Tin Resources of the World

GEOLOGICAL SURVEY BULLETIN 1301

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By C. L. SAINSBURY

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A description of the types of tin deposits and main tin-producing areas of the world. Reserves and resources are estimated to be sufficient for 87 years

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TIN RESOURCES OF THE WORLD

By C. L. Sainsbury

ABSTRACT

Lode deposits of tin, and commercial placers derived from them, almost invariably are associated with biotite or biotite-muscovite granite. Most lode deposits fall into one of two distinct types: (1) long, narrow belts of tin-bearing granites in a wider intrusive complex, or (2) diffuse belts of tin-bearing granites in extensive areas of Precambrian rocks. The most productive placer deposits of the world (Southeast Asia) are associated with a stanniferous region of type 1. At many places, extensive areas have fluctuated between marine and continental conditions because of oscillations of sea level during the Pleistocene, and productive placers have resulted from a complex interplay of stream and marine erosion and concentration, such as those in Southeast Asia, Brazil, and Western Australia. As a result, many economically important placers lie seaward of present shorelines.

Most tin is smelted from cassiterite (SnO_2) contained in placer concentrates, and many other valuable metal commodities are also recovered during the mining and concentration of tin. Lode deposits yield valuable amounts of tantalum, niobium, tungsten, copper, lead, zinc, silver, arsenic, and antimony; in the future, others may yield beryllium. Placer deposits yield valuable amounts of niobium, tantalum, and rare-earth minerals.

Tin reserves of the world, exclusive of the U.S.S.R. and China, at a price between $2,000 and $3,080 per long ton (2,240 pounds) of tin, are estimated to be at least 3,500,000 long tons in 1970; tin resources of lower grade are estimated to be at least 7,108,000 long tons. Reserves and resources of the U.S.S.R. and China together are estimated to be at least 2,130,000 and 4,260,000 long tons of tin, respectively.

Thus, world reserves are ample to satisfy demand at a yearly rate of production of 180,000 long tons of tin for about 31 years; resources should sustain production at a rate of 200,000 long tons per year for an additional 56 years.

INTRODUCTION

This report was prepared as a chapter on tin resources for inclusion in a U.S. Bureau of Mines Materials Survey on tin. Owing to a change in publication plans, however, the Materials Survey is not scheduled for publication in the near future. As this report presents data on reserves and resources of tin, data which change with time, the report is being presented now to retain the timeliness and applicability of the contained information.

Many of the tables of reserve data are from a report by M. A. Robertson (1965), prepared under the auspices of the International Tin Council; without Robertson's permission to use the data, preparation of the report would have been infinitely more difficult.

It is difficult to estimate the amount of tin that reasonably can be expected to be mined in the future. Factual data must be supplemented by subjective interpretation of factors such as geologic similarity of very large areas, unforeseen economic conditions, state of knowledge of known stanniferous areas, and availability and objectivity of published data, especially for the Iron Curtain countries. Resource figures represent multiplications involving factors and figures that are changeable, and they must be evaluated with this in mind. For those who would consider the presented estimates of potential resources as being unrealistically conservative, it is pointed out that the clarke (average crustal abundance) of tin probably exceeds 1 gram per metric ton. (See Borchert and Dybeck, 1959–60.) Thus, the earth, with a mass of about 5.976×10^{27} grams, should contain about 5.976×10^{15} metric tons of tin. Very little of this tin, however, is concentrated in amounts suitable for mining.

GEOLOGY

Tin, a useful metal of commerce since the bronze age, has long been sought and mined. Consequently, several major mining areas have been studied in three dimensions. Compared with that of many metals, the geology of tin deposits is relatively well known; and even though new producing areas are being found, the geology of each new district falls within that predicted from past experience as summarized in an early paper on the geology of tin deposits (Ferguson and Bateman, 1912).

Associated metals.—Most tin of commerce is smelted from concentrates that contain a high proportion of tin in cassiterite, many other valuable metals are recovered during the mining and concentration of tin ores. Lode deposits yield valuable amounts of tantalum, niobium, tungsten, copper, lead, zinc, silver, arsenic, and antimony; in the future, others may yield beryllium. Placer deposits yield notable amounts of niobium, tantalum, and rare-earth minerals.

Lode tin deposits of importance almost invariably are associated with biotite or biotite-muscovite granite or, as in Bolivia, with shallow-seated volcanic rocks such as quartz latite or dacite. The granites with associated tin deposits are generally referred to as tin granites. As a group, the tin deposits are probably the best example of epigenetic magmatic ore deposits. Most of the major lode areas of the world fall into one of two distinct types: (1) long, narrow belts of tin-bearing granites in a wider intrusive complex (Southeast Asia), or (2) more diffuse belts of younger granites in extensive areas of Precambrian rocks (Nigeria). Most of the major linear belts lie near continental margins or along major orogenic belts inland in which granite magma was generated (fig. 1). Some can be correlated with tectonism along segments of extensive transcurrent faults, which are the continuation under the continents of major fractures affecting subcrustal rocks of the ocean basins (Siberia). Thus, most tin deposits are localized along tectonic belts in which granite has been intruded; their ages range from Precambrian to Tertiary, but some workers (Pereira and Dixon, 1965) hold that statistical studies show that tin deposits are more common in younger rocks.

Lode tin deposits can be classified generally into six distinct types:[1]

1. Pegmatite deposits,
2. Pneumatolytic-hydrothermal deposits,
3. Subvolcanic or tin-silver deposits,
4. Disseminated deposits,
5. Contact-metamorphic deposits, and
6. Fumerole deposits.

Pegmatite deposits.—Tin-bearing pegmatites are generally associated with granitic rocks and contain cassiterite (SnO_2) as well as other uncommon, valuable minerals such as columbite-tantalite, beryl, or spodumene. Most productive pegmatites are in areas of deep tropical weathering, which allows the economic exploitation of pegmatites which contain less than 0.4 percent tin. Some pegmatites are very large, contain cassiterite throughout, and constitute major reserves of tin—for example, the Manono pegmatite in the Democratic Republic of the Congo, which is 10 kilometers long and 100–400 meters wide.

Pneumatolytic-hydrothermal deposits.—The bulk of the major lode tin deposits of the world (those of Bolivia excepted) are of this type.[2] Lodes are near or in biotite or two-mica granite and form replacement deposits or fissure fillings in diverse types of country rock. Owing to a regional zonation commonly displayed, deposits vary widely in mineralogy. In or near granite, lodes typically contain cassiterite in greisen (quartz-mica rock) or quartz-topaz-tourmaline rock that also contains wolframite and many base-metal sulfides. Farther from the granite, lodes may contain stannite (Cu_2FeSnS_4), base-metal sulfides, and silver; in some places, the deposit may be valued principally for the silver content. Some individual deposits are very large, such as the Dalcoath lode in Cornwall, England, which produced 80,000 tons of tin (Dines, 1956).

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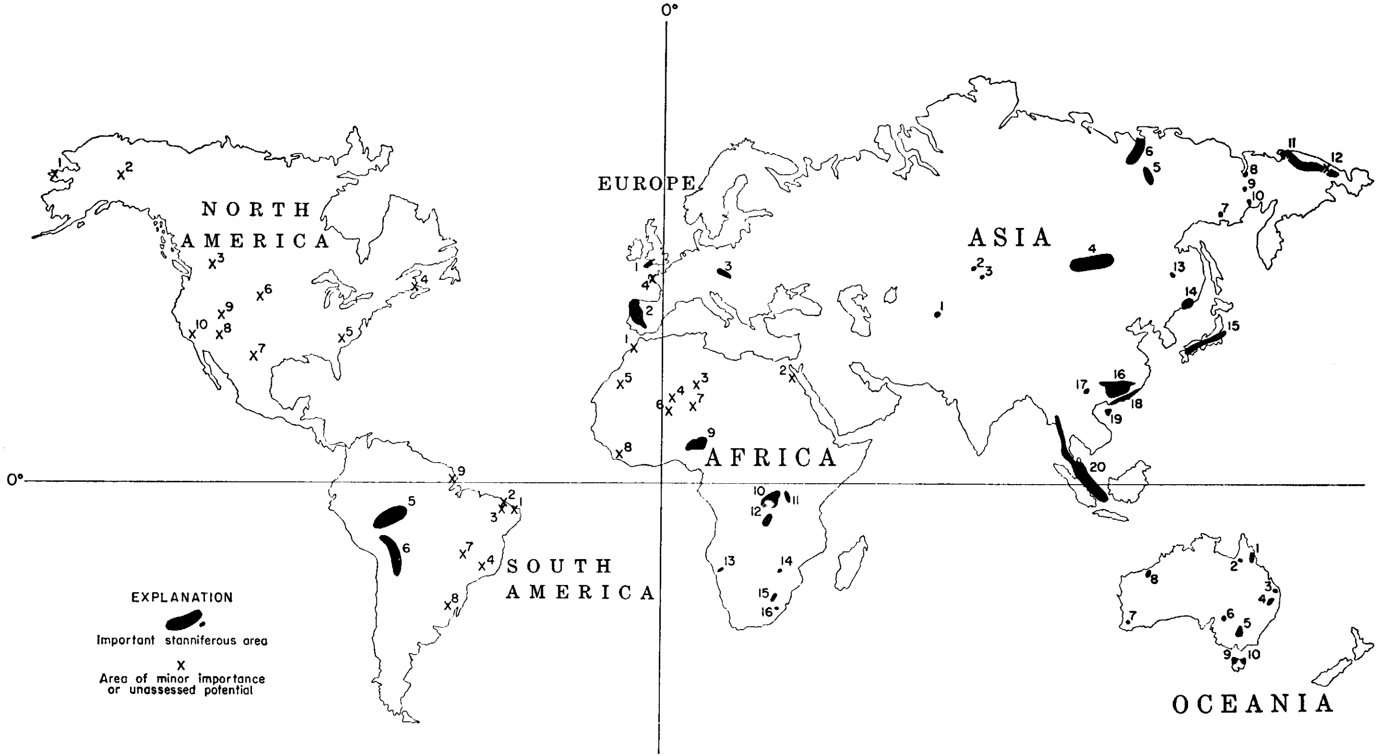
[1] This classification closely follows that of Ahlfeld (1958).

[2] This distinction of the Bolivian type of deposit from what may be called the Cornwall type may not be valid. The writer here is following most others, who consider them in separate categories.



TIN RESOURCES OF THE WORLD

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FIGURE 1.—Major stanniferous regions of the world.

NORTH AMERICA

1. Seward Peninsula, Alaska
2. Manley Hot Springs, Alaska
3. Sullivan mine, British Columbia, Canada
4. New Brunswick area, Canada
5. Southern Appalachian area
6. Black Hills area, South Dakota
7. Franklin Mountains, Tex.
8. Black Range district, New Mexico
9. Climax mine, Colorado
10. Gorman area, California

SOUTH AMERICA

1. Rio Grande do Norte-Paraíba, Brazil
2. Northeast Ceará, Brazil
3. Central Ceará, Brazil
4. Eastern Minas Gerais, Brazil
5. Rondônia-Tapajos, Brazil
6. Tin belt, Bolivia
7. Ipameri, Goiás, Brazil
8. Encruzilhalda, Brazil
9. Amapá area, Brazil

EUROPE

1. Cornwall, England
2. Portugal and Spain
3. Erzgebirge, German Democratic Republic (East Germany) and Czechoslovakia
4. France

AFRICA

1. El Karit area, Morocco
2. Igla, Nuweibeh Abu, and Dabbab el Mueilha areas, United Arab Republic (Egypt)
3. Djilouet area, Algeria
4. Tamanrasset area, Algeria
5. Bïr Oumgreine area, Mauritania
6. Iforas area, Mali
7. Aïr district, Niger
8. Tawalafa area, Sierra Leone
9. Jos Plateau, Nigeria
10. Maniema area, tin belt, Democratic Republic of the Congo
11. Rwanda, Burundi, Uganda, and Tanganyika (Tanzania)
12. Manono-Kitololo mines, Katanga, Democratic Republic of the Congo
13. South-West Africa
14. Southern Rhodesia and Nyasaland
15. Rooiberg-Leeuwport area, Republic of South Africa
16. Warmbad area, Republic of South Africa

AUSTRALIA

1. Herberton-Cooktown area
2. Croydon area
3. Stanthorpe-Ballandean district
4. New England district
5. Mount Tallenburg–Albury–Eldorado belt
6. Barrier Range
7. Southwest Western Australia
8. Northwest Western Australia
9. Northwest Tasmania
10. Northeast Tasmania

ASIA

1–14. Siberia, U.S.S.R.
   1. Altai Mountains
   2. Naryn, Kazakstan area
   3. Kalba, East Kazakstan
   4. Transbaikal (Zabaykal'ye) area
   5. Yana-Adycha area
   6. Ege-Khaya-Deputatskiy region
   7. Ust'-Omchug, Batugychag area
   8. Bilibina area
   9. Kolyma area
   10. Galimyy area
   11. Krasnoarmeyskoye area
   12. Iul'tin area
   13. Khingansk area
   14. Lifudzin-Khrustal'nyy area

15. Honshū Island, Japan
16. Kwangsi-Kwangtung-Hunan Provinces, China
17. Kochiu area, China
18. Coastal zone, China
19. Hainan Island, China
20. Malay Peninsula

Subvolcanic or tin-silver deposits.—This type is exemplified by the mineralogically complex and very rich deposits of Bolivia, where bonanza tin lodes also contain large amounts of silver. Deposition in a near-surface environment led to strong telescoping of the deposits and to mineralogical complexity, which creates a problem in the recovery of tin. Rare tin-bearing minerals, such as teallite ($PbSnS_2$), herzenbergite (SnS), cylindrite ($Pb_3Sn_4Sb_2S_{14}$), and canfieldite (Ag_8SnS_6), are common in these deposits. Individual mines in such deposits have produced enormous amounts of tin; one mine at Llallagua, Bolivia, produced over 500,000 tons (Ahlfeld, 1936).

Disseminated deposits.—In these deposits, cassiterite in small amounts is disseminated widely in altered granite, especially in border zones or parts changed by addition of tourmaline, topaz, or fluorite. Although only a few disseminated deposits are presently worked commerically, erosion of such lodes (particularly border zones of granites) has resulted in large and rich placer deposits (Southeast Asia and elsewhere).

Contact-metamorphic deposits.—Such deposits are relatively uncommon and generally consist of cassiterite or malayaite ($CaSnSiO_5$) in tactites near granite (Cornwall). The minerals customarily associated are magnetite, garnet, pyroxene, fluorite, tourmaline, various sulfide minerals, and, in the Lost River area, Alaska, beryllium minerals (Sainsbury, 1964a). The grade is generally less than 0.5 percent tin, but large tonnages and potential byproduct recovery of base metals, beryllium, and fluorite may give added importance to such deposits when other tin supplies dwindle.

Fumarole deposits.—This term was used by Ahlfeld (1958) to describe small but widespread deposits that form fracture fillings in Tertiary lavas. The fracture fillings contain cassiterite generally intergrown with specular hematite, and minute grains of cassiterite are distributed in kaolinized wallrock along veins. A few deposits are mined commercially, on a small scale. Placers derived from the erosion of such veins are mined in Mexico, New Mexico, and Argentina.

