Tin

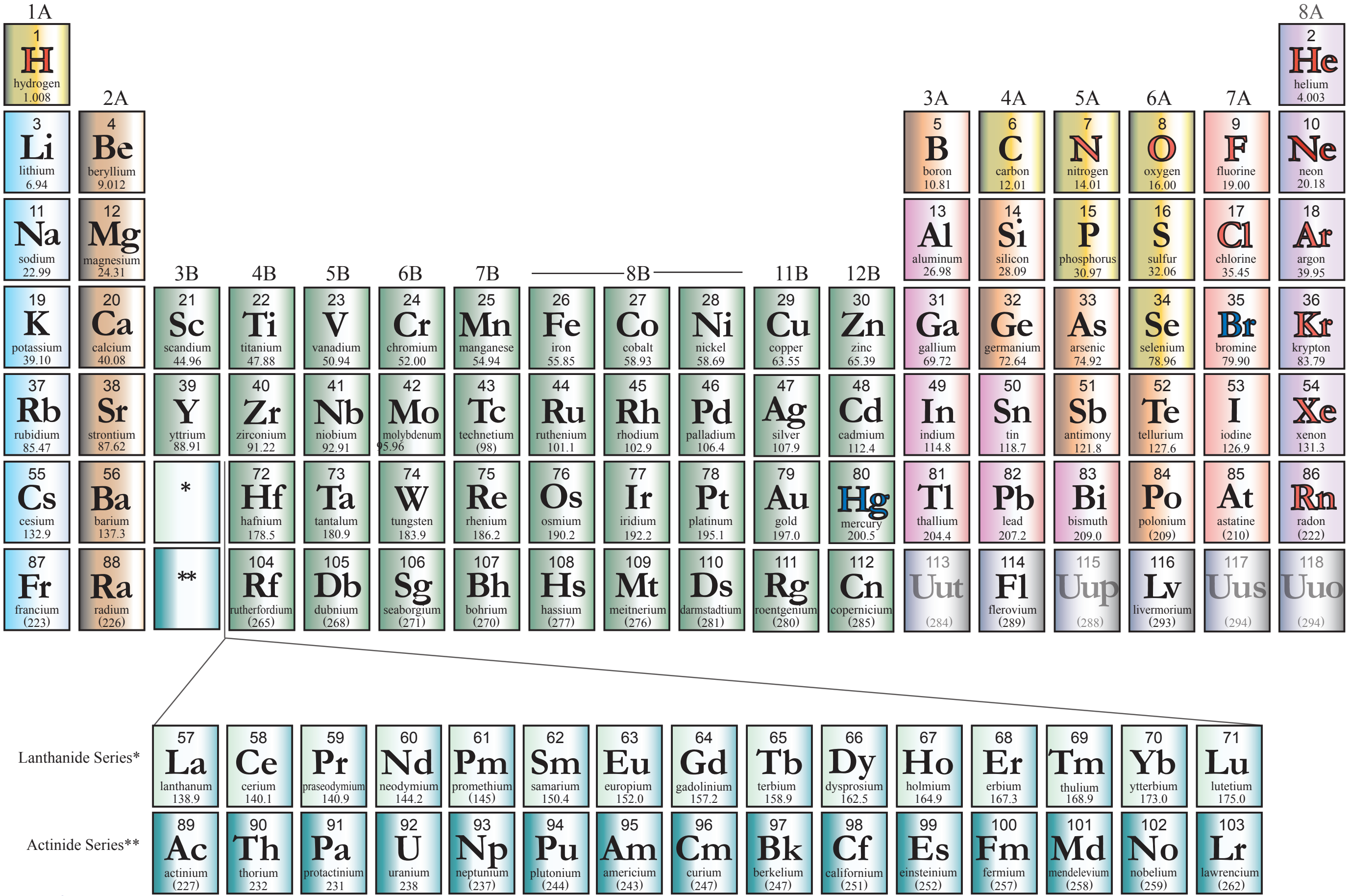
Chapter S of

Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

Professional Paper 1802–S

U.S. Department of the Interior
U.S. Geological Survey

Periodic Table of Elements



1A	2A	3B	4B	5B	6B	7B	8B			11B	12B	3A	4A	5A	6A	7A	8A
1 H hydrogen 1.008																	2 He helium 4.003
3 Li lithium 6.94	4 Be beryllium 9.012											5 B boron 10.81	6 C carbon 12.01	7 N nitrogen 14.01	8 O oxygen 16.00	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium 24.31											13 Al aluminum 26.98	14 Si silicon 28.09	15 P phosphorus 30.97	16 S sulfur 32.06	17 Cl chlorine 35.45	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.88	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.39	31 Ga gallium 69.72	32 Ge germanium 72.64	33 As arsenic 74.92	34 Se selenium 78.96	35 Br bromine 79.90	36 Kr krypton 83.79
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.96	43 Tc technetium (98)	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs cesium 132.9	56 Ba barium 137.3	*	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.9	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.5	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)
87 Fr francium (223)	88 Ra radium (226)	**	104 Rf rutherfordium (265)	105 Db dubnium (268)	106 Sg seaborgium (271)	107 Bh bohrium (270)	108 Hs hassium (277)	109 Mt meitnerium (276)	110 Ds darmstadtium (281)	111 Rg roentgenium (280)	112 Cn copernicium (285)	113 Uut (284)	114 Fl flerovium (289)	115 Uup (288)	116 Lv livermorium (293)	117 Uus (294)	118 Uuo (294)

Lanthanide Series*	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium (145)	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.2	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0	71 Lu lutetium 175.0
Actinide Series**	89 Ac actinium (227)	90 Th thorium 232	91 Pa protactinium 231	92 U uranium 238	93 Np neptunium (237)	94 Pu plutonium (244)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (247)	98 Cf californium (251)	99 Es einsteinium (252)	100 Fm fermium (257)	101 Md mendelevium (258)	102 No nobelium (259)	103 Lr lawrencium (262)

element names in **blue** are liquids at room temperature
element names in red are gases at room temperature
element names in black are solids at room temperature

Modified from Los Alamos National Laboratory Chemistry Division; available at http://periodic.lanl.gov/images/periodictable.pdf.

Cover. Left, cassiterite crystals. Photograph copyright © Dakota Matrix Minerals; used with permission. Right, wood tin cassiterite. Photograph copyright © R. Weller, Cochise College; used with permission.

Tin

By Robert J. Kamilli, Bryn E. Kimball, and James F. Carlin, Jr.

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Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

Edited by Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley

Professional Paper 1802–S

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
angstrom (Å) (0.1 nanometer)	0.003937	microinch
angstrom (Å) (0.1 nanometer)	0.000003937	mil
micrometer (µm) [or micron]	0.03937	mil
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
milliliter (mL)	0.03381	ounce, fluid (fl. oz)
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Mass	
microgram (µg)	0.00000003527	ounce, avoirdupois (oz)
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
gram (g)	0.03527	ounce, avoirdupois (oz)
gram (g)	0.03215075	ounce, troy
kilogram (kg)	32.15075	ounce, troy
kilogram (kg)	2.205	pound avoirdupois (lb)
ton, metric (t)	1.102	ton, short [2,000 lb]
ton, metric (t)	0.9842	ton, long [2,240 lb]
	Deposit grade	
gram per metric ton (g/t)	0.0291667	ounce per short ton (2,000 lb) (oz/T)
	Pressure	
megapascal (MPa)	10	bar
gigapascal (GPa)	10,000	bar
	Density	
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)
milligram per cubic meter (mg/m^3)	0.00000006243	pound per cubic foot (lb/ft^3)
	Energy	
joule (J)	0.0000002	kilowatthour (kWh)
joule (J)	6.241×10^{18}	electronvolt (eV)
joule (J)	0.2388	calorie (cal)
kilojoule (kJ)	0.0002388	kilocalorie (kcal)

International System of Units to Inch/Pound

Multiply	By	To obtain
Radioactivity		
becquerel (Bq)	0.00002703	microcurie (μCi)
kilobecquerel (kBq)	0.02703	microcurie (μCi)
Electrical resistivity		
ohm meter (Ω-m)	39.37	ohm inch (Ω-in.)
ohm-centimeter (Ω-cm)	0.3937	ohm inch (Ω-in.)
Thermal conductivity		
watt per centimeter per degree Celsius (watt/cm °C)	693.1798	International British thermal unit inch per hour per square foot per degree Fahrenheit (Btu in/h ft^2 °F)
watt per meter kelvin (W/m-K)	6.9318	International British thermal unit inch per hour per square foot per degree Fahrenheit (Btu in/h ft^2 °F)

