of these deposits will be developed in the near future. The annual curve, however, highlights the tonnage potential at different cost levels. The production breakdown, by country, for the years N + 5 and N + 10 at a 0- and 15-pct DCFROR is shown in tables 22 through 25.

A total of 10,100 mt of tin could potentially be produced in the year N + 5 at a total cost under $5.00/lb and return at least a 0-pct DCFROR (table 22). Of this potential amount, 33 pct is in Brazil, 32 pct is in Australia, 18 pct is in the United Kingdom, and 17 pct is in Bolivia. At a 15-pct DCFROR (table 23), approximately 5300 mt of tin could potentially be produced at a total cost under $5.00/lb. Approximately 62 pct of this potential capacity is in Brazil.

The relative lack of demonstrated resources with limited potential production from undeveloped deposits underscores the weakness of the international tin industry. There is very little incentive to expend money to explore for further resources that, given the state of the industry, will not be needed in the immediate future. The limited demonstrated resource from undeveloped deposits does not indicate a rapidly depleting resource. Rather, it reflects the lack of exploration activity in the major producing countries. Malaysia, however, has recently begun a large Government-funded exploration program.

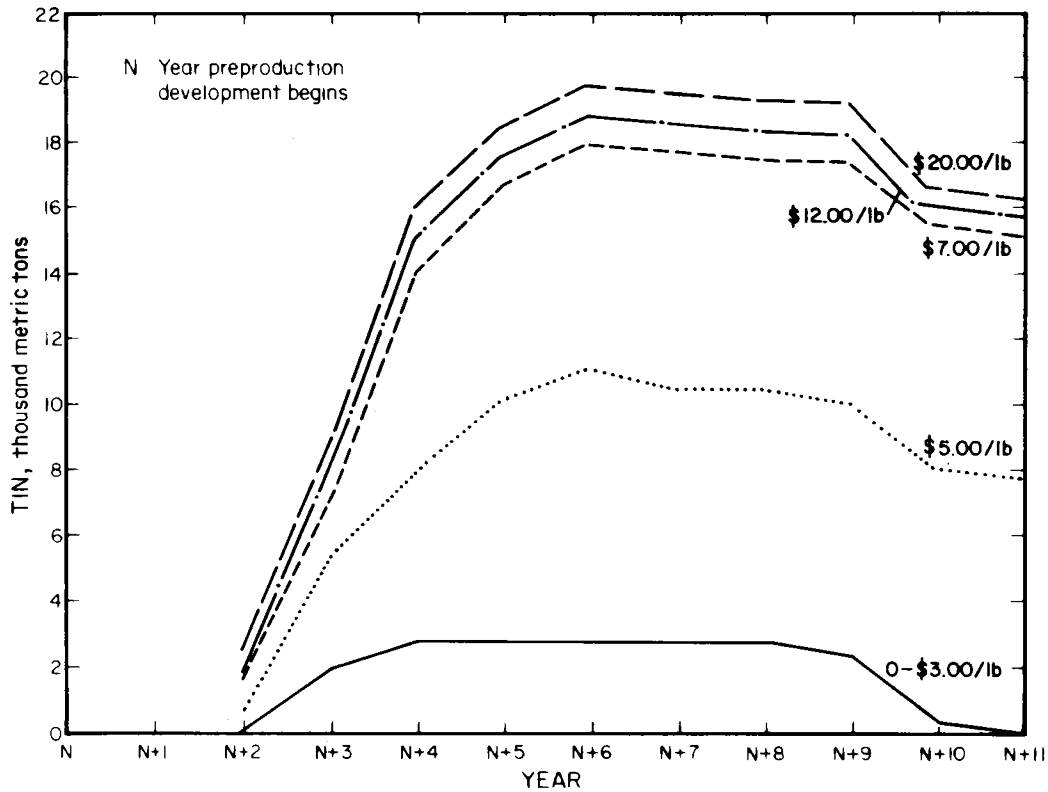


Figure 19.—Potential annual availability of tin from undeveloped deposits in MEC's at various cost levels including a 0-pct DCFROR in January 1984 U.S. dollars.