Worldwide, placer deposits are more productive and more cheaply mined than lode deposits; they furnish, therefore, the bulk of commercial production. Cassiterite, the main tin mineral of commerce, is both heavy and chemically resistant; consequently, it forms large placers or residual concentrations. Placers can be conveniently classed as residual, eluvial (slope), alluvial (stream), marine, and fossil placers.

Residual placers form in place over a bedrock source of cassiterite by the chemical decay and removal of the rock minerals. At places such as Kitololo in the Democratic Republic of the Congo, residual placers grade downward into weathered lodes and are mined either as placers or as open-pit lodes. In a truly residual placer, the enriched zone contains not only heavy minerals such as cassiterite and columbite-tantalite but also chemically resistant light minerals such as beryl. In Indonesia, residual placers commonly are cemented tightly by hydrous iron oxides, forming the "kaksa" of industry, which must be crushed to free the cassiterite.

Eluvial placers are formed by the chemical decay of tin-bearing rocks and the gravity separation of cassiterite and other heavy resistates as the decayed mantle moves downslope under the influence of sheetwash, gravity, and, locally, frost action. Such placers grade imperceptibly into residual placers upslope, and often into alluvial (stream) placers downslope. Because of active gravity sorting, eluvial placers may be richer than residual placers; often, however, they contain coarse rubble, and, in cold regions (Alaska and Siberia), fragments of unoxidized deleterious constituents such as arsenopyrite.

Alluvial placers, by far the largest and richest placers, furnish most commercial tin. In 1964, almost 60 percent of the world's tin production came from alluvial placers in Southeast Asia (Shelton, 1965). Other major producing placer areas are in Nigeria and in the newly developed tin fields in the Territory of Rondônia Brazil (Brazil Div. Fomento Prod. Mineral, 1964). Alluvial placers occupy both modern and fossil stream beds, and the distribution of tin is dependent upon the location of the source areas and the hydraulics of running water. The best placers form near lodes in sections of streams where the velocity is sufficient to result in good gravity separation but not so swift that the channel is swept clean. A type of location proven especially favorable for placer tin is a long stream that flows parallel to the margin of a tin-bearing granite.

In Southeast Asia, stream placers formed seaward of present shorelines when sea level was eustatically lowered periodically during the Pleistocene. These stream placers now lie beneath sea water; they are mined by seagoing dredges. In Rondônia, Brazil, some placers now lie in areas so low that sea water covered them during certain interglaciations when sea level stood much higher than at present. Elsewhere in the world, as in Cornwall and Tasmania, both lode and placer deposits occur within areas which have fluctuated between land and sea bottom during Pleistocene climatic changes; placers in such areas may have characteristics of both marine and alluvial deposits.

Owing to the long exposure to air and water and to good gravity separation, tin concentrates produced from alluvial placers are relatively free of deleterious constituents and may contain as much as 70 percent tin; as such, they constitute prime smelter concentrates.

Marine placers are for the most part beach placers or inundated beach placers. They form where a marine shoreline intersects or transgresses either a stream valley containing alluvial cassiterite or a bedrock source of tin. Although a true beach placer normally has a large length-to-width ratio, a placer of transgressive origin may consist of a sheet of heavy minerals buried beneath marine sediments (Australia). Placers of this type have yielded large amounts of cassiterite in Indonesia (Bangka and Billiton Islands) and will continue to do so.

Any or all of the preceding four types of placers may become fossil placers by burial beneath younger sediments or lava. Uplift and renewed erosion along disrupted drainages may expose such placers irregularly, and second-cycle alluvial placers may be generated (Nigeria). Depending in part on the age of a fossil placer, the gravels may be lithified to such an extent that they must be mined by lode-mining methods. In others, major postdepositional changes such as partial solution of cassiterite, may affect the value.

WORLD RESERVES

The International Tin Council assembled information on tin reserves and published a report by W. A. Robertson (1965) that gives detailed information on tin reserves of the world. The factual basis of the report was a questionnaire sent to all the leading noncommunist tin-producing countries, most of which responded with official projected reserve estimates for the years 1965 and 1970, based upon three price levels adjusted to a common index. Table 1, used by permission from Robertson's report, shows the status of world reserves by major producing areas, and although small modifications of this table are shown later in the present report, especially for Brazil and Canada, no great change in the reserve estimates can be made. The probable magnitude of submarginal and undiscovered resources,[3] as estimated by the writer, are given in table 2.

The reserves of China, Russia, and other Communist countries cannot be assessed from available data. Even the International Tin Council does not attempt a tabular summary. For this report, the writer has assembled table 3, which cannot be considered more than an educated guess based upon the parameters stated later in this report.

[3] The term "reserves," with only minor exceptions, refers to tin in deposits which are minable under present conditions at the price levels given. As used in this report, "resources" refers to tin in deposits not currently minable because of diverse factors such as low price, low grade, land-use problems, and beneficiation problems. "Undiscovered resources" refers to tin in deposits not yet discovered, but which are assumed to exist because of probable favorable geology in unexplored areas.

TABLE 1.—*Tin reserves of noncommunist countries, excluding the United States*

[Estimated total reserves, in long tons, of tin-in-concentrates; from Robertson (1965, p. 90)]

Year	1960	1965			1970		
Price, long ton tin		At $1,960 (£700)	At $2,520 (£900)	At $1,080 (£1,100)	At $1,960 (£700)	At $2,520 (£900)	At $3,080 (£1,100)
Bolivia	[1] 737,000	------------	514,000	514,000	------------	485,000	485,000
Nigeria	100,000	44,000	105,000	110,000	32,000	48,000	86,000
Democratic Republic of the Congo [2]	203,000	15,000	158,000	190,000	3,000	136,000	155,000
Thailand [3]	1,000,000	1,089,000	----------	1,500,000	1,010,000	----------	1,402,000
Malaysia [4]	[1,000,000]	900,000 (no price)			600,000 (no price)		
Indonesia [5]	558,000	650,000 (no price)			550,000 (no price)		
Australia	47,000	3,000	68,000	83,000	2,000	67,000	81,000
United Kingdom	47,000	------------	41,000	42,000	------------	18,000	37,000
Others [6]	102,000	30,000	62,000	65,000	25,000	56,000	65,000
Total	3,800,000	(approximately 4,000,000)			(approximately 3,500,000)		

[1] 1961.
[2] Democratic Republic of the Congo: $2,800 (£1,000) in 1965 and 1970.
[3] Thailand: Excluding measured reserves of dredging companies. Measured reserves, excluding offshore deposits, are in the order of 40,000–60,000 long tons of metallic tin (Robertson, 1965, p. 87).
[4] Malaysia: 1963, 1,000,000 tons, reported reserves; 1965 and 1970, our estimates, allowing for production in intervening years. Reserves of 1,000,000 tons used for 1960 column.
[5] Indonesia: 1970, our estimate, allowing for production in intervening years.
[6] Others: No figures for Mexico or Korea for 1965 and 1970. Countries included are Canada, France, Japan, Korea, Portugal, Republic of South Africa, Tanganyika (Tanzania). No allowance is made for Burma, Brazil, Argentina, Spain, Rwanda, Laos, Northern and Southern Rhodesia, and other parts of Africa. Reserves in Burma were put at 300,000 tons of tin metal in 1952 according to the Paley Commission. [These figures do not include recent estimates of Brazilian reserves. If the reserves estimated in the present report are included (see section on "Brazil"), these figures, particularly for the 1970 date, would be larger by several hundred thousand long tons of tin metal.]

TABLE 2.—*Tin resources of the world, exclusive of the U.S.S.R. and China*

[As used in this report, "resources" refers to tin in deposits not currently minable because of factors such as low price, low grade, and beneficiation problems. Estimates by C. L. Sainsbury]

	Thousands of long tons
North America:	
United States	43
Canada	40
Mexico	5
Total	88
South America:	
Bolivia	1,000
Brazil	1,074
Argentina	7
Total	2,081
Europe:	
England	94
Portugal and Spain	150
France	4
German Democratic Republic (East Germany) and Czechoslovakia	50
Total	298
Asia:	
Indonesia	540
Malaysia	1,000
Thailand	1,120
Burma	250
Vietnam and Laos	75
Japan	16
Total	3,001
Africa:	
Nigeria	138
Democratic Republic of the Congo	1,000
Republic of South Africa	22
South-West Africa	100
Southern Rhodesia	60
Rwanda, Burundi, Uganda, and Tanganyika (Tanzania)	20
Other areas in Africa	50
Total	1,390
Oceania:	
Australia and New Zealand	250
Grand total	[1] 7,108

[1] This obviously cannot represent the total tin that will be available eventually to industry. As geologic knowledge increases, and as price rises, new sources of tin will become classifiable as resources.

The figures in tables 1, 2, and 3 show that world reserves of tin are ample to satisfy world needs at a projected consumption rate of 180,000 tons per year for at least 31 years, and that resources are at least capable of sustaining production for another 56 years at a rate of 200,000 tons per year. Furthermore, if a critical shortage develops over a long term, new sources should become available, such as tin from malayaite, a tin silicate.

TABLE 3.—*Estimated tin reserves and resources of the U.S.S.R. and China*

[In thousands of long tons; estimates by C. L. Sainsbury for this report]

	Measured plus indicated	*Inferred*	*Submarginal resources*
U.S.S.R.	210	420	1, 260
China	*500*	*1, 000*	*3, 000*
Total	710	1, 420	[1] 4, 260

[1] This obviously cannot represent the total tin that will be available eventually to industry. As geologic knowledge increases, and as price rises, new sources of tin will become classifiable as resources.

NORTH AMERICA

UNITED STATES

Since the date of the last comprehensive report on tin prepared by the Pennsylvania State University (Ridge, 1953), continued work by government and industry has increased the domestic reserves of tin by several hundred percent; nevertheless, the United States remains critically short of tin. Additional reserves were generated in the long-known tin district of the western Seward Peninsula, Alaska, principally at the Lost River lode mine, and at Cape Creek, where a deep alluvial deposit was found by a private company supported by a U.S. Government loan.[4] Additional diamond drilling at the Lost River mine by a large United States company has confirmed the existence of additional marginal resources. Recent geologic mapping by the U.S. Geological Survey resulted in the discovery of large deposits of beryllium in fluorite in the tin district (Sainsbury, 1963), and of additional tin-bearing veins at Black Mountain which have not been assessed. Elsewhere in the United States, more information was obtained on placer tin deposits at Tozimoran Creek, central Alaska, and at Gorman, Calif., where tin is presently being produced in small amounts, but no large expansion of reserves is reported, The tin reserves and resources of the United States are estimated in table 4.

[4] This deposit is being mined (1968) and is proving to be richer than drilling had indicated.

TABLE 4.—*Reserves and resources of tin in the United States*

[In long tons of tin metal]

	Measured and indicated	Inferred
Lode deposits:		
Reserves	3, 035	3, 000
Resources	2, 700	[1] 36, 000
Total	5, 735	39, 000
Placer deposits:		
Reserves	2, 600	-------
Resources	100	[2] 4, 100
Total	2, 700	4, 100
Grand total	8, 435	43, 100

[1] Includes 10,000 long tons of tin in pegmatites of the Appalachian tin district which contain about 0.025 percent tin; this tin will be recovered only as a byproduct from the mining of other minerals, such as spodumene.
[2] Includes inferred known resources of 1,400 long tons, and unknown resources estimated to equal all known and inferred reserves and resources.

ALASKA

The Alaskan tin deposits form a belt that extends eastward across central Alaska from the Bering Strait, but the only important known deposits are on the Seward Peninsula. The geology of the Seward Peninsula deposits was first described by Knopf (1908). More recent information on the geology and on recent work at the Lost River mine was presented by Sainsbury (1964b) and by Lorain, Wells, Mehelich, Mulligan, Thorne, and Herdlick (1958). A comprehensive report on the lode area near Lost River gives up-to-date information on the structure and stratigraphy of the York Mountains (Sainsbury, 1969).

The main lode deposit at Lost River consists of cassiterite and wolframite associated with numerous base-metal sulfides in quartz-topaz greisen. The main ore shoot lies along a greisenized rhyolite porphyry dike; the shoot is confined to a zone some 500 feet in vertical extent above a buried biotite granite. Smaller, submarginal deposits are known along several altered dikes and in a conelike mass of altered limestone, know as the Cupola area, above the buried granite. Other lode deposits on the western Seward Peninsula are much smaller, but are mineralogically similar.

The known placer deposits are small; the largest one at Buck Creek on the Seward Peninsula yielded several hundred tons of tin between 1940 and 1959. The deep placer at Cape Creek on the Seward Peninsula is currently (1968) being mined. Investigations of placer deposits by the U.S. Bureau of Mines (Mulligan, 1959a, b; Mulligan and Thorne, 1959) have confirmed the absence of economic placers in the main streams near some other tin-bearing granites on the western Seward Peninsula. The absence of placers can be attributed to glacial scouring during a widespread glaciation of Wisconsin age that extended far beyond the limits previously assigned (Sainsbury, 1967).

New information on tin placers at Manley Hot Springs and elsewhere in interior Alaska has been released (Wayland, 1961; Chapman and others, 1963). A large American company currently is investigating the tin belt of Alaska.

CONTERMINOUS UNITED STATES

Small amounts of tin have been produced from distinctly different types of deposits in several widely spaced areas: (1) the southern Appalachians; (2) Black Hills area, South Dakota; (3) New Mexico; (4) Gorman area, California; and as a minor byproduct at the Climax mine, Colorado.

The Appalachian tin deposits lie in a linear belt along the east flank of the mountains from central Alabama to west-central Virginia. Two main types of deposits are clearly recognized: quartz veins or quartz-pegmatite veins, and greisen veins. In the pegmatites, cassiterite occurs in small amounts associated with minor beryl and columbite-tantalite, and much spodumene. Many of the greisens (quartz-mica or quartz-mica-topaz rock) occur as bands along the walls of quartz veins; in addition to cassiterite, the greisens contain sulfide minerals. Most of the deposits are small, and those that have yielded the few hundred tons of metallic tin produced to date contain from about 0.5 to about 1.5 percent tin. A few small placers are associated with outcropping lodes; some placers contain 12–75 pounds of tin per cubic yard. No systematic evaluation of the placers has been made. Some are of economic grade but may not be currently minable because of factors such as unavailability of water and problems of tailings disposal.

Tin deposits of the Black Hills occur principally as cassiterite-bearing pegmatites, some of which were mined on a small scale. Not all pegmatites contain tin; those that do may contain variable amounts of one or more of the following economically useful minerals: Columbite, beryl, spodumene, and albite. Most of the richer pegmatites contain less than 1 percent tin in the ore shoots. Reserves amount to less than a thousand tons of metallic tin.

Small tin deposits confined to rhyolitic lavas of Tertiary age are widespread in New Mexico, especially in Catron and Sierra Counties. The tin lodes consist of cassiterite and specular hematite in small discontinuous veins that are bordered by kaolinized rock which contains fine-grained cassiterite. Where streams eroded lode deposits, small placers were formed; these placers are mined on a small scale—total production is less than a hundred tons of tin metal. In the Petaca district, trace amounts to small amounts of cassiterite occur in pegmatites that are valued chiefly for their mica content.