Inch/Pound to International System of Units

Length		
mil	25.4	micrometer (μm) [or micron]
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Volume		
ounce, fluid (fl. oz)	29.57	milliliter (mL)
ounce, fluid (fl. oz)	0.02957	liter (L)
Mass		
ounce, avoirdupois (oz)	28,350,000	microgram
ounce, avoirdupois (oz)	28,350	milligram
ounce, avoirdupois (oz)	28.35	gram (g)
ounce, troy	31.10 348	gram (g)
ounce, troy	0.03110348	kilogram (kg)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	ton, metric (t)
ton, long (2,240 lb)	1.016	ton, metric (t)
Deposit grade		
ounce per short ton (2,000 lb) (oz/T)	34.285714	gram per metric ton (g/t)
Energy		
kilowatthour (kWh)	3,600,000	joule (J)
electronvolt (eV)	1.602×10^{-19}	joule (J)
Radioactivity		
microcurie (μCi)	37,000	becquerel (Bq)
microcurie (μCi)	37	kilobecquerel (kBq)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Celsius (°C) may be converted to kelvin (K) as follows:

$$K = °C + 273.15$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Datum

Unless otherwise stated, vertical and horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84). Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in soils and (or) sediment are given in milligrams per kilogram (mg/kg), parts per million (ppm), or parts per billion (ppb).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L), micrograms per liter (µg/L), nanogams per liter (ng/L), nanomoles per kilogram (nmol/kg), parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt).

Concentrations of suspended particulates in water are given in micrograms per gram (µg/g), milligrams per kilogram (mg/kg), or femtograms per gram (fg/g).

Concentrations of chemicals in air are given in units of the mass of the chemical (milligrams, micrograms, nanograms, or picograms) per volume of air (cubic meter).

Activities for radioactive constituents in air are given in microcuries per milliliter (µCi/mL).

Deposit grades are commonly given in percent, grams per metric ton (g/t)—which is equivalent to parts per million (ppm)—or troy ounces per short ton (oz/T).

Geologic ages are expressed in mega-annum (Ma, million years before present, or 10^6 years ago) or giga-annum (Ga, billion years before present, or 10^9 years ago).

For ranges of years, "to" and (or) the en dash ("–") mean "up to and including."

Concentration unit	Equals
milligram per kilogram (mg/kg)	part per million
microgram per gram (µg/g)	part per million
microgram per kilogram (µg/kg)	part per billion (10^9)

Equivalencies

part per million (ppm): 1 ppm = 1,000 ppb = 1,000,000 ppt = 0.0001 percent
part per billion (ppb): 0.001 ppm = 1 ppb = 1,000 ppt = 0.0000001 percent
part per trillion (ppt): 0.000001 ppm = 0.001 ppb = 1 ppt = 0.0000000001 percent

Metric system prefixes

tera- (T-)	10^{12}	1 trillion
giga- (G-)	10^9	1 billion
mega- (M-)	10^6	1 million
kilo- (k-)	10^3	1 thousand
hecto- (h-)	10^2	1 hundred
deka- (da-)	10	1 ten
deci- (d-)	10^{-1}	1 tenth
centi- (c-)	10^{-2}	1 hundredth
milli- (m-)	10^{-3}	1 thousandth
micro- (µ-)	10^{-6}	1 millionth
nano- (n-)	10^{-9}	1 billionth
pico- (p-)	10^{-12}	1 trillionth
femto- (f-)	10^{-15}	1 quadrillionth
atto- (a-)	10^{-18}	1 quintillionth

Abbreviations and Symbols

°C	degree Celsius
α-tin	alpha-tin (also known as gray tin)
ß-tin	beta-tin (also known as white tin)
µg/L	microgram per liter
µm	micrometer
3TG	tantalum, tin, tungsten, and (or) gold
AMD	acid mine drainage
ATPC	Association of Tin Producing Countries
ca.	circa
Congo (Kinshasa)	Democratic Republic of the Congo
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
Ga	giga-annum
g/cm^3	gram per cubic centimeter
HFO	hydrous ferric oxide
kg/m^3	kilogram per cubic meter
km	kilometer
km^2	square kilometer
LC_{50}	lethal concentration 50 (concentration that kills 50 percent of test population within a given timeframe)
m	meter
Ma	mega-annum
MC–ICP–MS	multiple collector-inductively coupled plasma-mass spectrometry
mg/L	milligram per liter
mg/m^3	milligram per cubic meter
ng/L	nanogram per liter
ng/m^3	nanogram per cubic meter
pg/L	picogram per liter
pg/m^3	picogram per cubic meter
ppm	part per million
QSP	quartz-sericite-pyrite
SEC	U.S. Securities and Exchange Commission
SHRIMP	sensitive high-resolution ion microprobe
TBT	tributyltin

TBTCl	tributyltin chloride
TBTO	bis(tri-*n*-butyltin) oxide
TPT	triphenyltin
UST	unidirectional solidification texture
WGS 84	World Geodetic System of 1984

Tin

By Robert J. Kamilli, Bryn E. Kimball, and James F. Carlin, Jr.[1]

Abstract

Tin (Sn) is one of the first metals to be used by humans. Almost without exception, tin is used as an alloy. Because of its hardening effect on copper, tin was used in bronze implements as early as 3500 B.C. The major uses of tin today are for cans and containers, construction materials, transportation materials, and solder. The predominant ore mineral of tin, by far, is cassiterite (SnO_2). Tin has not been mined or smelted in the United States since 1993 and 1989, respectively.

In 2015, the world's total estimated mine production of tin was 289,000 metric tons of contained tin. Total world reserves at the end of 2016 were estimated to be 4,700,000 metric tons. China held about 24 percent of the world's tin reserves and accounted for 38 percent of the world's 2015 production of tin.

The proportion of scrap used in tin production is between 10 and 25 percent. Unlike many metals, tin recycling is relatively efficient, and the fraction of tin in discarded products that get recycled is greater than 50 percent.

Only about 20 percent of the world's identified tin resources occur as primary hydrothermal hard-rock veins, or lodes. These lodes contain predominantly high-temperature minerals and almost invariably occur in close association with silicic, peraluminous granites. About 80 percent of the world's identified tin resources occur as unconsolidated secondary or placer deposits in riverbeds and valleys or on the sea floor. The largest concentration of both onshore and offshore placers is in the extensive tin belt of Southeast Asia, which stretches from China in the north, through Thailand, Burma (also referred to as Myanmar), and Malaysia, to the islands of Indonesia in the south. Furthermore, tin placers are almost always found closely allied to the granites from which they originate. Other countries with significant tin resources are Australia, Bolivia, and Brazil.

Most hydrothermal tin deposits belong to what can be thought of as a superclass of porphyry-greisen deposits. The hydrothermal tin deposits are all characterized by a close spatial, temporal, and genetic association with highly differentiated, peraluminous porphyritic granite intrusions. The intrusions form pegmatites; disseminated ore; parallel or subparallel, greisen-bordered sheeted veins that either cross-cut the intrusion or are peripheral to it; skarns; and (or) limestone replacements that contain different amounts of cassiterite, molybdenite, and wolframite.

The tectonic settings of tin-bearing granites are relatively well understood and of limited variety. Tin and tungsten deposits and their associated igneous rocks are found mainly in continental settings.

Historically, prospecting for tin has been carried out by the time-honored methods of panning, drilling, trenching, and assaying. Geophysical and geochemical surveys have been employed to cover large areas more rapidly, isolating areas of possible tin deposits so that drilling can be more effective and less costly. Elemental concentrations and relationships of the lithophile elements, especially barium, lithium, niobium, potassium, rubidium, and zirconium, are the most reliable chemical indicators of ore-forming processes and tin-bearing potential.

The average human diet includes an intake of about 10 milligrams per day of tin. Ingestion of tin in significantly greater amounts than 10 milligrams per day may lead to a stomach ache, anemia, and liver and kidney problems. Exposure to some organo-tin compounds can interfere with brain and nervous system function and, in severe cases, can cause death. Extended inhalation of tin oxide—an issue mainly for those people who work in the tin industry—results in a higher potential to develop stannosis, which is a mild disease of the lungs caused by the inhalation of tin-bearing dust. Inorganic tin is poorly absorbed by the body, and no evidence exists for the carcinogenicity of metallic tin and tin compounds in humans.