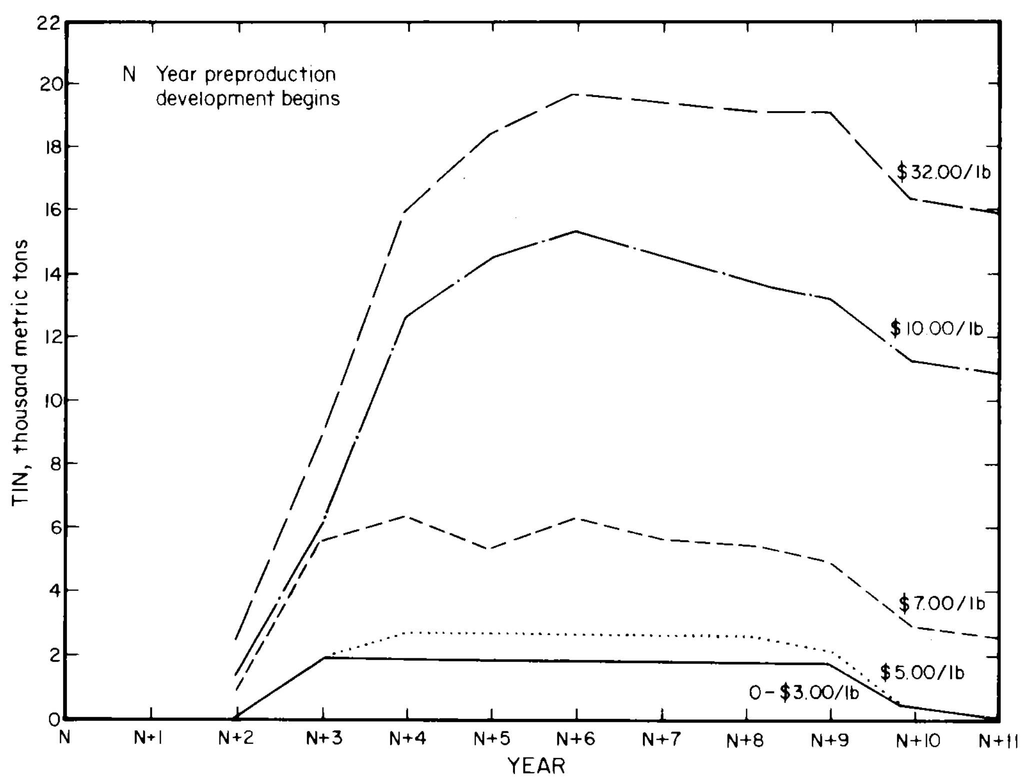


Figure 20.—Potential annual availability of tin from underground deposits in MEC's at various cost levels including a 15-pct DCFROR in January 1984 U.S. dollars.

Table 22.—Estimated potential production capacities from undeveloped deposits in year N + 5, with costs derived at a 0-pct DCFROR, metric tons per year[1]

Country	Tin cost, $/lb				Total[2]
	0-3.00	3.01-5.00	5.01-7.00	Over 7.00	
Australia	0	3,210	0	1,150	4,360
Bolivia	0	1,740	0	0	1,740
Brazil	2,740	600	240	0	3,590
Canada	0	0	3,910	0	3,910
Malaysia	0	0	2,210	0	2,210
Namibia	0	0	130	0	130
United Kingdom	0	1,790	0	0	1,790
United States	0	0	0	690	690
Total[2]	2,740	7,340	6,490	1,830	18,410

N Base year.
[1] Costs are in Jan. 1984 U.S. dollars.
[2] Data may not add to totals shown because of independent rounding.

Table 23.—Estimated potential production capacities from undeveloped deposits in year N + 5, with costs derived at a 15-pct DCFROR, metric tons per year[1]

Country	Tin cost, $/lb				Total[2]
	0-5.00	5.01-7.00	7.01-10.00	Over 7.00	
Australia	0	0	3,210	1,150	4,360
Bolivia	0	0	1,740	0	1,740
Brazil	2,740	600	240	0	3,590
Canada	0	0	3,910	0	3,910
Malaysia	0	260	0	1,950	2,210
Namibia	0	0	0	130	130
United Kingdom	0	1,790	0	0	1,790
United States	0	0	0	690	690
Total[2]	2,740	2,650	9,100	3,910	18,410

N Base year.
[1] Costs are in Jan. 1984 U.S. dollars.
[2] Data may not add to totals shown because of independent rounding.