In California, the principal tin deposits, all small, occur in veins in granitic rocks or in contact-metamorphic zones nearby. A small production has come from the Gormani, Temescal, and Cima districts, and small deposits have been explored elsewhere, within the State.

Elsewhere in the United States are diverse groups of deposits each containing a sufficient number of prospects to be of economic interest; these groups are principally in eastern Washington, the New England States, Colorado, Nevada, Montana, Missouri, Texas, and Idaho (mostly placers).

CANADA

Discovery of tin-bearing greisens in New Brunswick, Canada (Hosking, 1963), has increased known Canadian reserves of tin. The deposits at Mount Pleasant, New Brunswick, consist of cassiterite associated with base-metal sulfide minerals near or in altered silicic dikes (Petruk, 1964). Ore minerals occur in altered dikes along two main kaolinized zones, and in quartz-topaz greisen around the borders of a siliceous "core." The Mining Journal (1963) announced that proven reserves were calculated at 2,630,000 short tons of ore averaging 0.59 percent tin, 2.0 percent zinc, 0.36 percent lead, and 0.30 percent copper. Thus, known reserves of tin amount to about 14,000 long tons, and exploration is continuing.

For many years byproduct cassiterite has been produced from the Sullivan mine in British Columbia, where it is a minor constituent of lead-zinc ores. Yearly production amounts to a few hundred tons of tin; and although lead-zinc reserves are sufficient to last for many years, total tin reserves are nominal. Other occurrences of tin in Canada are summarized by Mulligan (1966); none are large. For this report, all Canadian reserves are assumed to total some 20,000 long tons of tin. Submarginal and undiscovered resources are estimated at twice this figure, or 40,000 long tons of tin.

MEXICO

Mexico produces a few hundred tons per year of tin-in-concentrate derived from small-scale placer mines and lodes. The placers are derived from lodes which consist of encrustations of cassiterite and specularite along small fractures in Tertiary rhyolite lavas, similar to the small vein deposits in New Mexico. In addition, several thousand tons of tin was produced from the San Antonio mine, which was also worked for lead, zinc, and silver. Cassiterite also occurs in altered porphyritic granite near Guadalcazar, 60 miles northeast of the city of

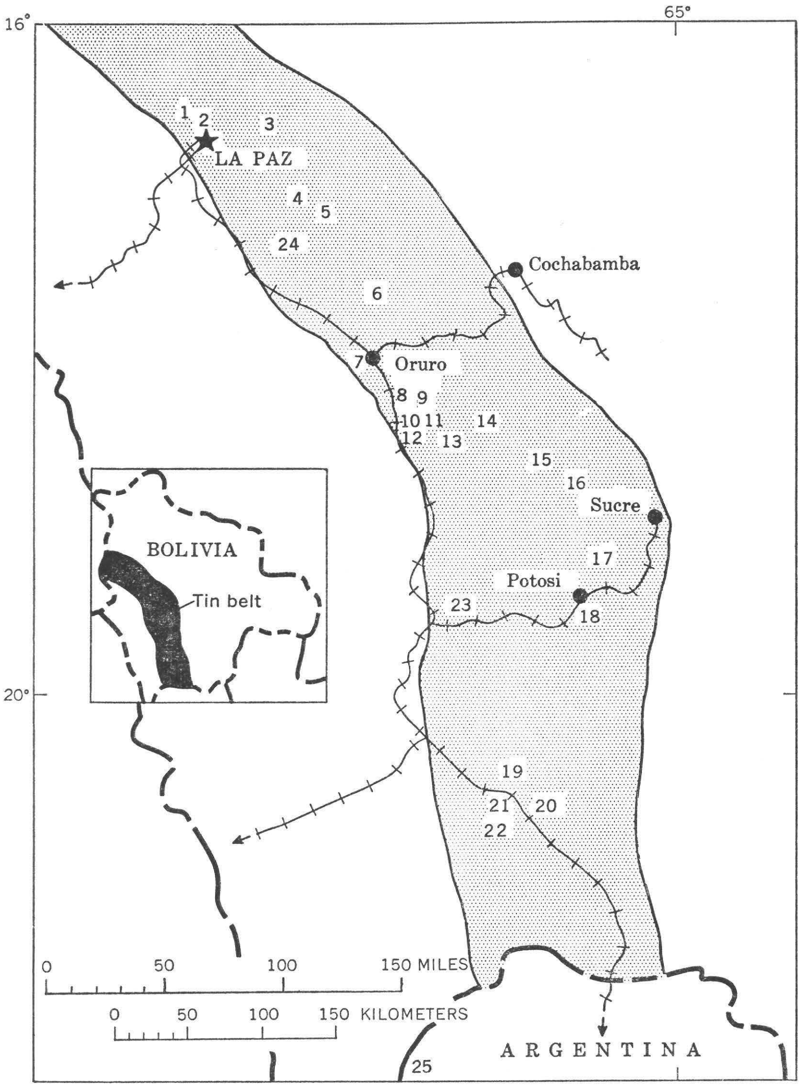
San Luis Potosi, State of San Luis Potosi (Foshag and Fries, 1942); the altered granite also contains tourmaline, topaz, molybdenite, and many other minerals found in greisen tin deposits. No known deposits in Mexico are of sufficient size or richness to allow notable expansion of the long-established but small tin-mining industry. In this report, proven reserves are estimated at not more than 1,000 long tons of tin, and submarginal and undiscovered resources, at five times this amount, or 5,000 long tons.

SOUTH AMERICA

BOLIVIA

The bulk of the lode tin of commerce comes from Bolivian mines, which produced about 19 percent of the world's tin output in 1964. The lodes lie in a belt coextensive with the Cordillera Real, or eastern Andes; the lodes extend from Peru through Bolivia to Argentina, a distance of 500 miles. The deposits, classed as the subvolcanic type, are characterized by close association with Tertiary volcanic rock and older stocks of biotite granite, dacite, and quartz monzonite. Although cassiterite is the main ore mineral, many tin-bearing sulfide minerals and large amounts of silver are associated with it. The mineralogical and textural complexity of the deposits prevents preparation of high-grade concentrates and hinders the recovery of tin. In the northern part of the region, erosion has exposed the subjacent granite stocks, whereas in the south the stocks are not yet exposed. This relationship apparently has resulted in exposure of different zones of ore deposition and, therefore, of different mineral suites. Schneider-Şcherbina (1964) postulated that the complexity of ores is partly caused by the superposition of a younger (Tertiary) silver-rich suite of sulfide minerals on an earlier (Mesozoic) mineral assemblage containing cassiterite.

Figure 2 shows the location of the more important tin deposits in Bolivia; only the large deposits are discussed here. The great mine at Llallagua (No. 13, fig. 2), which has produced over 500,000 tons of tin (Ahlfeld, 1936), is developed on a network of veins that generally strike N. 20° E. and dip steeply. The veins are localized in and near a stock of quartz porphyry which has intruded graywacke, sandstone, and shale. The quartz porphyry is funnel shaped, contracting at depth, and some veins that are restricted to the quartz porphyry on the surface pass out of it at depth. Most of the veins are fracture fillings which consist of cassiterite, quartz, and many sulfide minerals, including bismuthinite, pyrite, pyrrhotite, sphalerite, galena, wurtzite, stannite, tetrahedrite, marcasite, and franckeite. Wolframite locally is abundant and is recovered. Apatite, as well as other phosphates else-



Principal tin mines

1. La Fabulosa
2. Milluni
3. Chojila
4. Araca
5. Caracoles
6. Colquiri
7. Oruro
8. Morococala
9. Santa Fe
10. Huanuni placer
11. Huanuni mine
12. Monserrat
13. Llallagua-Uncia
14. Vila Apacheta
15. Colquechaca
16. Ocuri
17. Colavi
18. Potosí
19. Tasna
20. Chorolque
21. Oploca-Siete Suyos } Chocaya
22. Animas } Chocaya
23. Carguaicallo
24. Monte Blanco
25. Pirquitas (Argentina)

FIGURE 2.—Main tin deposits of Bolivia.

where rare, is abundant in some veins; siderite and rhodochrosite are the major gangue minerals. At the Uncia mine, within the Llallagua district, very rich veins contained as much as 6 percent tin. Very large reserves of low-grade ore are known; these deposits consist chiefly of mineralized shear zones and poorly mineralized areas of quartz porphyry between major veins.

Tin ores in pegmatites are mined at La Fabulosa mine, north of La Paz. The pegmatites are associated with granite and contain cassiterite as the main ore mineral, accompanied by molybdenite, chalcopyrite, ferroan sphalerite, arsenopyrite, pyrrhotite, and stannite. The tin content of the pegmatites is about 1 percent, increasing slightly where stannite is abundant.

Tin-silver ores are mined at Oruro, Potosí, Colquechaca, and Chocaya. At Oruro, veins striking northwest are associated with three dacite stocks intruded into fine-grained pelitic rocks. The veins are fissure fillings in the dacite stock, in explosion breccias associated with the stocks, and in the surrounding pelitic rocks. Vein material consists of quartz, cassiterite, pyrite, freibergite, andorite, sphalerite, lead-antimony sulfosalts, and, in the latest phase, galena, franckeite, alunite, and dickite. The mine also has millions of tons of low-grade ore that contains 0.2–0.4 percent tin.

The mines at Potosí were originally worked for silver, but today they produce principally tin ores. A funnel-shaped dacite stock, narrowing at depth, has intruded sandstone, shale, conglomerate, and, near the surface, tuffs. An en echelon vein system extends to a depth of 1,100 meters and passes out of the stock at depth. The veins are strongly zoned; in the upper part they contain complex tin and silver minerals, in the center only tin minerals, and at depth cassiterite, wolframite, and bismuthinite.

South of Potosí, Bolivia, the tin belt dies out rapidly, and the southern end contains only a few major districts (Tasna, Chorolque, Oploca–Siete Suyos, Animas). However, the richest tin vein in Bolivia, which contained nearly 6 percent tin, was worked at the Oploca–Siete Suyos mine. The deposits, vein fillings and impregnations associated with volcanic rocks, contain cassiterite and sulfides of tin, bismuth, antimony, and silver. For more complete discussions of the tin deposits of Bolivia, see Ridge (1953) and Turneaure and Welker (1947).

In spite of the abundance and richness of lode deposits in Bolivia, only a small amount of tin has been produced from associated placers, partly because of lack of active chemical decay in the high altitudes at which the tin veins occur. At Huanuni, a placer mine contained unweathered lode material that was separated, crushed, and treated in a typical lode mill (Ferron, 1941). Unquestionably, large reserves of tin will be found in Bolivia in placer deposits, many of which may be covered by young volcanic rocks.

The tin reserves of Bolivia are summarized in table 5, which is modified from Robertson's report (1965). It is assumed for this report that submarginal and undiscovered lode and placer deposits contain at least twice as much tin as the known reserves at the $3,080 figure, or about 1 million long tons.

TABLE 5.—*Estimated tin reserves of Bolivia*

[In thousands of long tons. Data from Robertson (1965, p. 81). Expressed in terms of the tin content of concentrates prepared by Bolivian concentrating plants]

Year	1965		1970	
Price, long ton of tin	At $2,520 (£900)	At $3,080 (£1,100)	At $2,520 (£900)	At $3,080 (£1,100)
Measured (=positive and probable):				
Lode	361	361	325	325
Indicated (=possible):				
Lode	96	96	160	160
Tailings and dumps	20	20	----------	----------
Other	36	36	----------	----------
Total	152	152	160	160
Grand total	513	513	485	485

ARGENTINA

The southernmost tip of the Bolivian tin belt crosses the border into Argentina, where a single mine (Pirquitas, No. 25, fig. 2) has produced tin from a lode system and associated placers. Yearly production never exceeded a few hundred tons of tin. The mine is developed on several veins in metamorphosed shale and sandstone. The most important vein was about 3 feet wide and contained 3.5 percent tin. The vein minerals include quartz, cassiterite, pyrite, sphalerite, galena, proustite, stannite, pyrargyrite, polybasite, andorite, and marcasite.

Near the Bolivian border, at Cerro Pululus, and farther south at Pairique Grande, cassiterite is intergrown with specularite in veinlets in rhyolite, occurrences similar to those in Mexico and New Mexico. Southwest of Catamarca, province of Catamarca, cassiterite occurs in greisen zones in granite, in a region that contains many tungsten deposits (Ahlfeld, 1958, p. 46).

For this report, measured and indicated ore reserves are assumed to equal 10 years' production at the 1965 rate of 343 long tons, or 3,430 long tons of tin. Undiscovered resources are assumed to be at least twice the known reserves, or 7,000 long tons.

BRAZIL

Production of tin in Brazil, which has recently increased notably, reflecting production from the new tin district in the Territory of Rondônia, reached 1,556 long tons in 1960 (Robertson, 1965, p. 68). Although Brazilian production may not become important in relation to world production in the near future, the reserves in the new district most certainly are important. Producing areas of Brazil are shown in figure 1.

In eastern Brazil, State of Rio Grande do Norte, cassiterite is a constituent of Paleozoic(?) pegmatites that also contain beryl, amblygonite, and columbite-tantalite enclosed in rocks of Precambrian age. Placer deposits of cassiterite occur in eastern Minas Gerais, and a cassiterite-bearing pegmatitic-muscovite granite is mined there at the Nazareno mine. The cassiterite is accompanied by tantalite and microlite.

The Ipameri deposit, in the State of Goiás, is a folded vein that contains cassiterite associated with sulfide minerals. The vein occurs in greisenized schist; granite may occur at depth. The vein contains an ecomonically important amount of tin.

The placer deposits of Amapá, which contain cassiterite derived from tin bearing pegmatites, supported a small tin smelter for several years. Reserves are now small.

The new tin district in the Territory of Rondônia is large, covering a known area of some 60,000 square miles (fig. 1) in the drainage basin of the Rio Madeira (Kloosterman, 1967). Many stocks of biotite granite are intruded into the older Precambrian and lower Paleozoic rocks; many are crudely alined north-south. The tin deposits consist of lodes in the granites and of many associated placers. For the most part, the known lodes consist of cassiterite locally associated with wolframite in topaz greisen in granite. Fluorite locally is abundant, and many lodes are localized in argillized granite. Eluvial and alluvial placers are rich; some contain several pounds of cassiterite per cubic yard. New districts are being discovered yearly, and reserves are very large. Kloosterman (1967) points out that the area contains some ring complexes and other features similar to those of the tin-producing area of Nigeria.

The other deposits of Brazil shown in figure 1 are mostly small and of little economic worth. Those of Ceará are principally tin-bearing pegmatites with a very small production of tin.

The total tin reserves of Brazil, estimated for this report by Pieter Van Leeuwen, an industry geologist familiar with many of the tin deposits in Brazil, are given in table 6.