Most placer tin deposits are mined by open pit and (or) dredging methods. Mining of alluvial placers in modern streambeds and riverbeds is likely to increase the amount of sediment delivered downstream. This, combined with potential diversion of rivers and streams, may negatively

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[1] Deceased.

affect downstream ecosystems. Many of the placer deposits located in Burma, Indonesia, Malaysia, and Thailand are located offshore. Most offshore placer tin deposits are mined by dredging methods, which have the potential to negatively affect benthic, midwater, and pelagic ecosystems.

In a congressionally mandated U.S. Department of Defense study of strategic minerals published in 2013, tin has the greatest shortfall amount (insufficient supply to meet demand) at $416 million; this amount is more than twice that of antimony ($182 million), which is the strategic mineral with the next largest shortfall amount (U.S. Department of Defense, 2013). The United States imported 75 percent of its tin supply in 2015. During the period 2012–15, these imports were from, in descending order of amount imported, Peru, Indonesia, Malaysia, and Bolivia.

A promising advancement concerning research into the origin of tin deposits is the recent development of a reliable method of analyzing tin isotopes in cassiterite. Although the mechanism of transport and deposition of tin is fairly well understood, the means by which tin is incorporated into the parent magma at the points of magma generation and ascent needs further investigation.

Tin metallogenic provinces worldwide are well known. Consequently, any undiscovered tin deposits will likely be spatially close to known deposits or extensions of the same.

Introduction

Tin was one of the earliest metals known to humanity. Aside from native gold and copper, which are found in nature, tin and lead were the first metals to be smelted. Because of its hardening effect on copper, tin was used in bronze implements as early as 3500 B.C., although the pure metal was not commonly used until about 600 B.C. Bronze, which is a copper-tin alloy that can be sharpened and is hard enough to retain a cutting edge, was used in construction tools as well as in weapons. Arsenic-containing bronzes, which were probably accidentally created by smelting arsenic- and copper-containing minerals, preceded tin bronzes by about 2,000 years (fifth millennium versus third millennium B.C.). Oven-fired Mesopotamian pottery from the Ubaid culture (about 6500 to 3800 B.C.) was contemporaneous with the origins of metallurgy. The origins of metallurgy, therefore, may have been the serendipitous outcome of firing of ceramics when ore-bearing rocks were accidentally placed in the kiln (Cowen, 1999).

Tin placer deposits commonly form in streambeds where running water removes lighter material and leaves the heavier cassiterite (SnO_2), which has a specific gravity of 6.8 to 7.1, behind. Cassiterite was probably first picked up in streambeds, as its density and translucent brown-black color make it conspicuous.

The area of Cornwall, England, was historically a leading world producer of tin. Tin deposits in Cornwall had been worked since at least Roman times, although the mining of tin likely began there as far back as the early Bronze Age. Most mining up to the 17th century was from alluvial sources. Cornwall continued to be a major world producer of tin up through the 19th century (Penhallurick, 1986, p. 148). Although the area still has identified resources of tin, the last working tin mine in Cornwall (the South Crofty Mine) was closed in 1998 (Carlin, 2000).

The predominant ore mineral of tin is cassiterite, although small amounts of tin are recovered from other tin-bearing minerals, including stannite (Cu_2FeSnS_4), cylindrite (Pb_3Sn_3,Sb_2S_{14}), franckeite ($Pb_5Sn_3Sb_2S_{14}$), canfieldite (Ag_8SnS_6), and teallite ($PbSnS_2$). Rock-forming minerals that may contain significant amounts of tin (that is, tens to hundreds of parts per million) are, in order of increasing tin content, muscovite, biotite (annite), titanite, and titanomagnetitite (Wang and others, 2013). Table S1 includes a more comprehensive, although not exhaustive, list of tin-bearing minerals. The chemical symbol for tin, Sn, comes from the Latin *stannum*; hence, the name stannite for one of its minerals. After the Bronze Age and up to the 20th century, pewter, which is an alloy of 85 to 90 percent tin coupled with copper, antimony, and (or) lead, was the leading material for kitchenware, tableware, and other items, such as candlesticks, in households that could not afford sterling silver or gold. Tin cans, which are made mostly of steel, are so named because the steel is coated with tin to form tin plate, which has low toxicity.

Tin is silvery, malleable, and not easily oxidized in air. The metallic form of tin, or beta-tin (ß-tin, also known as white tin), is stable at and above room temperature, is malleable, and has an unusual, tetragonal crystal structure. Tin becomes a superconductor below 3.72 Kelvin (−269.43 degrees Celsius [°C]) (De Haas and others, 1935); in fact, tin was one of the first superconductors to be studied. In contrast, the nonmetallic form of tin, or alpha-tin (α-tin, also known as gray tin), which is stable below 13.2 °C, is brittle and has a diamond cubic crystal structure, similar to diamond, germanium, and silicon. The α-tin has no metallic properties at all because its atoms form a covalent structure where electrons cannot move freely. It is a dull-gray powdery material with no common uses, other than a few specialized semiconductor applications (Holleman and others, 1985). The spontaneous transformation of tin from the β form to the α form, a phenomenon known as “tin pest,” takes place at temperatures of 13.2 °C and below. The presence of impurities (for example, aluminum, zinc, and others) lowers the transition temperature to below 0 °C; upon the introduction of antimony or bismuth, the transformation may not take place at all. The addition of these elements thus increases the durability of tin (Schwartz, 2002).

Table S1. List of selected tin-bearing minerals.

[Data are from Fleischer (1983). NA, not available]

Mineral name	Chemical formula	Location of geographic occurrence
Berndtite	SnS_2	Cerro de Potosí, Bolivia
Canfieldite	Ag_8SnS_6	Bolivia; Tasmania, Australia
Cassiterite	SnO_2	Worldwide
Colusite	$Cu_3(As,Sn,V,Fe)S_4$	Butte, Montana; Australia
Cylindrite	$Pb_3Sn_4FeSb_2S_{14}$	Bolivia; Tasmania, Australia
Franckeite	$Pb_5Sn_3Sb_2S_{14}$	Bolivia; Tasmania, Australia
Herzenbergite	SnS	Bolivia
Hulsite (also called Paigeite)	$(Fe^{2+},Mg)_2(Fe^{3+},Sn)BO_5$	Brooks Range and Seward Peninsula, Alaska; eastern Siberia Russia
Malayaite	$CaSnSiO_5$	Malaysia; Cornwall, United Kingdom
Mawsonite	$Cu_6^{1+}Fe_2^{3+}Sn^{4+}S_8$	New South Wales; Tasmania, Australia
Native tin	Sn	Native tin is found in placer deposits and in unusual igneous intrusions. Australia has the recognized type locality.
Nigerite (More correctly, Ferronigerite–2N1S)	$(Zn,Mg,Fe^{2+})(Sn,Zn)_2(Al,Fe^{3+})_{12}O_{22}(OH)_2$	Nigeria
Nordenskiöldine	$CaSnB_2O_6$	Norway; Namibia
Ottemannite	Sn_2S_3	Bolivia
Renierite	$Cu_3(Fe,Ge,Zn)(S,As)_4$	Democratic Republic of the Congo (Congo [Kinshasa]); Namibia
Sorensenite	$Na_4SnBe_2Si_6O_{16}(OH)_4$	Greenland
Stannite	Cu_2FeSnS_4	Worldwide
Stannomicrolite (Sukulaite)	$Sn_2Ta_2O_7$	NA
Stokesite	$CaSnSi_3O_9{\cdot}2H_2O$	Cornwall, United Kingdom
Teallite	$PbSnS_2$	Bolivia
Thoreaulite	$SnTa_2O_6$	Democratic Republic of the Congo (Congo [Kinshasa])
Varlamoffite (?)	$(Sn,Fe)(O,OH)_2$	Democratic Republic of the Congo (Congo [Kinshasa]); Bolivia

Strategic and Critical Resource Issues

The United States has no tin reserves and is dependent on imports to meet its tin requirements (Anderson, 2016b). Tin is considered a critical and strategic metal because of its importance to national security (McGroarty and Wirtz, 2012). In a congressionally mandated U.S. Department of Defense (DOD) study of strategic minerals published in 2013, tin was shown to have the greatest shortfall amount (insufficient supply to meet demand measured in monetary terms—$416 million) in a list of strategic minerals, and more than twice the shortfall amount of the next strategic mineral, antimony ($182 million). The shortfall amounts result from a modeling process that, given a 4-year scenario that assumes 1 year of conflict and 3 years of recovery and regeneration, computes material demand at all levels of the U.S. economy and then compares the quantity of material supply with the quantity demanded, taking a number of conflict-related factors into account. These factors include unavailability of supply from adversaries, war damage, shipping losses, infrastructure and (or) ability degradation, anti-U.S. orientation, and foreign competition (that is, market share) (U.S. Department of Defense, 2013).