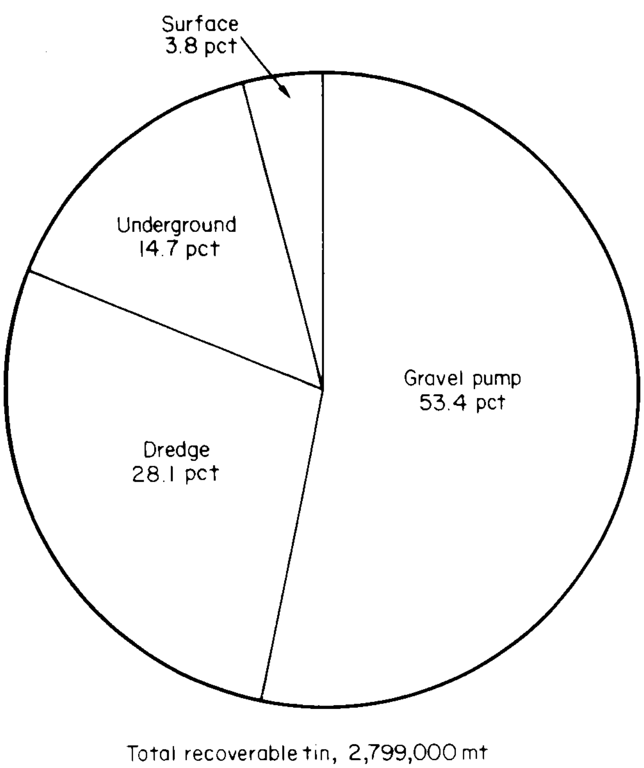


Figure 21.—Percentage share of potentially recoverable tin from producing and undeveloped mines, deposits, and regions in MEC's, by mining method.

Table 24.—Estimated potential production capacities from undeveloped deposits in year N + 10, with costs derived at a 0-pct DCFROR, metric tons per year[1]

Country	Tin cost, $/lb				Total[2]
	0-3.00	3.01-5.00	5.01-7.00	Over 7.00	
Australia	0	3,210	0	330	3,540
Bolivia	0	1,740	0	0	1,740
Brazil	300	0	0	0	300
Canada	0	0	3,320	0	3,320
Malaysia	0	0	3,910	0	3,910
Namibia	0	0	130	0	130
United Kingdom	0	2,760	0	0	2,760
United States	0	0	0	690	690
Total[2]	300	7,720	7,350	1,010	16,380

N Base year.
[1] Costs are in Jan. 1984 U.S. dollars.
[2] Data may not add to totals shown because of independent rounding.

Table 25.—Estimated potential production capacities from undeveloped deposits in year N + 10, with costs derived at a 15-pct DCFROR, metric tons per year[1]

Country	Tin cost, $/lb				Total[2]
	0-5.00	5.01-7.00	7.01-10.00	Over 10.00	
Australia	0	0	3,210	330	3,540
Bolivia	0	0	1,740	0	1,740
Brazil	300	0	0	0	300
Canada	0	0	3,320	0	3,320
Malaysia	0	0	0	3,910	3,910
Namibia	0	0	0	130	130
United Kingdom	0	2,760	0	0	2,760
United States	0	0	0	690	690
Total[2]	300	2,760	8,270	5,060	16,390

N Base year.
[1] Costs are in Jan. 1984 U.S. dollars.
[2] Data may not add to totals shown because of independent rounding.

There is little doubt that hypothetical and inferred resources will eventually be blocked out as demonstrated resources when the need arises.