TABLE 6.—*Tin reserves of Brazil, by area*

[In thousands of long tons of cassiterite containing 65 percent tin; not differentiated by class. Estimates by Pieter Van Leeuwen]

	At 1966 price	*At twice the 1966 price*
Rondônia:		
Productive mines	88.2	543
Nonproductive mines	50	250
Tapajos	10	30
Ipameri [1]	.8	1.4
San João del Rei (eastern Minas Gerais)	1	1.9
Total, cassiterite	150	826
Total, metallic tin	97.5	537

[1] Conservative estimate.

NOTE.—For purposes of this report, tin resources in submarginal and undiscovered deposits are considered to equal at least twice the known reserves of the larger figure above, or 1,074,000 long tons of tin. This is probably a conservative estimate, possibly by a factor of 2 or 3.

EUROPE

ENGLAND

The mines of Cornwall, which during their mining history produced more than 2 million tons of tin, are now largely exhausted. In 1860, some 300 mines were active and employed 100,000 workers (Ahlfeld, 1958, p. 82). In 1964, only two mines were operating (Robertson, 1965, p. 71). Many fundamentals of mining geology were learned in Cornwall, where extensive underground mining gave three-dimensional exposures throughout the entire district. Here, the concept of zoning in lode deposits was developed and tested and became a fundamental geologic tool. Because many other deposits of cassiterite in greisen resemble the Cornwall deposits, the zoning in Cornwall, as originally established by Dewey (1925), is shown in figure 3.

The numerous lode deposits are related to several outcropping stocks of biotite granite and occur in granite and in the surrounding pelitic rocks, which are converted to hornfels near the granites. Cassiterite is the main ore mineral and is accompanied by quartz, tourmaline, topaz, arsenopyrite, wolframite, chalcopyrite, galena, sphalerite, and, locally, sulfosalts. Owing to the zoning, some mines produced principally copper ores; others lead-zinc ores; and others tin, wolframite, and minor sulfide ores. The Dalcoath mine, one of the most productive lode tin mines of the world, was worked to a depth exceeding 3,000 feet; the veins extended 1,500 feet into the granite. The Dalcoath mine produced 80,000 tons of tin and 350,000 tons of copper. Dines (1956) presented a detailed description of the mines of Cornwall. For a recent discussion of the geology of the lode deposits of Cornwall and Devon, as well as geologic problems yet unsolved, see Hosking (1964).

The tin reserves of Cornwall (Robertson, 1965, p. 88) are given as 47,000 long tons (inferred) in 1960. Deep exploration will increase these reserves, perhaps by an order of magnitude. For this report, it is assumed that submarginal and undiscovered deposits contain twice the

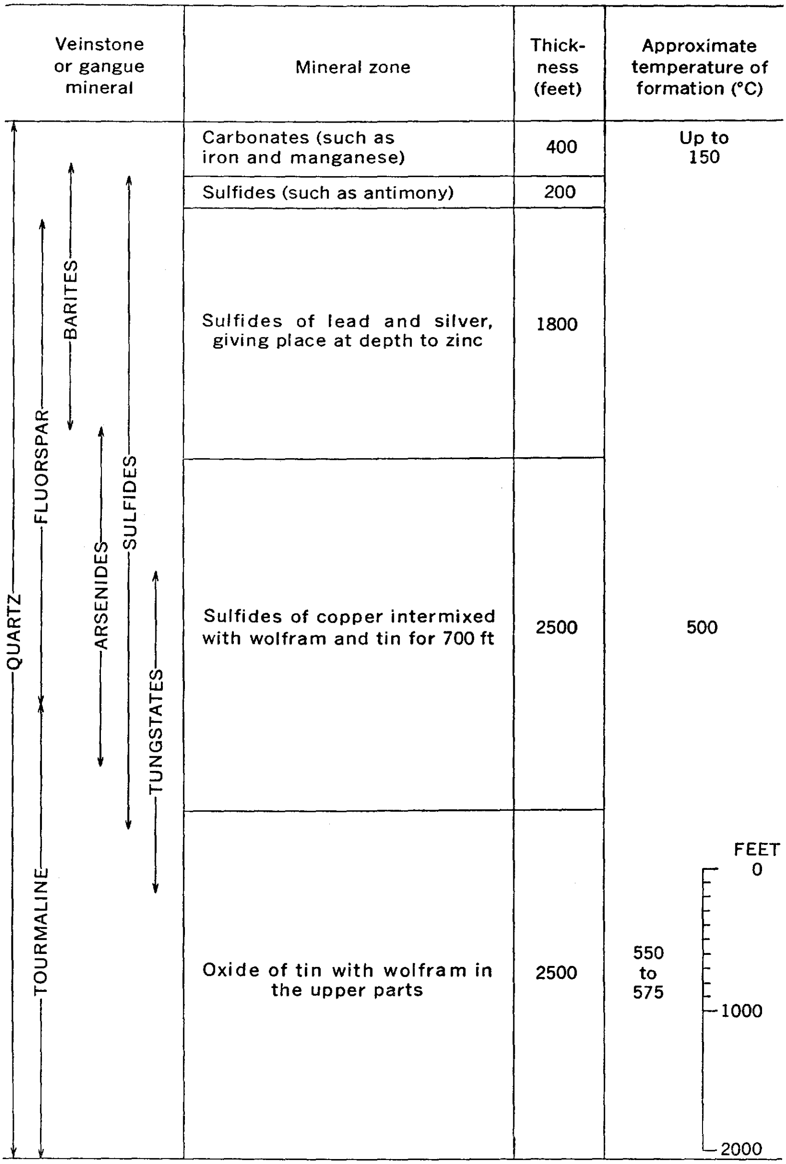


Figure 3.— Zoning in the tin deposits of Cornwall, England. (From Dewey, 1925, fig. 7.)

inferred reserves, or 94,000 long tons of tin, here classed as resources. As proved by the successful reopening of the South Crofty mine, large areas of Cornwall are as yet incompletely explored; the ultimate tin production from Cornwall may well exceed the quoted figure for resources.

PORTUGAL AND SPAIN

A single complex, but continuous, tin district extends southeastward through Portugal and Spain. For a distance of 500 miles, tin and tungsten deposits of diverse types are associated with plutonic rocks, dominantly porphyritic biotite or biotite-muscovite granites (Cotelo Neiva, 1944, p. 33), many of which contain tourmaline. The deposits consist of veins, stockworks, and alluvial and eluvial placers. The veins can be further classified into pegmatite and hypothermal veins, with characteristic mineralogy. The veins may contain cassiterite and wolframite, or wolframite alone, associated with other minerals. Columbite, tantalite and beryl occur with cassiterite at some places in the pegmatites. The elements characteristic of the deposits are Sn, W, As, Fe, Pb, Zn, Cu, Si; at places, Au, Ag, Ti, Sb, Li, Mo, U, Bi, Ca; more rarely, P, Be, Cl; and, most rarely, Nb, Y, Ta, Ni, Mn, V; B and F are common in the gangue minerals. Many vein deposits are transitional between pegmatites and high-temperature sulfide-bearing veins.

In Portugal as in many other tin districts, the major tin deposits occur near the granite borders or within the granites; tungsten deposits, on the other hand, tend to occur farther from the contacts, in the surrounding rocks. The major districts are Porte de Lima, Borralha, Villa Real, Ervedosa, Minas de Ribera, Viseu and the placer district of Belmont. (For locations, see Ahlfeld, 1958, p. 105.) In Spain, the main mines and producing areas are San Fiox and the area of Presqueiras-Avion in the northwest; Dominica, Barquilla, and Alemedilla along the Portuguese border; and Logrosán and Valdeflores-Trasquilon, about 200 kilometers southwest of Madrid.

The tin and tungsten resources of the Iberian Peninsula undoubtedly are large. Neither Spain nor Portugal estimated her reserves for the Robertson volume. For this report, tin reserves in measured and indicated ore are estimated to be equivalent to 10 years' average production of about 750 tons per year for each country, or 15,000 tons of tin. Submarginal resources are estimated at 10 times the measured and indicated reserves, or 150,000 tons of tin. This is probably a very conservative figure, possibly by an order of magnitude.

FRANCE

A small amount of tin has been mined sporadically in France since Phoenician times. The known lode deposits are similar to those in Spain

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and Cornwall; the French deposits are related to Hercynian granites intruded at the same time as those in England and Spain. Lodes contain cassiterite in association with the usual high-temperature sulfide minerals. Recent production has come mainly from a dredging operation in Brittany in ground that contains 0.2–0.4 kg cassiterite per cubic meter (Robertson, 1965, p. 71).

Reserves of tin in France were not reported by Robertson (1965). However, it is estimated that production will continue until 1970 at 400 tons of tin-in-concentrates per year; hence, measured and indicated reserves are assumed to be 2,000 long tons of tin. Resources in undiscovered and marginal deposits are conservatively estimated at twice the measured and indicated reserves, or 4,000 long tons.

GERMAN DEMOCRATIC REPUBLIC (EAST GERMANY) AND CZECHOSLOVAKIA

The ancient metalliferous province in the Erzgebirge of East Germany and Czechoslovakia has produced tin since about 2000 B.C. (Janecka and Stemprok, 1967, p. 3), and although production fell to less than 500 tons of tin in the early 1900's, Germany was able to raise production to more than 1,000 tons annually during World War II. Present production from the region is but a few hundred tons of tin per year. Total production to 1964 was estimated by Janecka and Stemprok (1967, p. 3) at about 120,000 tons of tin.

Several large granitic plutons of two distinct suites are intruded into metamorphic rocks along a northwest trend at right angles to the trend of the main range (Erzgebirge). The earlier granites are poorer in alkalies than the later granites, which were intruded after the quartz porphyries (Janecka and Stemprok, 1967). The ore deposits are associated with the younger biotite granite, much of which contains tourmaline or topaz. Cassiterite, locally with wolframite, in typical high-temperature veins is accompanied by numerous base-metal sulfides and locally by silver minerals and uranium. The grade of mined lodes seldom exceeded 2 percent tin.

No reserve figures are available for the deposits of the East Germany–Czechoslovakia area; however, as production has been maintained at the level of several hundred tons per year, and because exploration of lower grade deposits is continuing, it is assumed that measured plus indicated reserves of the grade being mined total at least 10 years' production, or about 5,000 long tons of tin. Submarginal resources of substantially lower grade are probably large, and are estimated here to be 10 times the measured and indicated reserves, or 50,000 long tons of tin. These lower grade deposits consist principally of greisens, stockworks, and skarns; tin content of some stockworks (near

Vernérov) is as much as 0.38–0.64 percent, and that of some skarns 0.6–0.8 percent, according to Janecka and Stemprok (1967, p. 11–14).

ASIA

Asia leads the world in tin production and in tin reserves. The world tin supply consequently is dependent largely on Asian production. The period of high prices and world shortage in 1962–66, for example, was caused largely by the loss of Indonesian production, which fell from 35,000 long tons in 1952 to about 13,000 long tons in 1963.

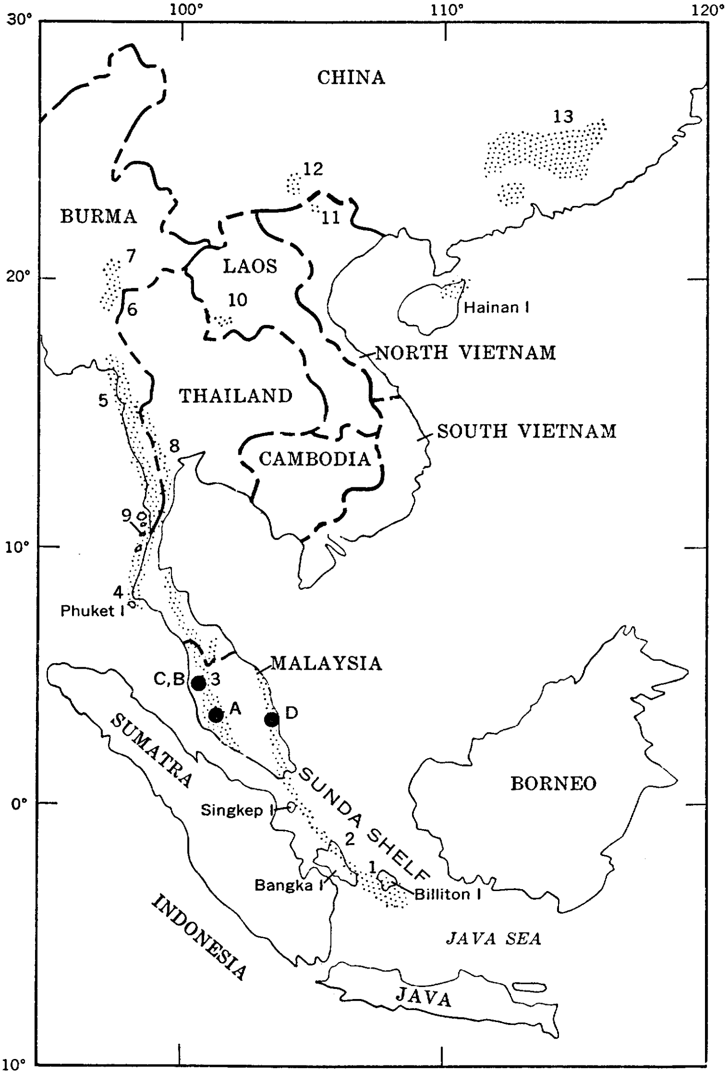
Throughout the tin belt of Southeast Asia, primary tin deposits are closely related to biotite or biotite-muscovite granite, although most production is from placer deposits. Most of the lode deposits consist of veins, disseminated deposits, and stockworks that are closely related to quartz-topaz greisens or quartz veins, in which cassiterite is associated with numerous base-metal sulfide minerals. The tin belt of Southeast Asia is shown in figure 4.

Several geologic factors have contributed to the unusual size and richness of the Southeast Asian tin deposits: (1) an unusual concentration of tin granites, (2) deep and rapid tropical weathering that has released large amounts of primary tin from lode sources, (3) formation of rich and extensive placers during a complex geomorphic history during which rich and extensive placers formed, both marine and alluvial, many of which are now seaward of present shorelines, and (4) low relief and sluggish stream action that preserved the placers.

The most productive tin belt stretches more than 1,500 miles from Billiton (Belitung) Island in Indonesia (fig. 4) through Malaysia and Thailand into northern Burma. Many placer deposits and a few important lode deposits are worked throughout the belt. The most productive areas are numbered in figure 4.