Artisanal and small-scale mining of tin in the Democratic Republic of the Congo (Congo [Kinshasa], formerly Zaire) and neighboring countries has been identified as a potential source of funding for armed groups engaged in civil unrest. This has led the United States, through passage of Section 1502 of the Dodd-Frank Wall Street Reform and Consumer Protection Act (Pub.L. 111–203, H.R. 4173; commonly referred to as Dodd–Frank) in 2010, to make it a statutory obligation for all companies registered with the U.S. Securities and Exchange Commission (SEC) to perform due diligence to determine whether the products or components they manufacture contain tantalum, tin, tungsten, and (or) gold (3TG) minerals and, if so, to determine whether these minerals were sourced from Congo (Kinshasa) and (or) its neighboring countries. In addition, under rules issued by the SEC, publicly traded companies are required to report the sources of 3TG materials used, starting in 2014.

In 2015, the United States relied on foreign sources for 75 percent of its annual apparent consumption of tin. The major foreign sources of tin, other than scrap, during the period 2011–15 were, in descending order of amount imported, Peru, Indonesia, Malaysia, and Bolivia (Anderson, 2017). Nearly 30 percent of the U.S. tin supply from 2010 through 2014 was produced from scrap (Papp, 2016).

Uses and Applications

Almost without exception, tin is used in alloys. Although it is a metallic mineral, it is rarely used in the elemental form because it decomposes at temperatures below 13.2 °C (Sainsbury and Reed, 1973, p. 637). Up to 28 percent tin can be combined with copper, but 10 percent produces an optimum-strength alloy, and as little as 2 percent tin will harden copper (Wheeler and Maddin, 1980). U.S. consumption of tin by end-use category in 2014 was in cans and containers, 23 percent; construction, 18 percent; transportation, 17 percent; electrical, 12 percent; and other, 30 percent (Anderson, 2015). U.S. consumption of tin by end use finished product is shown in figure S1.

Substitutes for Tin

Common substitutes for tin in cans and containers are aluminum, glass, paper, plastic, or tin-free steel. Other materials that are used to substitute for tin are epoxy resins for solder; aluminum alloys, copper-base alloys, and plastics for bronze; plastics for metal bearings that contain tin; and compounds of lead and sodium for some tin chemicals (Anderson, 2016b).

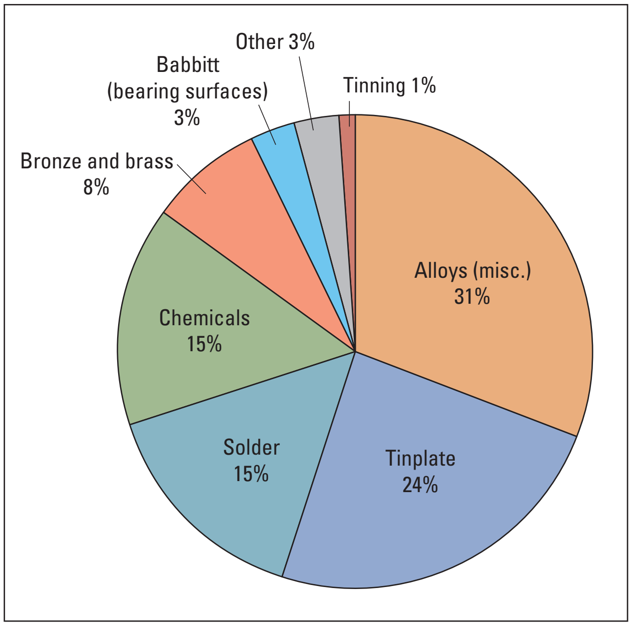
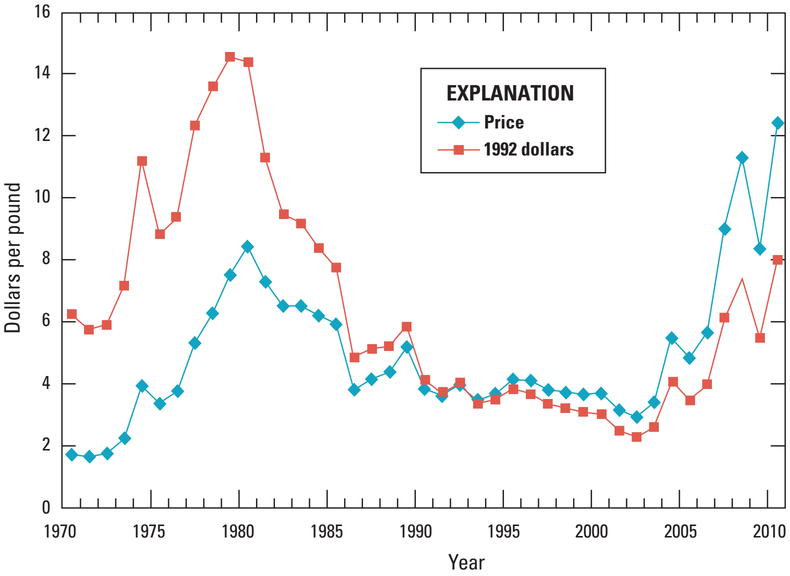


Figure S1. Pie chart showing major end uses of tin as a percentage of total consumption in the United States in 2014. Data are from Anderson (2016a, table 3). misc., miscellaneous

Tin Prices and Pricing

During the 20th century, the pricing of tin was somewhat “regulated” by a series of agreements structured between producer countries and consumer countries dating back to 1921 (Carlin, 2013). The International Tin Council, an association of leading world tin-producing and -consuming countries, was established in 1956 to try to stabilize both tin prices and the supply of and demand for tin until the organization was disbanded in 1989. The Association of Tin Producing Countries (ATPC) was chartered on August 16, 1983, to perform activities complementary to those of the International Tin Council. The five charter members of the ATPC were Bolivia, Congo (Kinshasa), Indonesia, Malaysia, and Thailand, with Australia and Nigeria joining later. The ATPC was disbanded in 2001. Figure S2 shows the average annual prices of tin metal from 1970 to 2010 (Carlin, 2013).



Significant events affecting tin prices since 1970

1956–85	International Tin Agreements (a continuous series of complex, global, 4-year pacts)
1973–80	Rampant inflation
1981–82	Sharp recession
1980–2010	Increased toxicity issues with lead, leading to increased tin consumption as a lead replacement
2002–08	A period of world steel company (tinplate producers) consolidations and mergers that often resulted in lower available world tinplate and increased tin pricess
2002–09	Tin mine and smelter production declined in Indonesia owing to Government closures of illegal tin smelters, smuggling, and severe weather
2008–09	Global financial crisis

Figure S2. Graph showing the average annual prices of tin metal from 1970 to 2010. Both the nominal (unadjusted) prices and real prices (in 1992 constant dollars) are shown. Graph is from Carlin (2013).

Geology

Geochemistry

Tin has an atomic number of 50 and an atomic weight of 118.69. It has two oxidation states: +2 and +4; the +4 oxidation state occurs in the mineral cassiterite. Tin is the 49th most abundant element, and it has the largest number of stable isotopes (10) in the periodic table of elements. The average abundance of tin in Earth's crust is low at about 2.3 parts per million (ppm) compared with 70 ppm for zinc, 60 ppm for copper, and 14 ppm for lead. Tin is both siderophile and, to a lesser extent, lithophile; thus, it has an affinity for both iron and oxygen and is associated with boron, fluorine, lithium, and rubidium in the late-stage differentiates of granites or their extrusive equivalents. In pegmatitic settings, tin is associated with beryllium, boron, lithium, niobium-tantalum, tungsten, and the rare-earth elements (Rose and others, 1979; Carlin, 1985).