Availability of Tin by Mining Method

Of the 130 producing mines evaluated for this study, 41 were actual or proposed dredging operations, 42 were underground, 37 were gravel pumps, and 10 were surface operations. Mines that used a combination of mining methods were classified on the basis of the mine that produced the highest proportion of revenues. Over half (53.4 pct) of the potential recoverable tin from all types of mining methods, for producing mines, was accounted for by gravel pumps, followed by dredges (28.1 pct), underground mines (14.7 pct), and surface mines (1.8 pct). These relative percentages are shown graphically in figure 21.

The distribution of potentially recoverable tin from producing mines, by country and mining method, at a 0-pct DCFROR, is shown in table 26. As shown in the table, dredges had the lowest estimated weighted-average total production cost, followed by underground mines, gravel pumps, and surface mines. The underground cost value was skewed somewhat low, however, by the low 1984 dollar figure for Bolivia, as explained earlier. Substituting the 1982 dollar figure for Bolivia, increases the weighted-average cost for underground mines to $5.60/lb, which is on par with the cost for gravel pumps. Although underground mining operations have the highest mining operating costs on a cost-per-metric-ton-of-ore basis, they also mine higher ore grades than the other types of mining operations, thus providing a lower cost per pound of metal.

Table 26.—Potentially recoverable tin from producing mines and estimated total cost[1] at a 0-pct DCFROR, by mining method

Country	Underground		Open pit		Gravel pump		Dredge	
	Potential production, 10^3 mt	Weighted-av total production cost, $/lb Sn	Potential production, 10^3 mt	Weighted-av total production cost, $/lb Sn	Potential production, 10^3 mt	Weighted-av total production cost, $/lb Sn	Potential production, 10^3 mt	Weighted-av total production cost, $/lb Sn
Zaire	NAp	NAp	NAp	NAp	NAp	NAp	NAp	NAp
Argentina	2.9	W	NAp	NAp	NAp	NAp	NAp	NAp
Australia	94.2	4.0	23.5	11.40	4.0	W	17.1	W
Bolivia	89.4	5.70	NAp	NAp	4.5	W	4.0	3.40
Brazil	NAp	NAp	1.9	W	34.9	3.97	8.3	3.80
Burma	9.0	W	NAp	NAp	8.4	W	NAp	NAp
Indonesia	44.7	W	NAp	NAp	275.0	4.10	365.5	4.10
Japan	7.0	7.70	NAp	NAp	NAp	NAp	NAp	NAp
Malaysia	3.4	W	7.2	W	844.2	5.90	162.9	3.50
Nigeria	NAp	NAp	NAp	NAp	NAp	NAp	16.0	W
Namibia	NAp	NAp	54.2	W	NAp	NAp	NAp	NAp
Peru	34.4	W	NAp	NAp	NAp	NAp	NAp	NAp
South Africa, Republic of	29.1	4.60	NAp	NAp	NAp	NAp	NAp	NAp
Thailand	3.0	W	6.4	5.20	136.8	7.20	124.2	5.00
United Kingdom	39.4	4.50	NAp	NAp	NAp	NAp	NAp	NAp
Zaire	NAp	NAp	NAp	NAp	19.4	W	NAp	NAp
Zimbabwe	16.8	W	NAp	NAp	NAp	NAp	NAp	NAp
Total[2] or weighted av	365.2	4.80	93.2	5.90	1,323.5	5.60	696.7	4.20

NAp Not applicable. W Withheld; company proprietary data.
[1] Jan. 1984 U.S. dollars.
[2] Data may not add to totals shown because of independent rounding.

CONCLUSIONS

The 146 mines and deposits (or regions) evaluated for this study in 18 MEC's represent a demonstrated in situ tonnage of 23.1 billion mt ore containing 2.8 million mt of potentially recoverable tin metal. Producing mines accounted for approximately 2.5 million mt of recoverable tin (88.5 pct of the total), and undeveloped deposits (including deposits under development) accounted for 320,000 mt (11.5 pct). According to resource estimates of the countries studied, Malaysia, Indonesia, and Thailand had the largest demonstrated tin resources, accounting for over 73 pct of the total recoverable tin from the mines and deposits evaluated in MEC's.

Almost half (47.9 pct) of the potential recoverable tin from all types of mining methods was accounted for by gravel pumps, followed by dredges (29.7 pct), underground mines (14.2 pct), and surface mines (8.2 pct). Dredges had the lowest estimated weighted-average total production costs, followed by underground mines, gravel pumps, and surface mines.