INDONESIA

In 1941, Indonesia (then Dutch East Indies) produced 53,370 long tons of tin. By 1963, after nationalization of the mines and expulsion of foreign capital, the output had fallen to 12,947 tons (Shelton, 1964, p. 1125), a situation which contributed to the present period of world shortage. The reduced output does not represent exhaustion of reserves, however. Indonesian production comes principally from placer deposits both onshore and offshore of the islands of Billiton (Belitung), Bangka, and Singkep in the Java Sea (shown in fig. 4). Bangka is the major source, followed by Billiton and Singkep in the ratio 20:10:2. Bedrock of the islands consists of alternating beds of sand-



1. Billiton (Belitung) Island, Indonesia
2. Bangka Island, Indonesia
3. Malaysia
   A. Gunong Bakau mines, Selangor
   B. Lahat pipe, Kinta Valley, Perak
   C. Beatrice mine, Selabin
   D. Pahang mines, Pahang
4. Phuket Island, Thailand

5–9. Burma
   5. Maulmein area
   6. Mawchi area
   7. Byingyi district
   8. Tavoy district
   9. Mergui Islands

10. Nam Pha Tene mine, Laos
11. Pia Oak Mountains, Tonkin, Vietnam
12. Kochiu area, China
13. Kwangtung-Kwangsi-Hunan Provinces, China

FIGURE 4.—Tin-bearing areas of Southeast Asia.

stone and shale intruded by batholiths and stocks that range in composition from gabbro to granite. The primary ore deposits are associated with biotite granite. Lodes occur in the granite and in the sedimentary rocks. The largest lode deposit—Klappa Kampit on Billiton Island—is restricted to the sedimentary rocks and consists of replacement bodies containing cassiterite and associated magnetite, pyrite, chalcopyrite, pyrrhotite, arsenopyrite, sphalerite, galena, bismuthinite, bismuth and phenakite along with fluorite, quartz, tourmaline, and other silicates. The deposit was mined to a depth of about 1,000 feet below sea level, and produced about 240 tons of metallic tin per month during 1934–52 (Adam, 1960, p. 410). The mine was flooded during the Japanese occupation and has not been reopened.

The placers of Bangka and Billiton Islands are widespread, and extend seaward from the present shorelines. During the Pleistocene, lowering of sea level exposed the wide Sunda Shelf to erosion, and Pleistocene streams carved extensive but shallow drainages on the shelf. Placers were localized along these drainages as well as in older valleys elsewhere on the islands. Much of the alluvial material in the placers is cemented by iron hydroxides and forms a coherent conglomerate called kaksa, in which cassiterite is distributed between coarse fragments of quartz and sandstone. Much placer production is from seagoing dredges.

Tin reserves of Indonesia unquestionably are large. The official reserve figures furnished to the International Tin Council (Robertson, 1965) are give in table 7.

TABLE 7.—*Tin reserves of Indonesia, 1965*

[Estimated reserves of tin-in-concentrates. Data from Robertson (p. 87)]

	Thousands of long tons
Demonstrated reserves [1]:	
Alluvial [2]	516.7
Lode	16.6
Disseminated primary ore (stockworks)	10.3
Total	543.6
Inferred reserves:	
Alluvial [2]	66.4
Grand Total	610.0

[1] Closely equivalent to measured plus indicated; not differentiated by price.
[2] Including tailings and dumps.

The inferred reserve figure (table 7) is considered to be conservative, and it excludes reserves that may be discovered by offshore exploration. The entire shelf area from an unknown end point east of Billiton Island to north of Singkep Island is geologically favorable for offshore placer deposits, and for the purposes of this report it is assumed that resources yet to be discovered in this area will equal the measured and indicated reserves of table 7, or about 540,000 tons. This assumption is supported by the fact that Indonesian placer reserves average 0.639 pounds of tin per cubic yard (Robertson, 1965, p. 88), much higher than the grade of reserves in Malaysia (0.33–0.38 lb of tin per cu yd). If high-grade reserves are extensive, lower grade resources also must be extensive. Moreover, lode resources also must be considerable.

MALAYSIA

Historically, Malaysia has furnished 30–55 percent of the world's yearly tin production. All the main cities of the country are mining centers, and, according to Tin News of January 1966, 67 dredges, 975 gravel pump mines, and 55 other mines were operating in Malaysia at that time; almost 45,000 people were employed in tin mining.

Tin deposits in Malaysia include both lodes and placers, but placers are the dominant producers. The deposits extend through the country in two north-trending belts nearly parallel to the coastlines. The mineral belts coincide with two mountain ranges that consist of batholiths and stocks of biotite granite and related rocks, probably of Cretaceous age, which intrude a thick series of sedimentary and metamorphic rocks of Cambrian to Cretaceous age. Widespread unconsolidated clays, gravels, and boulder clays (clays containing residual boulders) contain the placer cassiterite deposits. Marine placers are widespread (Fitch, 1952, p. 5); several were being mined in 1967.

Athough placers are mined throughout Malaysia, the most productive area is the Kinta Valley, State of Perak (No. 3B in fig. 4). The geology of the valley has been described in detail by Ingham and Bradford (1960), from whose report the following description is abstracted. The valley is about 30 miles long and about 15 miles wide at the southern end, and narrows into the mountains to the north. Bedrock of the valley consists principally of crystalline limestone and is encircled by hill-forming biotite granite. The lode deposits are principally in the contact areas of the granite and surrounding limestone; they consist of cassiterite, quartz, arsenopyrite, and pyrite, with small amounts of galena, sphalerite, chalcopyrite, bismutite, scheelite, wolframite, and antimony sulfosalts. Fluorite, lithium mica, tourmaline, and corundum are locally abundant. At the surface numerous deep solution cavities in the limestone have trapped the alluvial cassiterite, which is recovered by dredging, gravel pump mining and hydraulicking. Trace amounts of columbite-tantalite, monazite, ilmenite, cobaltite, rutile, and strüverite occur in placer concentrates. During 1876–1950, the Kinta Valley produced 1,200,000 tons of metallic tin, which, at today's prices, would be worth about $2 billion.

Other important placer areas in Malaysia are in the Selangor River about 100 miles south of the Kinta Valley (Roe, 1953), and in the Frasers Hill area, about 20–40 miles northeast.

Important lode mines in Malaysia include the Gunong Bakau mines, Selangor; the Lahat pipe, in the Kinta Valley, Perak; the Beatrice mine, Selabin; and the Pahang Consolidated Co. mines near Sungei Lembing, State of Pahang. Respectively, these are A, B, C, and D in fig. 4. Only the mines in Pahang are currently (1967) operating.

The mines at Gunong Bakau produced tin at the rate of about 600 tons per year during 1900–38. The veins consisted of quartz-topaz-cassiterite greisen in fractured biotite granite. The ore averaged 1.6–1.7 percent SnO_2; pyrite, chalcopyrite, and torbernite (a uranium mineral) were also present.

The Lahat pipe, mined in 1903–10 to a depth of 340 feet, never exceeded a few dozen feet in cross section; yet it yielded 1,500 tons of tin. The pipe was in limestone; it consisted of cassiterite intergrown with iron oxides and secondary calcite in the weathered part, and it contained arsenopyrite below the weathered zone.

The Beatrice mine, also in a replacement pipe in limestone, generally did not exceed 50 by 70 feet in cross section. At the surface, it consisted of cassiterite, arsenopyrite, iron oxides, and scorodite (a secondary arsenic mineral). At depth the pipe contained cassiterite, arsenopyrite, chalcopyrite, and bornite in a gangue of tremolite, fluorborite, fluorite, phlogopite, and dolomite. The pipe was mined over a slope length of about 850 feet and yielded almost 9,000 tons of cassiterite.

The Pahang mines are developed upon a complex system of veins in an area of about 6 square miles in which the bedrock consists of interbedded shale and quartzite intruded by biotite granite. Most veins are in rocks surrounding the granite, but some extend into the granite. The lodes are fissure fillings and replacement veins that contain cassiterite, pyrite, chalcopyrite, arsenopyrite, galena, sphalerite, cobaltite, manganese minerals, magnetite, and secondary minerals. The gangue in the veins is quartz, chlorite, calcite, fluorite, clay, and tourmaline. Some ores occur in greisen, and most veins are bordered by chloritized rock. In the period 1888–1948, these mines produced 79,509 tons of cassiterite.

The tin reserves of Malaysia, according to the official figures furnished to the International Tin Council (Robertson, 1965, p. 86), are listed in table 8.

TABLE 8.—*Tin reserves and known resources of Malaysia*

[Estimated reserves of tin-in-concentrates. Modified from Robertson (1965 p. 86)]

	Thousands of long tons
Reserves:	
Measured and indicated	600
Reserves in Malay Reservations[1] (first indications) [inferred reserves?]	170
Resources (known):	
Submarginal	230
Old tailings and residual areas	
Areas within which mining is prohibited or restricted	
Total, reserves plus known resources	1, 000

[1] Lands designated as mining lands. Not differentiated by price.

NOTE.—For the purposes of this report, it is assumed that resources in undiscovered lodes, offshore placers, and unknown submarginal resources will equal an additional 1 million tons of tin, a figure which may be conservative by a factor of 2 or 3.

THAILAND

Lode and placer tin deposits, continuations of the Malaysian deposits, are widespread in Thailand. The deposits are closely associated with biotite granite intrusive rocks of Late Cretaceous age (younger granites) which form the backbone of the main mountain system that forms the peninsula between Malaysia and Thailand (Brown and others, 1951). In parts of Thailand, granites of Triassic age (older granites) may contain deposits; these are being actively studied by the Thailand Department of Mineral Resources (1967) to determine if they are stanniferous. In northern Thailand, along the Burmese border, the mountains contain tungsten deposits as well as deposits of tin, which may be related to Triassic granites. The principal tin placers are near Phuket Island (No. 4 in fig. 4), and near Ranong, about 60 miles north. As elsewhere in Southeast Asia, placers are more important tin producers than lode deposits are. Tin production from Phuket Island has come from alluvial stream-channel deposits and their submarine extensions. After World War II, Union Carbide Corp. installed a seagoing dredge to mine the offshore deposits, which probably are extensive. Lode deposits on Phuket Island consist of cassiterite accompanied by tourmaline, topaz, white mica, and lesser amounts of zircon, ilmenite, monazite, and garnet in quartz veins and pegmatite dikes.

The lode deposits of northwestern and western Thailand consist of fissure veins, stockworks, and pegmatite than contain wolframite and cassiterite accompanied locally by arsenopyrite, scheelite, pyrite, chalcopyrite, and molybdenite. In several districts, more tungsten is produced than tin.

In the province of Yala, adjoining the Malaysian border, several lode mines have produced cassiterite from veins in crystalline limestone and from other metamorphosed rocks near the biotite granite contacts. In this province, the Japanese, during World War II, installed the first plant designed to use the Cavaet process of tin recovery. In the Cavaet process, cassiterite is converted to stannous chloride, which in turn is dissolved in water and the tin is then recovered electrolytically.

Tin reserves of Thailand are large. Robertson (1965, p. 86) gave figures (table 9) based upon the official Thailand response to the International Tin Council questionnaire.

TABLE 9.—*Tin reserves of Thailand, 1965*

[Estimated reserves of tin-in-concentrates, in thousands of long tons. Data from Robertson (1965, p. 87)]

Price, per long ton of tin	At $1,960 (£700)	At $2,520 (£900)	At $3,080 (£1,100)
Measured:[1]			
Alluvial	29.7	35.9	37.9
Tailings and dumps	1.3	1.4	1.4
Total	31.0	37.3	39.3
Indicated plus inferred	[2] 1,089.0	----------	[2] 1,500.0
Grand total	1,120.0	37.3	1,539.3

[1] Measured reserves of dredging companies, excluding offshore deposits.
[2] Inland, alluvial, eluvial, and offshore deposits.

[NOTE.—As the above figures include no reserves in lode deposits, the writer has, for the purposes of this report, estimated that lode resources and submarginal placer resources equal th 1965 measured, indicated, and inferred placer reserves at the $1,960 (£700) rate, or 1,120,000 long tons of tin.]

BURMA

The known tin deposits of Burma lie along the Thailand-Burma border and are the extension of the Indonesia-Malaysia-Thailand belt of deposits. The deposits are similar to those in Thailand and Malaysia; they consist of lodes and placers related to biotite granite that intrudes slates, agglomerates, and quartzites that contain some interbedded limestone. The tin belt in Burma is about 750 miles long, extending from the Byingyi-Mawchi district on the north (Nos. 6, 7, in fig. 4) through the Moulmein and Tavoy districts (Nos. 5, 8 in fig. 4) to the Mergui Islands on the south (No. 9 in fig. 4).

The Mawchi mine was one of the most important tin-tungsten mines of the world (Ahlfeld, 1958, p. 72). The mine was developed along many veins that cut a tourmalinized granite and the enclosing slates. The veins carry quartz, tourmaline, mica, cassiterite, wolframite, a little scheelite, and small amounts of galena, chalcopyrite, pyrite, arsenopyrite, molybdenite, sphalerite, bismuthinite, covellite, chalcocite, beryl, phenakite, and fluorite. In 1939, the Mawchi mine produced 3,100 tons of tin concentrate and 2,700 tons of tungsten concentrate (Ridge, 1953, p. 53). The mine closed during World War II, and since then it has produced only on a much smaller scale; reserves, however, are probably large. Tin mining in Burma has not recovered from the setback of the Japanese occupation.

In the Tavoy district, quartz veins in granite and surrounding sedimentary rocks contain both cassiterite and wolframite, the wolframite being preponderant (Brown and Heron, 1923). The veins range in thickness from a few inches to several feet and are most numerous in or near granite. In addition to wolframite and cassiterite, the veins contain fluorite, scheelite, molybdenite, pyrite, chalcopyrite, galena (rare), pyrrhotite, arsenopyrite, sphalerite, native bismuth, bismuthinite, and topaz. The walls of most veins consist of quartz-mica greisen.

Veins containing wolframite and cassiterite are mined in the Mergui Islands. These veins are in most respects similar to those in the Tavoy district.

Tin and tungsten have been won from many small placers in Burma, but no major producing placer districts are now operating. Without question, placer deposits will produce important amounts of tin, but the rather mountainous terrain of Burma is not as favorable for the occurrence of large placer fields as is the terrain of Malaysia.

Reserves of tin in Burma were not estimated by the Burmese government for Robertson's report (1965). For the present report, the writer assumes that proved reserves amount to 60,000 tons, calculated from 10 years' production at the highest pre-World War II rate and that the total known and undiscovered resources of submarginal grade must equal at least 250,000 tons of tin.

VIETNAM AND LAOS

Important tin deposits occur at two localities in Vietnam and Laos. Before World War II, the Nam Pha Tene mine (No. 10 in fig. 4) was a large producer (914 tons of cassiterite in 1939), but figures of present production are unavailable. The deposit consists of a pipelike replacement body in limestone. Near the surface it contains needlelike crystals of cassiterite in limonite. At depth the pipe passes into veins in the sandstone beneath the limestone, and there the veins contain fine-grained cassiterite and sphalerite, galena, chalcopyrite, arsenopyrite, and jamesonite. The deposit is related to a biotite-hornblende granodiorite.

In the Pia Oak Mountains, northern Tonkin Province of Vietnam (No. 11 in fig. 4), veins containing cassiterite and wolframite occur in and around a biotite granite or granodiorite. The deposits are in veins, stockworks, and veinlets in both the granite and surrounding rocks. The veins also contain quartz, scheelite, molybdenite, pyrite, pyrrhotite, sphalerite, galena, and autunite (a uranium mineral).

Placer cassiterite deposits also are worked in the Pia Oak area. The richest placers are found in deep solution cavities in limestone, similar to deposits in the Kinta Valley, Malaysia.