According to the study of tin-bearing and tin-barren granites in northern Nigeria by Olade (1980), highly evolved biotite granites are genetically and spatially related to tin mineralization (also Falconer, 1912; Williams and others, 1956; MacLeod and others, 1971; Bowden and Kinnaird, 1978). Beus (1969) also showed that statistically significant variations are found between granites of nonstanniferous regions and granites of stanniferous regions, as well as among biotite granites in different areas of Russia. Part of the explanation for this association lies in that, in less differentiated granites, tin is locked up in early crystallized silicate minerals, such as fayalite, hornblende, and riebeckite. This conclusion is confirmed by the high contents of tin and other elements, such as niobium, in these rocks, particularly the peralkaline riebeckite granites (Bowden and Van Breemen, 1972). In contrast, biotite crystallized late within the biotite granites; consequently, tin and other elements were able to be concentrated into the volatile-rich fraction of the melt and subsequently in exsolved mineralizing fluids. Alexsiyev (1970) and Bowden and Van Breemen (1972) suggested that the enrichment of tin and related elements in tin-bearing granites is connected with albitization and the trace-element overprinting by post-magmatic fluids. Albitization is a product of subsolidus recrystallization (hydrothermal alteration) and is accompanied by the enrichment of the magma in trace elements, such as niobium, rubidium, and tin, and its depletion in barium, strontium, and zirconium. This pattern of trace-element association may be attributed to the development of an alkali-volatile-rich phase during the evolution of the granitic magmas.

Tin-bearing granites tend to show a similar pattern of enrichment in trace elements. According to Bowden and Kinnaird (1978), this enrichment may be the result of a continuum of ore-forming processes: that is, an early dispersed phase of mineralization associated with alkali-volatile-rich, early post-magmatic fluids, and a later phase of fracture-controlled mineralization associated with hydrothermal solutions from which sulfides are commonly deposited. This is consistent with the occurrence of both types of mineralization within the same intrusive body (Olade, 1980).

Three mechanisms have been proposed by Heinrich (1995) for cassiterite precipitation. The first is acid neutralization by feldspar hydrolysis, which takes place during the formation of alteration assemblages. The second is vapor separation (boiling), which effectively removes hydrogen chloride (HCl) and hydrogen gas (H_2) and causes cassiterite deposition. The third is mixing of hot, saline magmatic fluid with a nonmagmatic fluid.

Mineralogy

Cassiterite is a member of the rutile group of metal oxides that includes rutile (TiO_2), pyrolusite (MnO_2), and plattnerite (PbO_2); it is tetragonal and belongs to the space group $P4_2$/mnm. The structure of the conventional unit cell of SnO_2, which is depicted in figure S3, is characterized by two lattice parameters, *a* and *b*, and an internal parameter *u* associated with the O (oxygen) atomic position. There are two formula units per primitive unit cell, with the threefold-coordinated oxygen atoms forming distorted octahedral configurations around the tin atoms (Floriano and others, 2010). Members of the rutile group show little variation in composition and little tendency to form isomorphous series between the species. Cassiterite has an adamantine, greasy, submetallic luster (fig. S4); it ranges from transparent to opaque, and can be black, yellow, brown, red, or white. It has a Mohs hardness of 6 to 7, imperfect cleavage ({100} and {110}), and a density range of from 6.98 to 7.01 grams per cubic centimeter (g/cm^3). Optically, it has very high relief and weak pleochroism and is anomalously biaxial (Hudson Institute of Mineralogy, 2016).

A radially fibrous colloform variety of cassiterite ("wood tin") (fig. S5) can form by secondary processes in the zone of oxidation of tin deposits. It can also form as a hypogene mineral both in deep-seated veins and, in particular, as colloform masses associated with rhyolite flow-dome deposits of lavas and associated tuff (Palache and others, 1944).

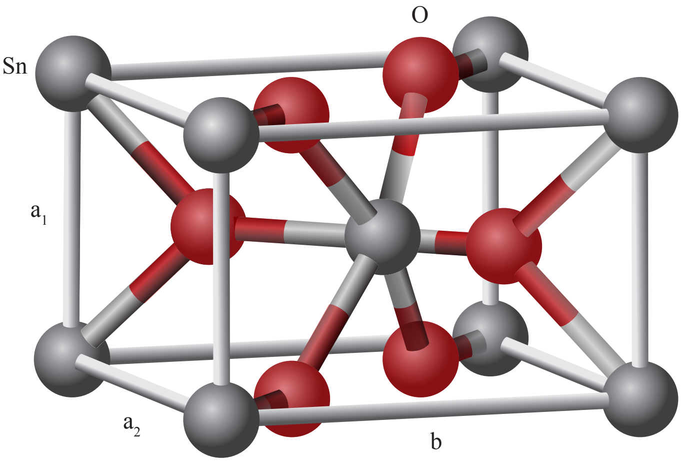


Figure S3. Ball-and-stick model of part of the crystal structure of cassiterite (SnO_2). Oxygen (O) atoms are shown in red, and tin (Sn) atoms, in gray. Courtesy of Ben Mills.

Figure S4. Photograph of cassiterite crystals. Copyright © Dakota Matrix Minerals; used with permission.

Figure S5. Photograph of wood tin cassiterite. Copyright © R. Weller, Cochise College; used with permission.

Deposit Types

Placer Tin Deposits

Placer deposits have traditionally been an important source of tin; in 2012, they accounted for about 70 percent of the world output of cassiterite concentrates, principally from, in order of output, Malaysia, Indonesia, China, Burma (also referred to as Myanmar), Thailand, Nigeria, and Congo (Kinshasa) (Taylor, 1979; Carlin, 2014). Because cassiterite is both heavy and chemically inactive, it is concentrated in residual placers that form over or adjacent to bedrock source areas where weathering and erosional processes remove lighter rock materials. Furthermore, gravity assists in downslope movement of heavy minerals that are released by weathering to form eluvial placers (that is, deposits that remain relatively close to the primary deposit from which they are derived). The richest placers are found in stream deposits where flowing water has concentrated heavy minerals generally derived from residual or eluvial placers. Ocean beach sands may also contain placer accumulations of tin, such as those mined offshore in Indonesia and Thailand. No extensive placer deposits have been found in the conterminous United States (Carlin, 1985).

Granite-Related Tin Deposits

Granite-related tin deposits are another important source of tin. Lehmann (1990) traced the history of research on granite-related deposits. According to Lehmann, the close relationship between tin deposits and granites has been well known since the mid-19th century. Research since then has mainly refined the understanding of the chemistry of the associated granites, the tectonic environment, and the mechanisms of deposition and localization of tin mineralization.

As discussed by Lehmann (1990), Alexander von Humboldt (1823) introduced the term “tin granite” as opposed to “normal granite.” The first comprehensive treatise on the geology of tin and the first scientific theory of magmatic-hydrothermal ore formation in general was developed by Élie de Beaumont (1847). He concluded that tin ore deposits are associated with granites and are located preferentially in apical portions of granites and their immediate country rocks (fig. S6). Daubrée (1841) had already observed that tin deposits in the areas of Cornwall (United Kingdom), Bretagne (France), and Erzgebirge (Germany) are always confined to a zone extending less than 500 m from the granite contact. Élie de Beaumont (1847) further concluded that tin ore deposits are commonly associated with individual granite bodies extending out of larger batholiths, and that the ore occurs in rocks particularly rich in quartz, tourmaline, and fluorine-bearing minerals and that formed as a result of alteration of the original host rock (that is, greisens). Tin granites are anomalous in texture—for example, unidirectional solidification textures (USTs, also known as comb quartz layers or stockscheiders), graphic intergrowths, and pegmatitic dikes and pods (Shannon and others, 1982; White and others, 1981; Kirkham and Sinclair, 1988); they are also anomalous in composition—for example, “specialized, S-type granites” enriched in Rb, Cs, Li, Th, U, Nb, Ta, and W and depleted in Sr, Eu, Ba, Ti, Co, and Ni (Lehmann, 1990).

Classifications of Granite-Related Tin Deposits

Granite-related tin deposits can be classified according to the following general types. This information is modified primarily after S.S. Smirnov from Magak’yan (1968), Taylor (1979, p. 45–76), and Lehmann (1990).