At the January 1984 market price of $5.69/lb, an estimated 1.7 million mt of tin could be recovered from producing operations at a 0-pct DCFROR. Among the evaluated mines and mining regions producing at the time of this study, approximately 141,000 mt of tin capacity was available in 1984 at costs under $7.00/lb (at a 0-pct DCFROR). This compares with an estimated 1983 production of about 172,000 mt. The difference can be explained by production from mines not evaluated in this study, tin originating from unknown or illegal sources (smuggled), and production at costs greater than $7.00/lb.

From 1980 through 1984, domestic primary tin production averaged less than 100 mt/yr, of which over 35 pct was a byproduct from the Climax molybdenum mine in Colorado. The remaining production is from a small alluvial operation in Alaska. The Lost River, AK, deposit, the only domestic deposit evaluated, contained less than 20,000 mt of recoverable tin. There are additional undeveloped resources in the United States (virtually all in Alaska), but they would require high-cost operations or are at the inferred resource level.

Tin differs from most commodities in that the market price of the metal is agreed upon by both consumer and producer members of the ITC. Owing to falling tin prices, members of the ITC have decreased sales by about 40 pct, resulting in closures, stockpiling, reduced production and some smuggling among member nations. Nonmember nations with low mining costs, especially Brazil, have not reduced production, but have actually expanded. In addition, smuggling of tin, primarily from Southeast Asia, may account for at least 10 pct of world production. These elements could become the major catalysts in undermining any price stabilization efforts taken by the ITC.

There have been concerns among ITC members that sales from the GSA stockpile would further flood the market and have deleterious effects on the price of tin. To partially allay these fears, the U.S. Government has tentatively agreed to limit sales to 3,000 mt/yr of tin. Another concern is that tin consuming nations, especially Canada and the United Kingdom, are developing or expanding their own tin mining industries, thus reducing potential sales to these countries.

The U.S. position, with respect to the availability of tin, is relatively secure owing to the large domestic stockpile and the fact that tin is readily obtainable on the market.

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APPENDIX A.—DEPOSITS INVESTIGATED BUT NOT INCLUDED IN EVALUATION

Country and deposit	Reason(s) for exclusion
Bolivia:	
Catavi	Demonstrated resource exhausted.
Enramada	Tin is a minor byproduct.
Brazil: Oriente Novo	Demonstrated resource exhausted.
Canada:	
Kidd Creek	Tin is a minor byproduct.
Sullivan	Do.
Portugal: Panasquiera	Do.
Spain:	
La Parilla	Do.
Santa Comba	Do.
United Kingdom: Hemerdon	Do
United States:	
Alaska: Cape Mountain, Ear Mountain, Tofty Tin Belt, Circle Hot Springs.	Small resource, high cost, or inferred resource.
Arizona: MINCO	Lack of available data.
Colorado: Climax molybdenum mine	Tin is a minor byproduct.

APPENDIX B.—WORLD TIN SMELTERS AND REFINERS

The following table lists the location, capacity, grade of feed, and other pertinent data for 1982 smelters and refineries in MEC's. The largest plant capacity was in Malaysia, followed by Indonesia, Thailand, Bolivia, and Brazil.

Members of the ITC recently cut tin sales significantly below capacity (by over 39 pct), while at the same time Brazil was expanding mine production. Brazil's smelter and refining capacity exceeds the availability of domestic concentrates, but Brazil does not accept foreign material. Some plants that relied totally on foreign concentrates to operate have either closed or reduced production as a result of reduced production among ITC members, poor market conditions, and the development of vertically intergrated industries among tin producing nations. The U.S. facility receives virtually all of its feed from Bolivia. Bolivia also ships concentrates to the United Kingdom and the Federal Republic of Germany. Bolivia formerly exported concentrates to Brazil, but owing to high import taxes, shipping has ceased. Burma exports concentrates, some of which are from illicit sources, primarily to Malaysia, the Netherlands, and Singapore. Singapore ships concentrates to the U.S.S.R., Spain and Mexico. Up until 1979, Singapore also shipped to Brazil and the Republic of Korea, but the combination of the closure of the Korean plant, high taxes in Brazil, and marketing of tin from undisclosed sources have encouraged an expansion of Singapore's domestic smelting and refining capacity.