The tin reserves of Vietnam and Laos are unknown. For the purpose of this report, it is assumed that measured plus indicated reserves are equivalent to 5 years' production at the pre-World War II level (about 1,500 tons was produced in 1939), or 7,500 tons. Resources are assumed to be at least 10 times the measured and indicated reserves, or 75,000 tons.

JAPAN

Since the 16th century, tin deposits on Honshū Island have produced moderate amounts of tin (Japan Geol. Survey, 1960, p. 184). According to Takomoto (1944), the deposits occur mainly as pegmatitic and quartz veins associated with biotite granite intrusive rocks. Veins occur in both granite and the invaded country rocks. Cassiterite is the main tin mineral, but stannite and stanniferous tetrahedrite also are present. Associated minerals are wolframite, scheelite, arsenopyrite, chalcopyrite, pyrite, sphalerite, stibnite, galena, pyrrhotite, molybdenite, bismuthinite, and several gangue minerals especially topaz, quartz, tourmaline, and fluorite. In 1958, operating mines in three areas (Ikuno-Akenobe, Obira-Mitate, and Suzuyama) produced 1,126 tons of tin-in-concentrate, of which the major part came from the Akenobe mine, where many quartz veins that contain cassiterite, wolframite, and numerous base-metal sulfide minerals are mined. The veins, which cut both diorite and gabbro intrusive rocks as well as the surrounding sedimentary and volcanic rocks, are considered to be related to an underlying granite.

Reserves of tin in Japan are moderate. According to the Japan Geological Survey, reserves in five working mines in 1962 were 2,654,000 tons of ore averaging 1.2 percent tin, or about 20,000 long tons of tin. Present reserves (1968) amount to about 16,000 long tons. As the tin deposits of Japan are not extensive and many are worked out, it is assumed in this report that undiscovered submarginal resources amount to not more than the known reserves, or about 16,000 long tons of tin.

AFRICA

Substantial producing tin deposits are found in Nigeria and the Democratic Republic of the Congo, and less important ones in Rwanda, Republic of South Africa, South-West Africa, Rhodesia, Tanzania, and Uganda. Small producing deposits occur in Burundi, Cameroon, Morocco, Niger, Swaziland, and Zambia (formerly Northern Rhodesia). Locations of all major producing districts are shown in figure 1.

NIGERIA

Nigeria is the world's fifth largest producer of tin (9,354 long tons of tin-in-concentrate in 1965, U.S. Bur. Mines, 1966), most is produced from placers that contain cassiterite, columbite, and tantalite. The large amount of byproduct columbite produced makes Nigeria the world's leading producer of that mineral.

The geology of Nigeria is well known; the Jos Plateau, from which about 95 percent of the placer cassiterite is produced, has been studied in detail (Jacobson and Webb, 1946; Mackay and others, 1949; Carter and others, 1963; and Jacobson and others, 1958). The plateau has a complex history of granitic-rock intrusion. Many of the intrusive rocks were emplaced as ring complexes. The general order of intrusion for a typical complex has been described as follows: (1) Rhyolite, tuff, and agglomerates, which filled ring faults that bounded a large caldera and the caldera itself; (2) late intrusive rhyolites and explosion breccias; (3) quartz-pyroxene-fayalite porphyries; (4) basic dikes and semiconformable intrusions; (5) arfvedsonite-fayalite granite-porphyry ring dikes; (6) biotite granites; (7) riebeckite microgranites; (8) riebeckite-aegerine granites; (9) albite-riebeckite granite; and (10) minor acid dikes (Jacobson and others, 1958, p. 30). The various granites are collectively grouped under the term "younger granites"; more than 40 younger granite complexes are known in Nigeria. Similar complexes are known elsewhere in north and west Africa.

Most of the tin deposits of Nigeria are associated with the biotite granites, which form ring dikes, bosses, and large stocks or batholiths as much as several hundred square miles in outcrop area. Texturally, the younger granites range from fine grained to coarsely porphyritic; their most noticeable chemical features are a rather high fluorine content and a paucity of boron. This paucity of boron leads to the complete absence of tourmaline in the tin deposits (Jacobson and others, 1958, p. 16). The younger granites intrude Precambrian rocks, but are themselves probably of early Paleozoic age. Lode cassiterite deposits consist principally of mineralized stockworks and quartz-topaz-mica greisens which are most common near the apices of granite stocks. Columbite and cassiterite are most common in the albite-biotite granite. The tin lodes contain cassiterite, wolframite, chalcopyrite, bornite, galena, arsenopyrite, sphalerite, and molybdenite.

Elsewhere in Nigeria, a suite of granites older than the younger granites intrudes the Precambrian rocks. Most of these older granites have gneissic textures and gradational contacts. Associated with the older granites are many pegmatites that contain cassiterite, columbite-tantalite, beryl, tapiolite [(Fe,Mn) $(Nb,Ta)_2O_6$], and minor sulfide minerals. Most of the cassiterite and columbite-tantalite was introduced during a late-stage albitization of the pegmatites. A few of the pegmatites have been mined, but most tin produced from the pegmatite areas is won from nearby alluvial deposits.

The rich and extensive placers of the Jos Plateau were formed largely from erosion of the basement rocks. During a period of elevated base level, streams aggraded their valleys and buried the placers beneath a blanket of clay and alluvium. Still later, extensive lava fields blocked valleys and buried the stream gravels; drainages reestablished on the lavas have intersected the buried placers, giving rise to modern placers from reworked older ones. Most production is from modern placers, but some placers beneath lava have been worked; these buried placers are probably very extensive.

Reserves.—In 1962, reserves in Nigeria were estimated (Robertson, 1965, p. 82) as 138,000 long tons of tin in a combined proved and inferred category. Undiscovered resources of economic and submarginal grade are estimated, for the purposes of this report, to equal at least the known and inferred reserves, or another 138,000 long tons. Judging from the known extent of deposits buried beneath lavas, this estimate is probably conservative.

DEMOCRATIC REPUBLIC OF THE CONGO

Important amounts of tin are won from both lode and placer mines in the Democratic Republic of the Congo. Tin deposits are found in the provinces of Maniema, Katanga, and Kivu, and the former Territory of Ruanda-Urundi (now the countries of Rwanda and Burundi). The deposits are tin-bearing pegmatites, some of which are large, and tin-bearing greisens and quartz veins; the pegmatites are more important in Katanga.

The basement rocks consist of a group of quartzites, schists, and gneisses of Precambrian age, locally intruded by mafic rocks and by biotite granite of younger age. The tin deposits are genetically related to the biotite granite. Columbite and tantalite are found in deeper parts of the granites and in some placers.

The lode deposits exploited by one company (Symetian) in Maniema have been described in detail by Varlamoff (1948); his descriptions are largely applicable to most of the area. A large granite intrusion has a border of coarse-grained microcline-quartz-muscovite rock, and an interior of medium-grained microcline-quartz-muscovite-biotite-albite granite. Following injection of the granite, several systems of veins and dikes formed in the following sequence: (1) Aplite-pegmatite, (2) early quartz veins containing columbite and tantalite, (3) greisen that contains columbite-tantalite and nonlithia mica, and (4) greisen that contains lithia mica, wolframite, and cassiterite. Later quartz veins contain ferberite, native bismuth, pyrite, and arsenopyrite. Veins are commonest above cupolas of granite intrusive rocks, where tourmalinization is often intense.

Varlamoff considered the differing mineralogy of various veins mined in the Congo to be largely a function of regional mineral zoning combined with the depth of erosion. In upper (or outer) zones, greisen deposits that contain cassiterite and sulfide minerals are important. In deep zones within granite, veins contain important amounts of columbite-tantalite in addition to cassiterite.

In Katanga, large pegmatites are mined by open-pit methods. The Manono pegmatite is about 10 km long, as much as 400 m wide, and contains cassiterite throughout (Geomines Co., 1967, p. 3). Cassiterite, which is present in amounts averaging about 2.2 kg of tin per cubic meter, is accompanied by thoreaulite ($SnTa_2O_7$), in the ratio one part thoreaulite to 20 parts cassiterite. Ore minerals recovered are cassiterite, tantalite, columbite, and thoreaulite. Spodumene is an important constituent of the pegmatite, but it is not routinely recovered. The Manono pegmatite produced 127,500 metric tons of cassiterite from about 1928 to 1967 (Geomines Co., 1967, p. 4). Other pegmatites in the Congo are worked on a smaller scale.

Placer deposits of cassiterite in the Congo are mainly small but rich. The deposits are localized near biotite granites, or where streams cross tin-bearing greisens or pegmatites.

Reserves.—The Democratic Republic of the Congo government estimated reserves for Robertson's report (1965, p. 84), and these figures are presented in table 10.

Robertson presented evidence to show that these reserve figures are extremely conservative; the writer agrees. For instance, measured and inferred reserves in the Manono pegmatite (Manono and Kitololo mines, to a depth of 125 ft) are estimated by the writer to be about 900,000 short tons of tin metal. Total reserves in the Democratic Republic of the Congo therefore are estimated to be at least 1 million long tons of tin metal, most of which is in the Manono pegmatite.

Resources.—As emphasized by Ahlfeld (1958, p. 52), the Congo tin fields were not discovered until 1933, and tin-bearing granites and pegmatites are widespread over many thousand square miles. The tin fields therefore are not yet considered to be completely explored. For the present report, the writer assumes that tin resources in submarginal and undiscovered deposits amount to another 1 million long tons of tin metal. This estimate probably is conservative. Thus, the Democratic Republic of the Congo contains one of the major tin reserves of the world.

TABLE 10.—*Estimated reserves of tin, Democratic Republic of the Congo, 1965*

[In thousands of long tons. Data from Robertson (1965). Expressed in terms of tin-in-concentrates of the grade produced by existing mines]

Price, per long ton of tin	$1,960 (£700)	$2,520 (£900)	$2,800 (£1,000)
Measured:			
Alluvial and eluvial	9	29	34
Lode		105	105
Total	9	134	139
Indicated:			
Alluvial and eluvial		8	9
Lode		2	7
Tailings and dumps	5	10	15
Total	5	20	31
Inferred:			
Lode			10
Tailings and dumps		5	10
Total		5	20
Grand total	14	159	190

REPUBLIC OF SOUTH AFRICA

Tin deposits of the Republic of South Africa are mainly in pipes and veins that occur in or near granites or granophyres of the Bushveld Complex. The mineral assemblages, which are characteritic of the Cornwall type, consist of abundant cassiterite accompanied by quartz, fluorite, pyrite, tourmaline, arsenopyrite, molybdenite, chalcopyrite, wolframite scheelite, sphalerite, bornite, chalcocite, tetrahedrite, tennantite, galena, covellite, and rare bismuth minerals (Strauss, 1954). The pipes are vertically and horizontally zoned and generally bottom on luxullianite (a rock consisting virtually of tourmalinized granite). The tin content ranges from 0 to 70 percent and averages 12–30 percent. Most of the known pipes in the Potgietersrus fields were mined out before 1926, and the present production comes mostly from disseminated deposits of cassiterite in granite (Robertson, 1965, p 69), which contain an average of about 1.5 percent tin. Detailed descriptions of many of the deposits were given by Leube and Stumpfl (1963).

Important deposits occur at Rooiberg, where veins and pockets contain cassiterite, scheelite, galena, sphalerite, chalcopyrite, pyrite, and bismuthinite. Gange minerals are quartz, tourmaline, fluorite, ankerite, and sericite. Smaller deposits are known at Leeuwpoort, and at Warmbad, cassiterite occurs in pegmatites, quartz veins, and breccia replacement bodies in granite (De Kun, 1965, p. 471).

Reserves.—No tin-reserve figures were given for the Republic of South Africa in Robertson's report (1965). However, the government forecast for the country calls for a production of 1,100 tons of tin in 1970, indicating that reserves are moderate. It is assumed here that measured and indicated reserves equal 10 years' production at 1,100 tons per year, or 11,000 long tons of tin. Undiscovered reserves and submarginal resources are assumed to equal at least twice the proved reserves, or 22,000 long tons.

SOUTH-WEST AFRICA

Tin deposits occur in four distinct northeast-trending belts in a small area of west-central South-West Africa (fig. 1). Two generations of biotite granite (and associated rocks) have intruded the Damara Complex of Precambrian age, which includes crystalline limestones, granulites, and crystalline schists. Many pegmatites intrude the schist and granite, but a single pegmatite that contains both cassiterite and wolframite furnishes the bulk of current production. Swarms of pegmatites occur in schists near the granite contacts, in tectonic zones in the schists, or where the schists change strike. The pegmatites that are genetically related to the younger granites contain the bulk of the cassiterite, and locally carry, in addition to the cassiterite, columbite-tantalite, scheelite, and wolframite. The ore minerals accompanied a late-stage albitization of pegmatites and the formation of tourmaline, muscovite, and lepidolite.

At the Steipelmann mine, near Arandis, a tin-bearing pipe in limestone contains herzenbergite (SnS), arandisite (a complex tin silicate), and nordenskioldine ($CaSn(BO_3)_2$) as the tin-bearing minerals (Ramdohr, 1935). Small lode deposits occur at Paukuab (greisenized pegmatites and greisen zones in granites) and in the Orange River area.

Small placers contributed most of the tin produced in South-West Africa until 1962; today placers contribute only a few hundred tons of tin concentrates yearly.

Reserves.—Robertson (1965, p. 70) stated that proved reserves at the main lode mines amount to 8 million tons of material containing tin and tungsten (grade unknown). He estimated that annual production will reach 900 tons of tin metal by 1970. For this report, it is assumed that proven reserves amount to at least 80,000 long tons of tin metal. Resources of submarginal grade and in undiscovered deposits are estimated to be at least 100,000 long tons of tin metal, a purely arbitrary figure that probably is conservative.

SOUTHERN RHODESIA

Tin-bearing pegmatites are mined on a substantial scale in the Kamativi area of Southern Rhodesia, principally at the Kamativi tin mines (Fick, 1960, p. 472). The tin-bearing pegmatites are especially abundant in a northeast-trending schist belt that extends about 80 miles across the Gwaai River in the south west corner of the country. The western part of the belt is called the Wankie tin belt, and the eastern, the Kamativi tin belt.

The schist and gneiss belt is part of the basement system of Precambrian metamorphosed sedimentary rocks. Biotite granite and two younger generations of pegmatites intrude this basement system. Fick (1960, p. 475) noted that an older generation of tourmaline-bearing pegmatites is tin free but that the younger ones contain cassiterite and can be classed as either lithium-poor or lithium-bearing pegmatites. The lithium-poor pegmatites are richer in tin and contain recoverable amounts of columbite-tantalite and spodumene. Albitized parts of tin-bearing pegmatities are enriched in columbite-tantalite. Small crystals of beryl occur but are not recovered. According to Watson (1962, p. 35), the mined ores average about 0.25 percent tin.

Reserves.—No official reserve figures were furnished to the International Tin Council by the Rhodesian government for Robertson's 1965 report. Because of recent plant expansion at Kamativi mines, however, one may assume that proved reserves are substantial. For this report, it is assumed that measured and indicated reserves of Rhodesia equal 10 times the yearly production, or about 6,000 long tons of tin. Submarginal and undiscovered resources are estimated to be at least 10 times the measured and indicated reserves, or 60,000 long tons of tin.