Stanniferous pegmatites.—“These pegmatites are of the quartz-microcline type, with albite, muscovite, [and commonly] spodumene, topaz, and tourmaline. Cassiterite is irregularly disseminated throughout the pegmatite body and commonly in areas where secondary processes have taken place” (Taylor, 1979, p. 46–47). Examples of stanniferous pegmatites include the Jābal as Silsilah pegmatites in Saudi Arabia

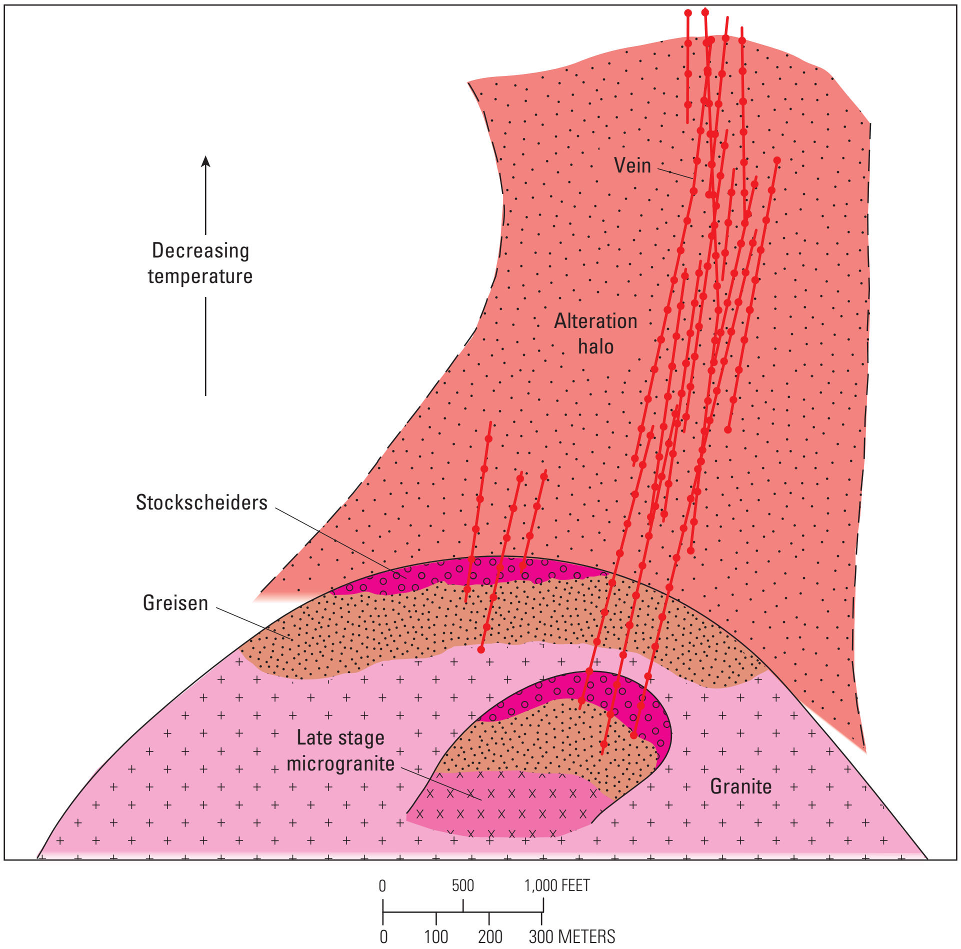


Figure S6. Schematic vertical section across a typical hydrothermal mineralized granite cupola showing salient features of a shallow granite-related tin-mineralized system. As a tin-bearing granitic magma intrudes into existing crustal rock and cools, residual metal-rich fluids left over from the crystallization of the primary igneous minerals are injected into voids and fissures within the granite and surrounding host rock, forming bodies with high concentrations of tin. After Cérný and others (2005).

(Kamilli and Criss, 1996) and the Wodgina and Kamativi pegmatites in Australia, which are the largest known examples (Daniel J. Kontak, Department of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada, written commun., 2014).

Quartz-cassiterite veins, stockworks, and greisens that formed in close genetic association with the same granitoid intrusions to which stanniferous pegmatites are related.—This type of deposit is characterized by intense development of greisenization with abundant formation of muscovite- and topaz-rich alteration zones that host the cassiterite mineralization; in addition, these alteration zones host wolframite, bismuthinite, molybdenite, arsenopyrite, tantalo-columbite, and uranium and copper minerals. This type of mineralization is the most widely developed type of granite-related tin deposit. Large primary deposits occur rarely, but very rich placer deposits formed by weathering and erosion occur more frequently. These types of deposits (chiefly the placers) account for 60 to 70 percent of the world production of tin (Taylor, 1979, p. 46). Examples of these types of deposits include the Geevor and Wheal Jane deposits in Cornwall, United Kingdom (Dines, 1956; Garnett, 1963; Hosking, 1964; Rayment and others, 1971); the Herberton deposit in Queensland, Australia (Blake and Smith, 1970); the East Kemptville deposit in Nova Scotia, Canada (Richardson and others, 1982, 1990; Richardson, 1988; Halter and others, 1996, 1998); and the Chojlla deposit in Bolivia (Lehmann, 1990).

Sulfide-cassiterite deposits.—This type of deposit commonly occurs independently of the pegmatite and vein-stockwork-greisen deposit types discussed above. Sulfide-cassiterite deposits are more commonly known as tin porphyries; many have been mined more for their silver than for the tin they contain. They are high-to-intermediate-temperature deposits and are related to hypabyssal and near-surface granitoid intrusions. Hydrothermal minerals commonly present include cassiterite, tourmaline, chlorite, pyrrhotite, chalcopyrite, sphalerite, galena, and arsenopyrite. The most notable examples are the Llallagua (Turneaure, 1935; Dietrich and others, 2000) and the Chorolque deposits in Bolivia (Sillitoe and others, 1975; Grant and others, 1980) and the San Rafael deposit in Peru (Kontak and Clark, 2002); other examples may include the Ardlethan deposit in New South Wales, Australia (Clarke and others, 1985; Ren and others, 1995), the Zeehan deposit in Tasmania, Australia (McAndrew, 1965; Taylor, 1979), and the Akenobe deposit in Japan (Shimizu and Kato, 1991; Taylor, 1979).

Skarn and carbonate-sulfide replacement deposits in which cassiterite is associated with arsenopyrite, scheelite, pyrrohotite, marmatite, and chlorite that form in the alteration zones (that is, skarns) adjacent to intrusions.—Examples of these types of deposits include the Aberfoyle and Rossarden deposit (Collins, 1981) and the Renison Bell deposit (Patterson and others, 1981; Sutphin and others, 1990, and references therein) in Tasmania, Australia; the Cuomolong deposit in China (Hou and others, 2007); and the Lost River deposit in Alaska (Sainsbury, 1964; Dobson, 1982).

High-temperature hydrothermal deposits of "wood-tin" cassiterite in association with specular hematite and topaz in fluorine-rich, lithophysal high-silica rhyolite domes, lava flows, and associated pyroclastic rocks.—Cassiterite appears to have formed largely by precipitation from magmatically derived fluids. Redistribution of cassiterite by cooler hydrothermal fluids precipitated wood tin. The Mexican tin-bearing rhyolites have mineralogical and chemical characteristics that are similar to the topaz rhyolites of the Western United States (Burt and others, 1982; Christiansen and others, 1986). Small deposits of this type occur in Mexico (Foshag and Fries, 1942; Huspeni and others, 1984; Ruiz, 1988), Russia (Korostelev and others, 2009), and in Nevada (Fries, 1942) and New Mexico (Fries, 1940; Rye and others, 1990) in the United States (Foshag and Fries, 1942; Huspeni and others, 1984; Ruiz, 1988).

Hydrothermal tin-silver deposits connected with near-surface stocks of rhyolite with high concentrations of silver.—Examples of this type of deposit occur in Cerra Rico de Potosí, Bolivia (Sillitoe and others, 1975, 1998), and Pirquitas, Argentina (Ross, 1941).