Table B-1.—Pertinent 1982 data for world primary tin smelters and/or refineries

Owner and/or operator and location	Capacity, mt/yr metal	Feed: Grade[1]	Feed: Sources[2]	Pct Sn in products	Processes used[3]	Byproducts
MARKET ECONOMY COUNTRIES						
Argentina: Sociedad Minera Pirquitas Picchetti y Cia. S.A. (Buenos Aries).	850	M	Dom, imp	99.80	Reverberatory smelting furnace.	None.
Australia:						
Associates Tin Smelters Pty Ltd. (Alexandria, NSW).	6,000	M	Dom	99.885	Reverberatory smelting furnace, siro-smelt slag cleaning process.	Do.
Greenbushes Tin N.L. (Greenbushes, W. Australia).	800	H	Cap	99.80	Electric smelting furnace.	Ta_2O_5, slag.
Total	18,900	NAp	NAp	NAp	NAp	NAp.
Belgium: Metallurgie Hoboken-Overpelt S.A. (Hoboken; closed 1980).	8,000	H	Imp	99.966	Electric smelting furnace, concentrate and/or slag fuming.	None.
Bolivia: Empresa Nacional de Fundiciones (ENAF) (Vintos Oruro).	25,000	M-L	Dom, solders	99.82	Electric smelting furnace, rotary smelting furnace, kivcet cyclone flash smelting process, vacuum distillation (refining).	Pb, Bi.
Funestano S.A. (Oruro)	3,000	M	do	99.5	Reverberatory smelting furnace.	None.
Total	28,000	NAp	NAp	NAp	NAp	NAp.
Brazil:						
Cia. Estanifera do Brazil (CESBRA) (Volta Redonda Rondonia).	10,000	H	Cap	99.982	Reverberatory smelting furnace, electrolytic refining (acid electrolytes).	Pb, Bi.
Cia. Industrial Amazonense S.A. (CIA) (Manaus).	4,000	H	Dom, Imp(?) solders.	99.90	Reverberatory smelting furnace.	Do.
Mamore Mineracao e Metalurgia (Sao Paulo).	12,000	H	Dom	99.953	Reverberatory smelting furnace.	Do.
Best Metais e Soldas S.A. (Sao Paulo).	1,200	H	Dom	([4])	Reverberatory smelting furnace, concentrate and/or slag fuming.	Do.
Bera do Brasil, S.A. (Santo Amaro, Sao Paulo).	500	H	Dom	99.95		Do.
Cia Industrial Fluminense S.A. (St. John del Rey).	1,200	H	Dom	[7]99.95		Do.
Total	28,900	NAp	NAp	NAp	NAp	NAp.
Germany, Federal Republic of: Berzelius Metallhutten GmbH (Duisburg).	3,600	M-L	Imp	([4])	Reverberatory smelting furnace, concentrate and/or slag fuming.	NAp.
Indonesia: Peltim-Indonesia State Tin Corp. (Mentok, Bangka Is.).	38,000	M-L	Imp	99.92	Rotary smelting furnace, reverberatory smelting furnace.	Ta, Cb.
Japan: Mitsubishi Metal Corp. (Naoshima Kagawa).	3,500	M-L	Imp, dom	99.99	Reverberatory smelting furnace, electrolytic refining (acid electrolytes).	None(?).
Korea, Republic of: Pyro Metal Industry Co. Ltd. (Seoul; closed 1981).	1,200	H	do	0	Reverberatory smelting furnace.	None.
Malaysia:						
Detuk Keramat Smelting Sdn. Bhd. (Georgetown, Penang).	70,000	H-M	Dom, imp	[5]99.89	Reverberatory smelting furnace, roast, electric smelting furnace.	Pb, Sb.
Straits Trading (MSC) (Butterworth, Penang).	60,000	H	Dom	99.89	Reverberatory smelting furnace, roast.	Ta_2O_5 slag.
Total	130,000	NAp	NAp	NAp	NAp	NAp.
Mexico:						
Metales Potosi (San Luis Potosi).	2,500	M	Imp	99.89	Reverberatory smelting furnace, concentrate and/or slag fuming.	None(?).
Estano Electro S.A. (Tlaepont1)	1,000	M	do	99.89	Reverberatory smelting furnace.	None.
Fundidora de Estano (San Luis Potosi).	800	M	do	99.50	Reverberatory smelting furnace.	Do.
Total	4,300	NAp	NAp	NAp	NAp	NAp.
Netherlands: Billiton Metallurgie B.V. (Arnhem).	2,500	M	Imp	99.935	Reverberatory smelting furnace, concentrate and/or slag fuming, chemical.	WO_3(?).
Nigeria: Makeri Smelting Co. (Jos.).	4,000	H	Dom	99.964	Reverberatory smelting furnace.	Ta_2O_5 slag.
Portugal: Neostano, Nova Empresa Estanifera do Mangualde S.A.R.L. (Mangualde).	800	M	Imp	99.90	Reverberatory smelting furnace, concentrate and/or slag fuming.	None.
Rwanda: Société Minière du Rwanda (Somirwa) (Kigali).	3,000	H-M	Dom	+99.80	Electronic smelting furnace, concentrate and/or slag fuming.	Ta_2O_5 slag.
Singapore:						
Kimetal PTE LTD, (Jurong)	6,000	H	Imp	+99.50	Rotary smelting furnace, electric smelting furnace.	Do.
Wattenmetals (Pte) Ltd. (Jurong)	500	H	do	+99.50	Reverbertory smelting furnace, electric smelting furnace, kettles.	Do.
Total	6,500	NAp	NAp	NAp	NAp	NAp.