RWANDA, BURUNDI, UGANDA, AND TANGANYIKA (TANZANIA)

A belt of lode and placer tin deposits east of Lake Kivu stretches from southwestern Uganda into northern Tanganyika (Tanzania). In Uganda, gneissic biotite granite has intruded and domed shales and sandstone of the Karagwe-Ankolean System of Precambrian age. Cassiterite veins are associated with the granites, but occur mostly in the surrounding rocks (Barnes, 1961, p. 28). The deposits are both hydrothermal and pegmatitic; hydrothermal deposits contain most of the tin, and pegmatitic deposits contain some columbite-tantalite and beryl. Sulfide minerals are lacking.

The belt of lode and placer tin deposits in Uganda continues into Tanganyika, where the deposits are mined, principally by a single large company (Kyerwa Syndicate, Ltd.), at the Kaborishoke deposit (Harris, 1961, p. 136). The mine is in the Karagwe Tinfields, a belt of deposits about 5 miles wide and 30 miles long. Biotite granite has intruded and thermally metamorphosed phyllites, sericite schists, and quartzites of the Karagwe-Ankolean System. Fissuring accompanied the intrusion of granite; younger fissures localized quartz-mica veins that carry cassiterite, hematite, and, locally, wolframite. Some veins occur in granite, but the majority are in the metamorphosed rocks. Placer deposits along the Murongo River were mined during the early development of the tin fields, but no extensive placers were found.

The tin deposits in Rwanda and Burundi are an extension of the deposits in the Democratic Republic of the Congo (Harris, 1961, p. 282). Most of the tin is won from stanniferous pegmatites that also carry recoverable amounts of columbite-tantalite and lithium minerals. According to Thoreau (1951, p. 282), the pegmatites near Usumbura (now Bujumbura) in Urundi (now Burundi) contain larger amounts of bastnaesite (a cerium carbonate) than do Congo pegmatites.

Reserves.—No reserve figures are available for these countries. For this report, it is assumed that measured and indicated ore is sufficient to sustain the 1964 rate of production for each country for 10 years. This leads to a reserves figure of about 20,000 long tons of tin. Undiscovered and submarginal resources are estimated to equal at least the proven reserves, or another 20,000 long tons.

OTHER AREAS IN AFRICA

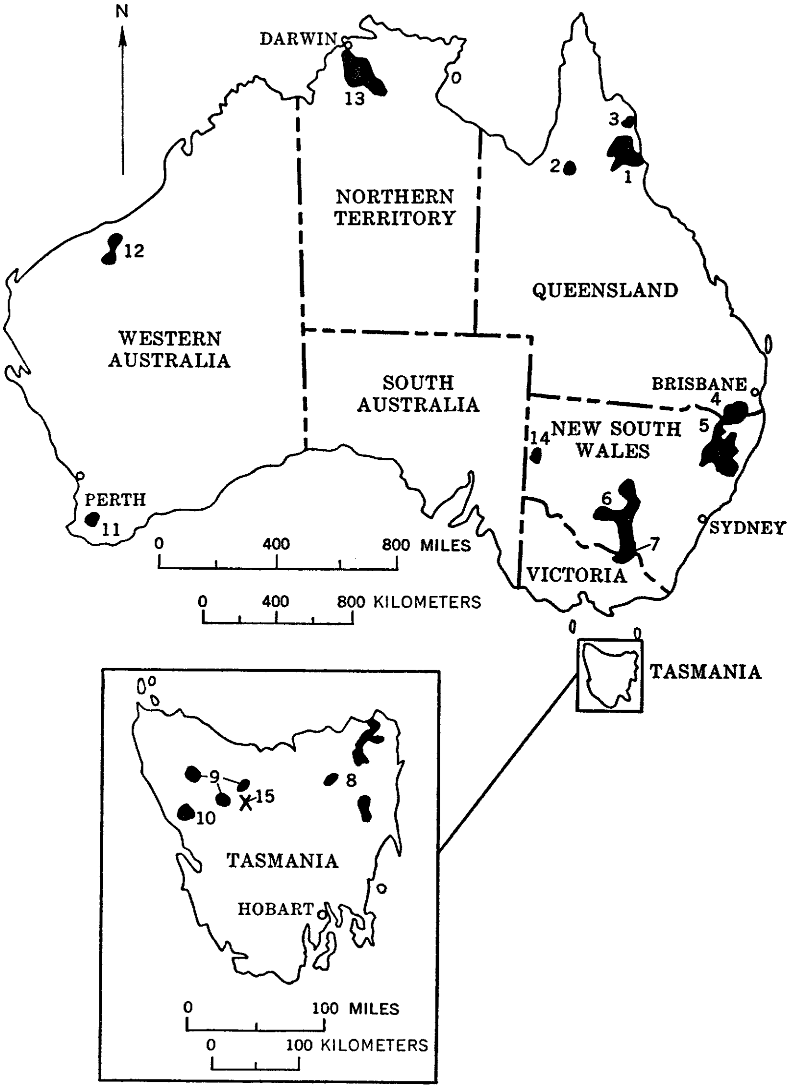
Small deposits of tin are worked in Cameroon, Morocco, Niger, Swaziland, and Zambia (formerly Northern Rhodesia); small deposits are known also in the United Arab Republic (Egypt), Algeria, Mali, Liberia, Sierra Leone, and Mauritania. (See fig. 1.) Present information indicates that none of these areas contain large proven reserves of tin, and for this report it is assumed that total resources amount to 50,000 long tons of tin, a purely arbitrary figure.

OCEANIA

Lode and placer tin deposits occur in Australia; each type of deposit has contributed roughly half of the 670,700 tons of tin concentrates produced in the country to the end of 1961 (Zimmerman, 1965b, p. 39). The large Australian deposits are mainly localized along the tectonic belt that follows the eastern margin of the continent (fig. 5). Several isolated occurrences, of detrital and lode cassiterite are known in New Zealand (Hutton, 1950).

AUSTRALIA

Substantial tin deposits in Queensland and New South Wales have been mined since 1891, and today these sustain the main producing mines of the country. The district in northern Queensland covers the Herberton–Watsonville–Mount Garnet area, where placer and lode



1. Herberton district
2. Croydon district
3. Cooktown district
4. Stanthorpe-Ballandean district
5. New England district
6. Mount Tallenbung–Albury tin belt
7. Beechworth-Eldorado district
8. Northeastern region
9. Northwestern region
10. Western region
11. South-West Division
12. North-West Division
13. Darwin-Katherine region
14. Barrier Range
15. Middlesex district

FIGURE 5.—Tin-bearing areas of Australia. Modified from Australia Bureau of Mineral Resources, Geology and Geophysics (1957, fig. 3).

deposits are associated with biotite granites intruded into metamorphic and sedimentary rocks. Blanchard (1947, p. 265–304) described the lode deposits in some detail. These lodes consist mainly of small- to moderate-sized pipes in granites or the surrounding bedded rocks. Those in granites contain cassiterite, wolframite, molybdenite, native bismuth, and smaller amounts of sulfide minerals. The pipes in surrounding rocks contain one or more of the following: Cassiterite, arsenopyrite, pyrite, pyrrhotite, tetrahedrite, sphalerite, galena, and stannite in a gangue of quartz, fluorite, mica, topaz, kaolinite, tourmaline, chlorite, calcite, and siderite. Some of the pipes contain sulfide minerals unaccompanied by cassiterite. The pipes in granite were classified by Blanchard (1947, p. 269) as (1) the quartz type, with abundant quartz; (2) the granite type, in which replacement by quartz is irregular; and (3) the garnet type, in which garnet replaces the mica. Garnet is found only in the molybdenite-cassiterite pipes.

In contrast to many pipes of the world, the Australian pipes (in granite) that contain molybdenite ores are older than joints and fractures of the granite. The cassiterite-bearing pipes, however, are localized along fractures or joints, leading Blanchard to conclude that the molybdenite-rich pipes were formed earlier. The largest pipe in the Herberton district (Vulcan pipe) produced 8,500 tons of tin from 165,000 tons of ore for a recovery of 5 percent tin. Most of the pipes are much smaller, however.

In northern Queensland, alluvial deposits are derived from lodes associated with biotite granites. Basalt flows of Tertiary age overlie some ancient channels in the Herberton area, where both dredges and sluices have been used. The gravels mined in the Herberton area in 1962 averaged about 0.5 pound of tin per cubic yard (Zimmerman, 1965a, p. 376). In the Cooktown district, eluvial (slope) and residual placers are mined on a small scale in addition to the main alluvial placers.

In southern Queensland (Stanthorpe district, fig. 5), most tin has been won from alluvial deposits, which now seem largely worked out. The placers were derived from lode deposits near and in biotite granite. A typical lode mine (Watson's Show) was developed on quartz veins along the contact area of granite and slate, where cassiterite was accompanied by chalcopyrite, galena, arsenopyrite, pyrite, and minor amounts of molybdenite, wolframite, and sphalerite.

Deposits of New South Wales include both lodes and placers; both types have been worked extensively. Main production came from the New England district and from Ardlethan in the Mount Tallenbung–Albury belt (fig. 5). In the New England district, which merges to the north with the Stanthorpe district of Queensland, granite, and granite porphyry intrude Paleozoic sedimentary rocks. Lode deposits in granite generally are more numerous in the silica-rich part of the granites and consist of veins, stockworks, and disseminations of cassiterite in altered granite. Other lodes are concentrated in the rocks peripheral to the granites, rarely more than 2 miles from the contact. The lodes at Torrington (New England district) are confined to granite and are localized along persistent joints. The lodes carry quartz, chlorite, cassiterite, ferberite, arsenopyrite, chalcopyrite, pyrite, molybdenite, sphalerite, galena, and monazite. Tungsten deposits in the same area contain quartz, topaz, cassiterite, beryl, bismuth, fluorite, and uranium minerals.

In the Mount Tallenbung-Albury tin belt, which extends southward into Victoria, lodes and placers are associated with biotite granite and contact rocks. Lode deposits are localized in fractures in granite, where it was extensively altered to quartz-tourmaline rock. Most lodes contain cassiterite, arsenopyrite, pyrite, wolframite, chalcopyrite, galena, molybdenite, and bismuth minerals. Productive placers are largest in streams that flow along margins of altered granites. According to Robertson (1965, p. 67), a new plant erected to treat ore from a mine on a large lode deposit in granite at Ardlethan will produce 650 tons of tin metal annually.

In western New South Wales, lodes in the Barrier Range (No. 14 on fig. 5) are localized along greisenized dikes and pegmatites in the Lower Precambrian schists.

Cassiterite produced in Victoria has come largely from placer and lode deposits in the Beechworth-Eldorado district on the border with New South Wales. The lodes are related to Devonian biotite granites, and contain cassiterite associated with base-metal sulfides in greisen zones and quartz veins within granite and the enclosing sedimentary rocks. A few placer deposits were large enough to sustain dredges; placers have yielded most of the tin produced from the district.

Tin deposits in Western Australia occur near Greenbushes in the South-West Division, and at the Moolyella fields in the North-West Division (fig. 5). At Greenbushes, ancient sand, clay, and gravel deposits (older alluvium) unrelated to present drainages are dredged for cassiterite. The deposits formed in a lake or shallow sea of Tertiary age and represent ancient beach deposits that formed around islands composed of Precambrian greenstones and gneisses. Recent alluvium along modern streams contains cassiterite that is derived from reworking of the older alluvium. The placers also yield small amounts of tantalite. Small lode deposits in the area consist of cassiterite-tantalite-bearing viens in granite.

In the Moolyella area, buried placers have yielded the bulk of the tin. The placers were derived from low-grade lodes consisting of stanniferous quartz veins and pegmatites.

Tin deposits in the Northern Territory are localized in a belt about 200 miles long that extends southeastward from Darwin and coincides roughly with the Pine Creek geosyncline (Walpole and Crohn, 1965, p. 168) of Precambrian age. These deposits consist of cassiterite-bearing greisens, quartz veins in or near granite, and cassiterite-tantalite-bearing pegmatite. Most deposits are small.

Tasmania contains many tin deposits grouped in the northern part of the island (fig. 5). According to Solomon (1965, p. 464) most of the mineral deposits were formed during the Tabberabberan orogeny of Devonian age; none are exposed in post-Devonian sedimentary rocks. Lode tin deposits are worked in the west, and placers in the northeast. Cassiterite is the main ore mineral, and in lodes it is accompanied by valuable amounts of copper, lead, zinc, and silver.

The placer deposits of northeast Tasmania consist of modern stream placers and of "deep leads" (older alluvium) which locally are overlain by basalt. Some deep leads contained as much as 78 pounds of cassiterite per cubic yard (Jack, 1965, p. 499). Grade of currently mined gravels ranges from 0.32 to 1.5 pounds of cassiterite per cubic yard. Jack (1965, p. 497) stated that placers of northeast Tasmania have produced 40,000 tons of tin.

Lode deposits in northeastern Tasmania consist of mineralized pegmatite and granite dikes, flat-lying "floors" in granite, and quartz and greisen veins, all localized in biotite or biotite-muscovite granite of Devonian age. Cassiterite, the main ore mineral, is accompanied by wolframite, scheelite, chalcopyrite, galena, and molybdenite. Tourmaline, topaz, quartz, mica, and kaolin are the main gangue minerals. In the Blue Tier and Branxholm-Weldborough areas, deeply weathered tin-bearing granite was mined as a residual deposit. The most important lode mine in northeastern Tasmania is the Aberfoyle tin mine, near Rossarden. The mine was developed on numerous veins in a zone 200 feet wide and 1,600 feet long in contact-metamorphosed shales, slates, and graywackes above a cupola of biotite granite (Edwards and Lyon, 1957). The ore minerals include cassiterite, wolframite, arsenopyrite, pyrite, molybdenite, pyrrhotite, chalcopyrite, sphalerite, stannite, galena, tetrahedrite, matildite, native bismuth, scheelite, marcasite, magnetite, and hematite. Gangue minerals are muscovite, topaz, apatite, triplite, fluorite, quartz, and carbonates. Storey's Creek mine, 2 miles distant, is similar, and drilling during 1961–62 at nearby Kookaburra-Lutwyche disclosed another major lode system (Kingsbury 1965, p. 506).

Lode tin and base-metal deposits of primary importance in western Tasmania include those in Mount Heemskirk–Zeehan (tin, silver, lead, zinc), Dundas–Renison Bell (tin, silver, lead, zinc), Mount Cleveland–Waratah (tin, lead, zinc), and Moina areas.

In the Mount Heemskirk–Zeehan area (western region of Tasmania), the Heemskirk granite of Devonian age is intruded into a thick series of clastic and volcanic rocks and intercalcated limestones and dolomite. Within the Heemskirk granite the lodes are associated with transitional masses of tourmaline granite. Tin lodes occur as pipes and irregular fissure fillings, and those in the granite contain cassiterite in a gangue of quartz, mica, and tourmaline. Outward from the granite, zoned lodes pass from those containing cassiterite, pyrrhotite, pyrite, chalcopyrite, sphalerite, and galena into ores containing stannite and valuable amounts of silver in argentiferous galena and tetrahedrite.