Similarities With Granite-Related Deposits of Other Metals

Although recent literature reviews of ore-deposit models have emphasized the differences among molybdenum, tin, and tungsten deposits related to highly differentiated granites, it is also important to emphasize that there are striking similarities among these deposits. Detailed studies by Kamilli and others (1993) and Kamilli and Criss (1996) of tungsten-tin greisen and tin greisen deposits in Saudi Arabia have documented similarities among wolframite-bearing quartz vein deposits, porphyry tungsten-molybdenum deposits, disseminated tin-greisen deposits in cupolas, and Climax-type molybdenum deposits. (The late stage so-called quartz-sericite-pyrite [QSP] veins at the Henderson and Climax Mines in Colorado are steeply dipping. They contain quartz, wolframite, topaz, and fluorine-bearing mica and garnet—a chemical and mineralogical greisen assemblage—even though the rock is fine-grained.) Following Burt (1981), it is useful to think of these granite-related molybdenum, tin, and tungsten deposits as a superclass of porphyry-greisen deposits. These deposits are characterized by close spatial, temporal, and genetic association with highly differentiated peraluminous porphyritic granites and by predominantly parallel or subparallel greisen-bordered and sheeted vein-granites that either crosscut the intrusion or are peripheral to it and that contain different amounts of cassiterite and wolframite (Kamilli and Ganster, 1995).

The porphyry-greisen deposits of this superclass are all located in tectonic settings that are intracratonic, extensional, and late orogenic, and were formed during a changeover from compressional to extensional tectonics. These deposits can also be closely related to tin- and tungsten-rich porphyry deposits associated with collision-related granites in Europe and Asia (Laznicka, 2006).

Effect of Cupola Size and Shape on Tin-Greisen Mineralization

A principal control of tin-greisen mineralization is the degree of magmatic differentiation in the different phases of the parent granite's apical cupolas. Nonetheless, differentiation alone does not explain why one intrusion does not produce any tin-greisen mineralization of consequence, although it is chemically almost identical to other intrusions that are mineralized. A possible reason is the differing geometries of the intrusions. One intrusion may be a small, plug-like cupola, whereas another intrusion may form a more extensive, flat-topped mass. The concentration of greisen- and ore-producing hydrothermal fluid may be the result of the focusing effect of small cupola diameters.

An excellent example of this relation is the Mount Emmons molybdenite deposit in Colorado. The richest mineralization is at the apex of a 500-meter (m)-diameter cupola located 3,000 m above sea level, where the small cross-sectional area of the cupola and virtually vertical side contacts with the country rocks allowed accumulation of hydrothermal fluids within a small volume at the highest elevation of the intrusion. Lower grade ore zones occur on an inflection in the gently dipping flank of the same intrusion about 2 kilometers (km) to the north at an elevation of about 2,400 m. Even lower grade mineralization is found about 1 km farther north, where the contact is even flatter, at an elevation of about 1,000 m (White and others, 1981).

In the Jābal as Silsilah tin deposit in Saudi Arabia, one intrusion of peraluminous granite in a ring structure forms a body with an area of 3.5 square kilometers (km^2) at the surface. Thus, ascending fluids in this intrusion, although trapped under an impermeable aplitic cap, would be spread out over an area of at least 3.5 km^2. By contrast, the small cupolas inside the ring have an outcrop area of only 0.06 km^2. Given mean tin concentrations of 58 and 145 ppm for these two intrusions, respectively, the total amount of tin is actually more than an order of magnitude greater in the larger intrusion in the ring for any given depth than for an equivalent depth in the small cupolas. Using the mean tin content of 58 ppm and the 0.06-km^2 area of the small cupolas, a magma column that is only 245 m high would be necessary to produce the measured resources in the small cupolas of 1.2 million metric tons grading 0.19 weight percent tin (2,280 metric tons of contained tin). This calculation assumes for simplicity that 100 percent of the tin was scavenged from the melt.

The relation between the volume of magma and the size of the resulting deposit also appears to apply to other deposits. The Akash granite (which is about 100 km^2 in area) in Saudi Arabia contains zones of strong greisenization on its western flank that are about one order of magnitude larger than the greisen zones at Jābal as Silsilah. The Jabal Akash deposit, however, is not of potential economic importance because the Akash granite is not sufficiently differentiated to have given rise to a commercial-grade tin deposit (Kellogg and Smith, 1985). The Akash granite is chemically similar to the "precursor granites" as described by Tischendorf (1977).

Tectonic Settings of Granite-Related Tin Deposits

The tectonic settings of tin-bearing granites are relatively well understood and limited in variation. Tin deposits and their associated igneous rocks occur in continental settings worldwide. More than 25 percent partial melt during crustal anatexis is probably a precondition for large-scale magma segregation. Magma segregation and intrusion into an upper crustal level is favored by a brittle lithosphere in crustal extension zones (Lehmann, 1990). The tectonic settings of tin granites and porphyries, according to Lehmann (1990), are as follows:

1. Post-orogenic magmatism in continental collision belts; for example, the Permian-Triassic tin belt in Southeast Asia (Mitchell, 1977; Beckinsale, 1979), and the Hercynian tin provinces in Western Europe and Central Europe (Mitchell, 1974; Holder and Leveridge, 1986).

2. Internal regions of active continental margins (back-arc regions), such as Tertiary tin porphyries in Bolivia, Mexico, and eastern Siberia, Russia (Sillitoe, 1976), and Cretaceous tin granites in Thailand and Burma (Beckinsale, 1979).

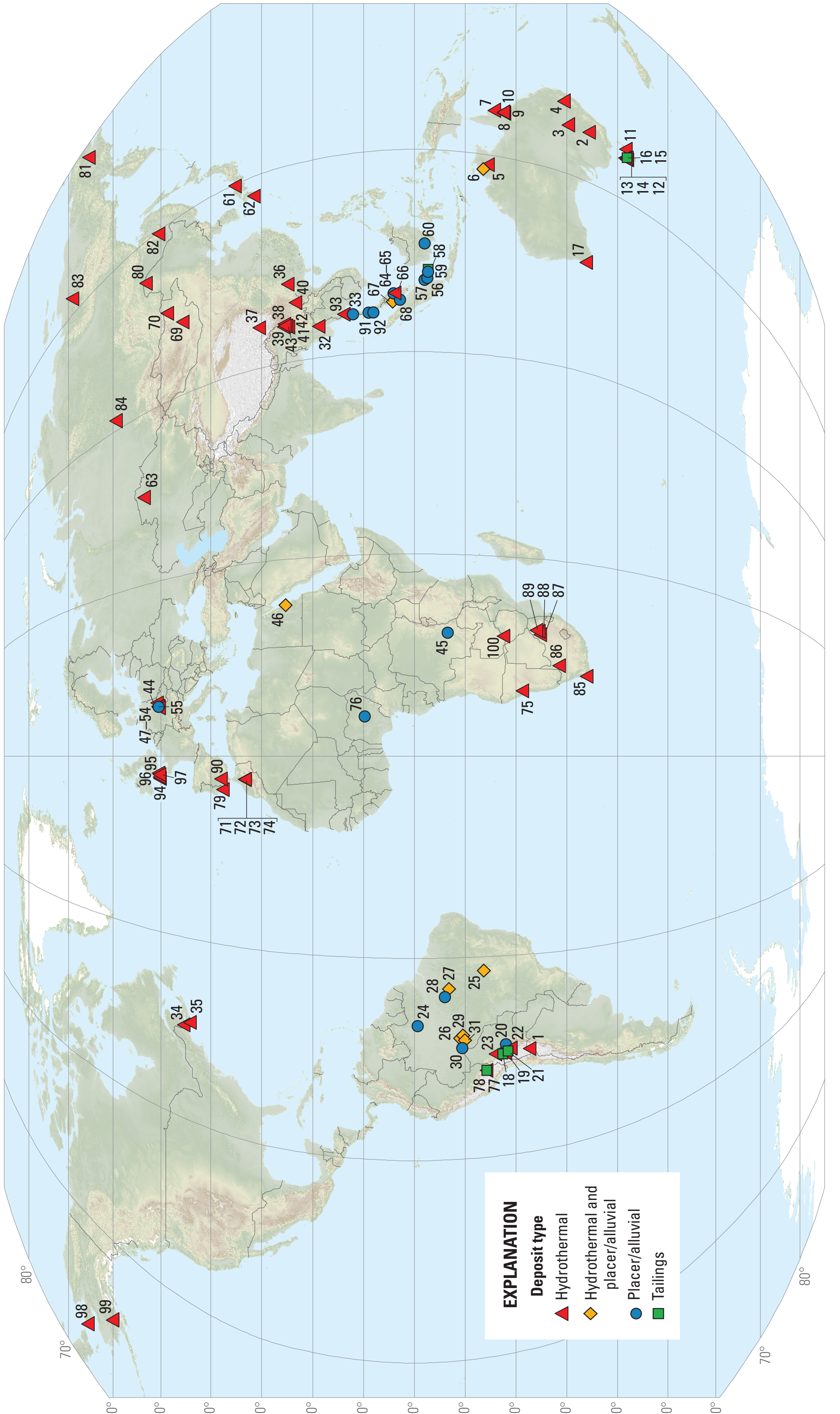
3. Intracratonic anorogenic and continental rift zones; for example, the Triassic and Miocene tin granites in Peru and northern Bolivia (Kontak and others, 1985), the Cretaceous tin granites in southern China (Chen, 1989), the Cretaceous tin granites in Nigeria (Bowden and Kinnaird, 1984), and the Precambrian Bushveld granites in South Africa (Hunter, 1973).