NAp Not applicable. (?) Indicates uncertain information.
[1] H—High-grade concentrates (>50 pct Sn), M—Medium-grade concentrates (25-50 pct Sn), L—Low-grade concentrates (25 pct Sn).
[2] Dom—Domestic sources of concentrates, Imp—Imported concentrates, Cap—Captive sources—own mines and concentrates.
[3] Processes used for production of refined tin metal.
[4] Tin alloys and solders only.
[5] Alloys also produced.
[6] Alloys only.
[7] Alloys and solders also produced.

Table B-1.—Pertinent 1982 data for world primary tin smelters and/or refineries—Continued

Owner and/or operator and location	Capacity, mt/yr metal	Feed		Pct Sn in products	Processes used[3]	Byproducts
		Grade[1]	Sources[2]			
		MARKET ECONOMY COUNTRIES—Continued				
South Africa, Republic of:						
Rooiberg Tin Ltd. (Rooiberg)	2,000	H	Cap, dom	99.95	Electric smelting furnace, electrolytic refining (acid electrolytes).	None(?).
South African Iron & Steel Industrial Corp. Ltd. (Vanderbijpart).	2,000	H	Imp, dom	[5]99.9	Electric smelting furnace.	None.
Zoaiplaats Tin Mining Co. Ltd. (Potgietarsfus).	2,000	H	Cap	99.95	Electric smelting furnace, concentrate and/or slag fuming.	Do.
Total	6,000	NAp	NAp	NAp	NAp	NAp.
Spain:						
Metalurgica del Noroeste S.A. (MENSA) (Villgarcia de Arosa).	4,500	M-L	Imp	+99.90	Reverberatory smelting furnace, concentrate and/or slag fuming.	NAp.
Minero Metalurgica Estano S.A. (Madrid).	1,000	M-L	Imp	+99.90	NAp	NAp.
Ferroaleaciones Espanolas S.A. (Medina del Campo).	800	M	Imp	([6])	Electric smelting furnace, concentrate and/or fuming.	NAp.
Electrometalurgica del Agueda S.A. (Villaralbo).	1,000	M	Imp	([6])	Concentrate and/or slag fuming.	NAp.
Total	7,300	NAp	NAp	NAp	NAp	NAp.
Thailand:						
Thailand Smelting & Refining Co., Ltd. (Thaisarco) (Phuket).	35,000	H	Dom, cap	99.925	Reverberatory smelting furnace, electric smelting furnace.	Ta_2O_5 slags.
Thai Pioneer Co. (Phathum Thani, Bangkok).	3,500	H	Dom	99.920	Electric smelting furnace, Ta recovery equipment.	Do.
Thailand Tantalum Industries Corp. (Thai Present Smelter Co.) (Phuket).	10,000	H	Dom, slags	99.920	Electric smelting furnace.	Ta products.
Sutin Seja Wongse (Bangkok)	600	H	Dom	99.90	Reverberatory smelting furnace.	Ta_2O_5 slags.
Liang Ngiab Co. Ltd. (Bangkok).	300	H	Dom	99.90	do	Do.
Total	49,400	NAp	NAp	NAp	NAp	NAp.
United Kingdom: Capper Pass & Son Ltd. (RTZ subsidiary) (North Ferriby, Hull).	18,000	M-L	Dom, imp, complexes, residues	99.80	Reverberatory smelting furnace, electric smelting furnace.	Pb, Cu, Ag, Bi.