At Dundas–Renison Bell, about 9 miles northeast of Zeehan, mafic rocks and quartz porphyry intrude gently folded shale and sandstone. Lode tin deposits consist of fissure-fillings and concordant bedding-replacement bodies. Near quartz porphyry, cassiterite is accompanied by abundant tourmaline and quartz; farther away, cassiterite occurs as disseminated grains within massive pyrrhotite that also contains minor pyrite, arsenopyrite, chalcopyrite, sphalerite, and galena, and trace amounts of stannite, canfieldite, and franckeite.

At Mount Cleveland, cassiterite is associated with pyrite, pyrrhotite, and chalcopyrite in lodes within shaly sandstone that is overlain by volcanic rocks and underlain by massive sandstone. Wollastonite, tourmaline, and fluorite, plus minor arsenopyrite, indicate that these lode deposits formed at high temperature. Recent drilling has established reserves of 2 million tons of ore containing 1 percent tin and 0.35 percent copper. Ten miles northeast of Mount Cleveland, the Mount Bischoff mine produced more than 54,000 tons of tin metal from mineralized quartz-feldspar porphyry dikes which probably lie above a buried granite cupola. Cassiterite occurred in pyrrhotite-talc-carbonate bodies that replaced dolomite, in fissure lodes consisting of cassiterite with pyrite, sphalerite, arsenopyrite, and minor stannite in a gangue of quartz, tourmaline, topaz, and fluorite.

Elsewhere in Tasmania, lode tin has been mined at Dalcoath Hill in the Middlesex district of north-central Tasmania (No. 15 on fig. 5), and cassiterite occurs as an accessory mineral in silver-base-metal lodes at numerous localities.

Reserves.—Robertson (1965, p. 88) gave the official Australian Government estimate of reserves in all categories in 1965 as 83,000 long tons of tin (at a price of $3,080 per long ton). As the new plant at Ardlethan will produce at the rate of 650 tons of tin metal per year, reserves there probably can be estimated to equal, at least, 10 years' production.

The International Tin Council (1966, p. 1628) has quoted Australian reserves as equal to 127,000 long tons of tin. Hence, it is possible that the total measured, indicated, and inferred reserves, plus undiscovered resources, may be equal to about 250,000 long tons of tin, assuming that undiscovered resources are at least equal to known reserves.

NEW ZEALAND

New Zealand has not produced tin, and only one known lode can be classed as a tin deposit. North of Port Pegasus on Steward Island, a roof pendant of schist and quartz in biotite granite has been altered to quartz-topaz greisen along a system of anastomosing veinlets in a zone about 2 miles long and a few feet to a few hundred feet wide (Williams, 1934, p. 414). Cassiterite is accompanied by wolframite, topaz, iron-bearing garnet, sphalerite, and gahnite. Elsewhere in New Zealand, cassiterite is confined to noneconomic amounts in stream gravels, beach sands, and pegmatites at widely scattered localities.

CHINA

The information on tin resources of China is incomplete, and has been for many years. The available recent information indicates that new deposits have been discovered, which, in conjunction with the older ones, have at least maintained large reserves.

A large tin field of China is an area about 350 miles long and 200 miles wide covering the southern parts of the provinces of Kiangsi and Hunan, eastern Kwangsi, and northern Kwangtung (fig. 1). The major deposits and reserves, however, lie in the Kochiu district of Yunnan Province. According to Hsieh (1963, p. 374), traces of cassiterite have been found recently in Heilungkiang Province. Most of the 400 known occurrences of tin in China are, however, in the long-known tin regions. Meng (1937, p. 441) pointed out that the main tin deposits of China can be correlated with two structural trends which he called the Nanling and Coastal zones (fig. 6). The Nanling zone parallels the east-west trend of the Nanling Ranges; the Coastal zone parallels the coastline from Hainan Island northeastward. Of these two stanniferous zones, the Nanling is the more important. Hsieh (1963, p. 374) considered the Yunnan (Kochiu) deposits to be related to the deposits of Southeast Asia.

The bedrock in the Kochiu region consists of a series of Precambrian gneisses and schists which are overlain unconformably by feebly metamorphosed slates, phyllites, quartzites, and schists, also of Precambrian age. These in turn are overlain by limestones that range in age from

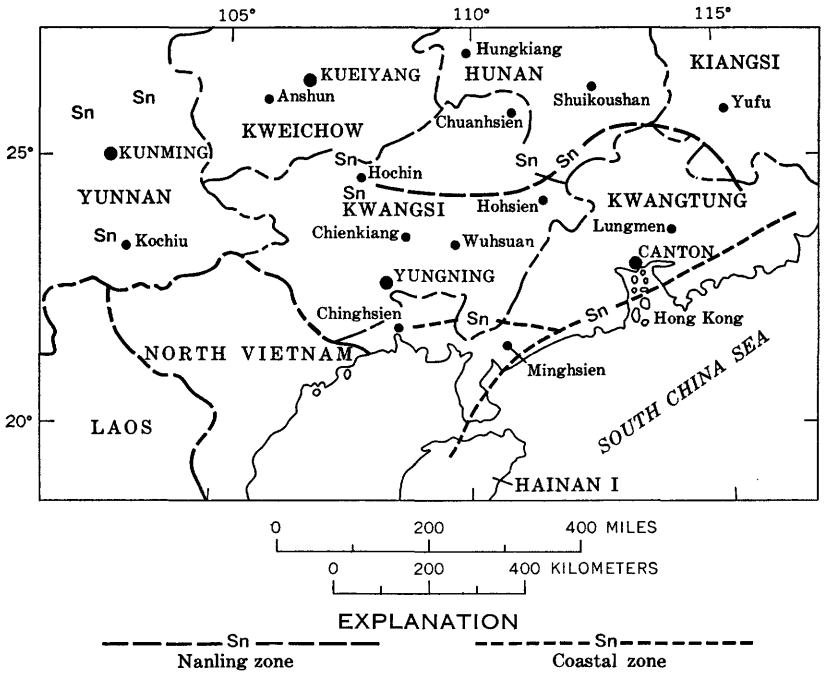


FIGURE 6.—Tin deposits in the Nanling and Coastal zones, China. (From Meng, 1937, fig. 1.)

Devonian to Triassic. In Kochiu valley, widespread karst topography is developed on Triassic limestones, which are the host rocks of most of the tin deposits. The geologic structure of this part of Yunnan consists of east-trending and northeast-trending mountain ranges (Yunnanese Arc), two of which come together at Kochiu (Meng and others, 1937, p. 431). At the Kochiu tinfields, two systems of faults striking north-northeast and northwest cross the ranges, and Meng, Chern, and Ho (1937) pointed out that the tin district occurs at this structural nexus. Biotite granite has been intruded into the limestone, which is host to most of the deposits; these deposits are concentrated along anticlines or above granite cupolas, the most important being those along the anticlines. Many granites of the area contain tourmaline and (or) topaz.

The numerous tin deposits consist of replacement veins and pipes in limestone. Locally the veins reach downward into the underlying granite, where wolframite becomes important. The ore minerals consist of cassiterite, molybdenite, wolframite, bismuthinite, arsenopyrite, pyrite, hematite, magnetite, galena, and sphalerite. Gangue minerals are quartz, tourmaline, topaz, lithium micas, fluorite, and, in contact deposits, diverse calc-siliciate minerals. Many veins have a marked zonation; some mines, originally opened as silver mines, became tin mines at depth (Meng, 1937, p. 444). The Kochiu area is believed to supply 70–80 percent of Chinese tin production and to contain 80 percent of China's reserves.

Tin deposits occur at irregular intervals along the Nanling zone, which extends eastward in Kwangsi Province, then swings northward into southern Hunan, thence eastward into Kiangsi Province, almost to the coast north of Hongkong (fig. 6).

Both lode and placer deposits have been worked in the Hochih area (Sen-Shing, 1928). Lodes occur in limestone, quartzites, and biotite granite. Cassiterite occurs in quartz veins that also contain pyrite, wolframite, stibnite, and bismuthinite. The placers are both eluvial and alluvial. Sen-Shing noted that 10,000 miners worked in the district in 1919, and that 180 tons of metallic tin per year were produced by extremely crude mining methods.

Pipe deposits in the Hohsien area are similar to those in southern Hunan; most consist of pipes in altered limestone near biotite or biotite-hornblende granite (Wang and Hsiung, 1935, p. 82). Most pipes do not exceed a few dozen feet in width. Ore minerals consist of cassiterite, arsenopyrite, chalcopyrite, stannite, bornite, sphalerite, enargite, tennantite, pyrite, and pyrrhotite. Pipes and veins in granite are rare and contain notable amounts of wolframite. Most of the current production comes from placer deposits associated with the lode deposits, and rich alluvial pockets in limestone are worked.

In southwestern Kiangsi Province, tungsten becomes important and most lode deposits are worked for both tin and tungsten. The lodes are fissure-filling quartz veins that occur in biotite granite as well as in the surrounding metamorphic rocks. The ore minerals include cassiterite, wolframite, arsenopyrite, sphalerite, chalcopyrite, molybdenite, bismuthinite, scheelite, and galena.

The tin deposits of the Coastal zone (figs. 1, 6) are associated with biotite granites that are widely distributed in the coastal area from Hainan Island to Japan. Hsieh (1963, p. 377) stated that a common lode type consists of cassiterite-quartz-chlorite veins in both biotite granite and surrounding rocks. The cassiterite is associated with pyrite, pyrrhotite, chalcopyrite, sphalerite, arsenopyrite, and some wolframite. Veins in limestone tend to contain more varied and richer sulfide minerals, and, throughout the region, cassiterite predominates over wolframite. The belt of deposits is correlative with a late Mesozoic tectonic deformation and widespread intrusion of biotite granite that can be considered a continuation of the Malay Peninsula zone.

Reserves.—The recent drop in Chinese tin production is probably caused by the unavailability of modern machinery to replace wornout equipment rather than by the depletion of deposits. Ahlfeld (1958, p.

39) gave reserve figures for 1946–47 that range from 652,000 tons to 1,873,330 tons of tin metal. The Paley Commission suggested 1.5 million long tons of tin metal for Chinese reserves. Because of the great extent of stanniferous regions in China, the writer is inclined toward an optimistic view of Chinese reserves; known reserves are assumed to be 1.5 million long tons of tin, of which 500,000 tons is classed as measured plus indicated, and 1 million tons as inferred.

Resources in submarginal and undiscovered deposits must be large. For this report, total resources are estimated to be at least twice the known reserves, or 3 million long tons of tin (table 3). This estimate is probably conservative.

U.S.S.R.

The information on tin resources of the U.S.S.R. is incomplete, and has been for many years. The available recent information indicates that new deposits have been discovered, which, in conjunction with the older ones, have at least maintained large reserves.

Numerous technical papers dealing with tin deposits of the Soviet Union have been published since 1945, leading to the inference that deposits are widespread. Important new deposits have been found, principally in Siberia. Recent literature mentions deposits on the Kolyma River which are similar geologically to those on the Alaska side of the Bering Strait (Gracheva and Zolotova, 1960). The Mining Journal (1960, p. 517) noted that a large tin concentrator plant was opened in 1960 near the Bering Strait.

The area east of the Urals is favorable for the occurrence of large tin deposits. Major orogenic belts have been extensively intruded by granite; tin deposits are known in most belts. The known producing deposits include both lodes and placers, the lode mines being more important. The fact that Russia no longer imports large amounts of tin indicates that needs are met either from stockpiled tin, or by current production. Robertson (1965, p. 100) suggested consumption is still rising relative to production.

The major known tin-producing regions are located in figure 1 as accurately as descriptions allow. Large production is derived from deposits in the Yakut Republic (Ege-Khaya-Deputatskiy region, fig. 1), and from deposits in the Anadyr Mountains, an east-trending mountain range near the Arctic coastline in easternmost Siberia (Iul'tin and Krasnoarmeyskoye areas, fig. 1). The Anadyr belt continues across the Bering Strait, and the Alaskan deposits on Seward Peninsula are probably along the continuation of this belt. The Ege-Khaya mine in Yakut Republic was opened in 1940, and other mines have been opened since 1953, including a placer mine at Deputatskiy. A large concentrating plant was installed at Iul'tin in 1954 (Mining Jour. 1960).

Several new deposits were developed during and after World War II in the Magadan region of Siberia (Ust'-Omchug, Batugychag, and Galimyy areas, fig. 1) along a mountainous belt trending northeast. Many granites are intruded along the range, and very persistent faults follow the range.

New deposits have been developed since World War II in an important district near Vladivostok on the Sea of Japan (Lifudzin-Khrustal'nyy fig. 1 and the Yaroshavsky and Karalerovo areas. These deposits are alined along a northeast-striking tectonic belt intruded by granitic rocks and cut by extremely numerous and persistent faults which extend landward from the Sea of Okhotsk.

New deposits have been opened since World War II in the older, established mining districts of Transbaikal and Kazakstan, which lie along east-trending ranges along the Mongolian border. Other deposits have been opened along the Kolyma River (Khingansk, fig. 1). These deposits are described as consisting of cassiterite associated with tourmaline, topaz, and numerous sulfide minerals in typical greisens related to silicic intrusive rocks of Late Jurassic and Cretaceous age (Gracheva and Zolotova, 1960).

No attempt is made here to describe the individual deposits in Siberia. The abundant literature (mostly in Russian) indicates that most are high-temperature deposits associated with granite intrusive rocks. Cassiterite is the main ore mineral. As elsewhere in the world, numerous sulfide minerals, including arsenopyrite, pyrite, galena, sphalerite, pyrrhotite, and silver-bearing sulfosalts, are associated with the cassiterite. Pegmatites containing cassiterite and beryl are also known. For brief descriptions of the main deposits known prior to 1952, see Ridge (1953).

Reserves.—Most writers have been hesitant to assign figures to Russian tin reserves, principally because official Russian figures are not available. An estimate of 500,000 tons has been considered reasonable, but this figure seems to have persisted unchanged since 1953, and, in this writer's opinion, does not realistically consider either the large number of producing mines opened since that date, or the tremendous extent of geologically favorable areas in which tin deposits are known to occur.

The writer takes a more optimistic view of Russian tin reserves (table 3) and assumes that proved reserves (measured and indicated category) amount to at least 10 years' production at the 1965 level (about 21,000 long tons, according to U.S. Bur. Mines, 1966), and that inferred reserves in known deposits equal twice the known reserves. Hence, measured reserves are assumed to be 210,000 long tons of tin, and inferred reserves to be 420,000 long tons, probably a conservative estimate.

Resources of submarginal grade, or in undiscovered deposits, are believed to be much larger. For the purpose of this report, resources are assumed to be at least twice the known reserves, or 1,260,000 long tons of tin. This is probably a conservation figure, for it is about equal to that for reserves of the same category in Thailand, and the Russian stanniferous areas are certainly much larger. However, the greater extent of the Russian deposits is in part compensated for by the severe Arctic climate, which is unfavorable for the formation of large and rich placers.

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