				99.999	Concentrate and/or slag fuming.	Au, others.
U.S.A.: Gulf Chemical & Metallurgical Corp. (Texas City, TX).	8,000	M-L	Imp	99.80	Kaldo furnace (high-grade slags and residue), electrolytic refining (acid electrolytes), chloride volatilization.	
Zaire: Zairetain (Manono)	1,200	H	Cap	+99.50	Reverberatory smelting furnace, concentrate and/or slag fuming.	Ta_2O_5 slags(?).
Zimbabwe: Kamativi Smelting & Refining Co. (Bulawayo).	1,200	H	Cap	+99.50	Electric smelting furnace, rotary smelting furnace.	Do.
Total for market economy countries.	308,500	NAp	NAp	NAp	NAp	NAp.
China:						
Yunnan Tin Corp. (Gejiu, Kokiu Yunnan).	10,000	M	Dom	99.75	Reverberatory smelting furnace, concentrate and/or slag fuming.	As_2O_3, Pb, Sb, Cu.
Linchow Smelter (Liuchow, Guangxi).	2,000	M	Dom	[7]99.95	Do	Do.
Kwangchow Smelter (Guangdong Province).	1,000	M	Dom	[7]99.92	Electric smelting furnace, concentrate and/or slag fuming.	Do.
Ping Gui Smelter (Ping Gui, Guangxi).	1,000	M	Dom	[7]99.98	Do	Not known.
Limo Smelter (Guangxi Province).	400	L	Dom	([4])	Reverberatory smelting furnace, roast, Ta_2O_5.	WO_3, Co_2O_5.
Kanchow Smelter (Guangxi Province).	100	M	Dom	([4])	Reverberatory smelting furnace, Ta_2O_5.	None(?).
Hungyang Smelter (Hengyang Hunan).	100	M	Dom	([4])	Do	None(?).
German Democratic Republic: Huttenkombinat, Albert Funk (Freibert).	1,500-2,200	L	Dom, imp	99.00	Reverberatory smelting furnace, concentrate and/or slag fuming.	None.
U.S.S.R.: state tin enterprises (Novosibirsk, Ryozan, and Podol'sk).	47,000	M	Dom, imp, and slag residues.	9.915	Electric smelting furnace, concentrate and/or slag fuming, vacuum distallation, electrolytic refining.	Not known.
Total for centrally planned economy countries.	110,500	NAp	NAp	NAp	NAp	NAp.
Grand total, all countries.	419,000	NAp	NAp	NAp	NAp	NAp.

NAp Not applicable. (?) Indicates uncertain information.
[1] H—High-grade concentrates (>50 pct Sn), M—Medium-grade concentrates (25-50 pct Sn), L—Low-grade concentrates (25 pct Sn).
[2] Dom—Domestic sources of concentrates, Imp—Imported concentrates, Cap—Captive sources—own mines and concentrates.
[3] Processes used for production of refined tin metal.
[4] Tin alloys and solders only.
[5] Alloys also produced.
[6] Alloys only.
[7] Alloys and solders also produced.

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