Resources and Production

The locations of selected major tin deposits and districts in the world, by deposit type, are shown in figure S7. Additional data on the major tin deposits and districts in the world are in table S2 at the back of this chapter.

About 80 percent of the world's identified tin resources occur in unconsolidated secondary or placer deposits in riverbeds and valleys or on the sea floor. The largest concentration of both onshore and offshore placers is in the extensive tin belt of Southeast Asia, which stretches from China in the north, through Thailand, Burma, and Malaysia, to the islands of Indonesia in the south. Most of the remainder (about 20 percent of the world's identified tin resources) occurs in primary veins, stockworks, and greisens in close association with silicic, peraluminous granites. The percentages of identified tin resources in primary versus placer deposits are estimations because many studies do not distinguish between the two types of deposits, which are commonly found together in the same districts. Furthermore, tin placer deposits are almost always found in close proximity to the granites from which they originate.

Although most tin is obtained from mining tin ores, cassiterite is also found in association with ores of tungsten,



Base from U.S. Geological Survey Global 30 arc-second elevation data (1996) and from Natural Earth (2014); Robinson projection; World Geodetic System 1984 datum

Figure S7. World map showing locations of major tin deposits and districts in the world, by deposit type. The numbers are keyed to the identification numbers listed in table S2.

tantalum, and lead. Minor quantities of tin are recovered as byproducts of the mining of these metals. Byproduct tin from massive sulfide deposits includes production from the Neves Corvo Mine in Portugal, which is the leading producer of tin in Europe, and the Kidd Creek Mine in Canada, which is a long-time producer of tin from stannite (Daniel Kontak, Department of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada, written commun., 2014).

Compared with commercially viable deposits of copper, lead, zinc, nickel, and bauxite, tin deposits are generally small. Most tin deposits fall in a grade range of 0.1 to 1 percent tin, have a resource tonnage range of from 1 million to 100 million metric tons, and have between 10,000 and 100,000 metric tons of tin content (fig. S8).

In 2016, world reserves of tin totaled 4,700,000 metric tons (table S3; C.S. Anderson, U.S. Geological Survey, written comm., December 16, 2016). The distribution of world mine tin reserves in 2016, by country, is shown in figure S9.

Total world tin mine production in 2015 was 289,000 metric tons of contained tin. The distribution of world mine production, by country, is shown in figure S10. China was the leading producer of tin (accounting for 110,000 metric tons, or 38 percent of world output), followed by Indonesia (18 percent), Burma (12 percent), Brazil (9 percent) and Bolivia and Peru (7 percent each) (Anderson, 2017).

Table S3. Tin reserves of the world in 2016, in metric tons of contained tin.

[Data are from Anderson (2017)]

Australia	370,000
Bolivia	400,000
Brazil	700,000
Burma	110,000
China	1,100,000
Democratic Republic of the Congo (Congo [Kinshasa])	110,000
Indonesia	800,000
Malaysia	250,000
Peru	100,000
Russia	350,000
Thailand	170,000
Vietnam	11,000
Other countries	180,000
World total	**4,700,000**

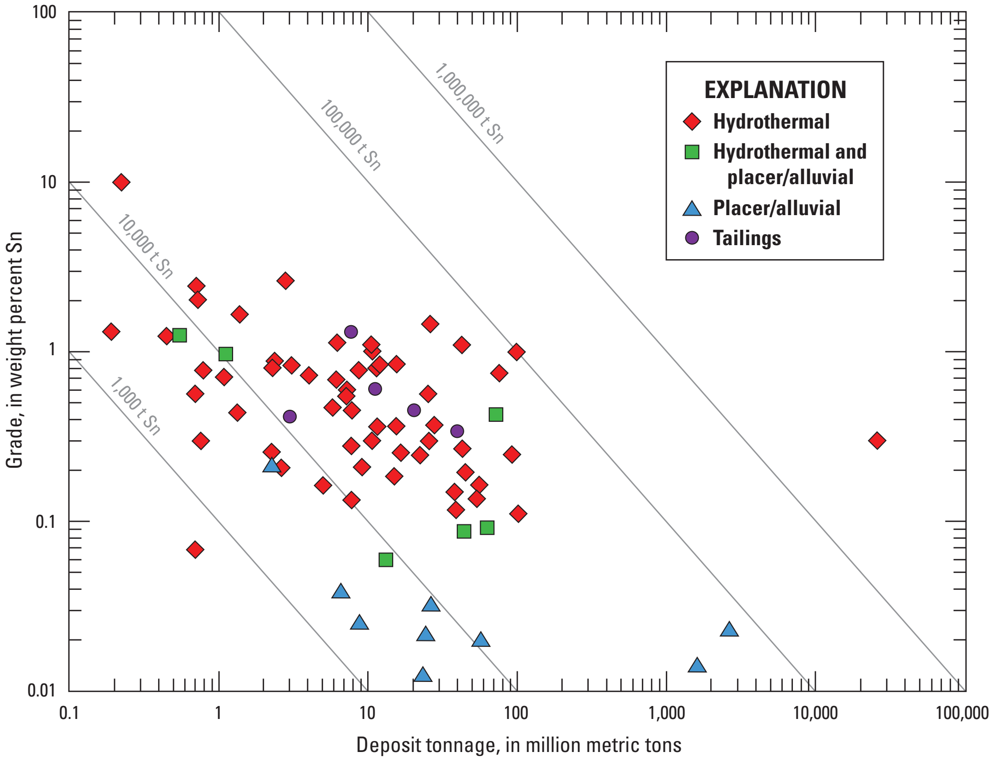


Figure S8. Graph showing grades and resource tonnages of major tin deposits in the world, by deposit type or source. Diagnonal lines are isolines of contained tin. Data are from table S2 and the references listed therein. Sn, tin; t, metric ton

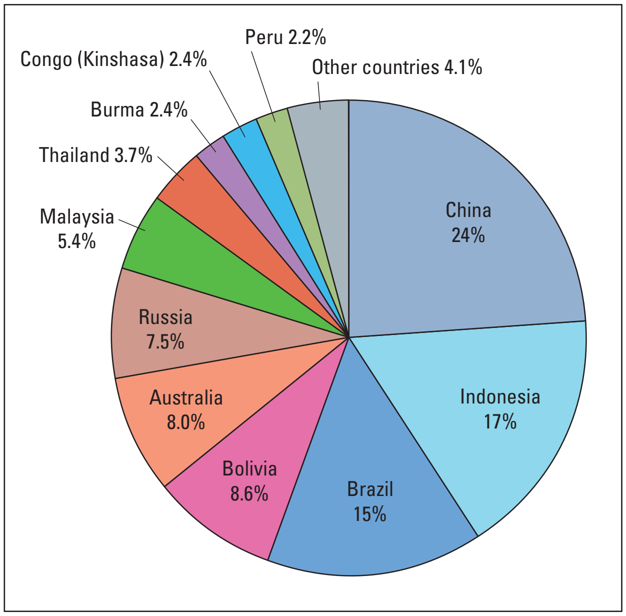


Figure S9. Pie chart showing percentage of world tin reserves in 2016, by country. Percentages have been rounded to two significant figures and do not add to 100. The world total reserves were 4.7 million metric tons. Data are from Anderson (2017). Congo (Kinshasa) is a short-form name for Democratic Republic of the Congo.

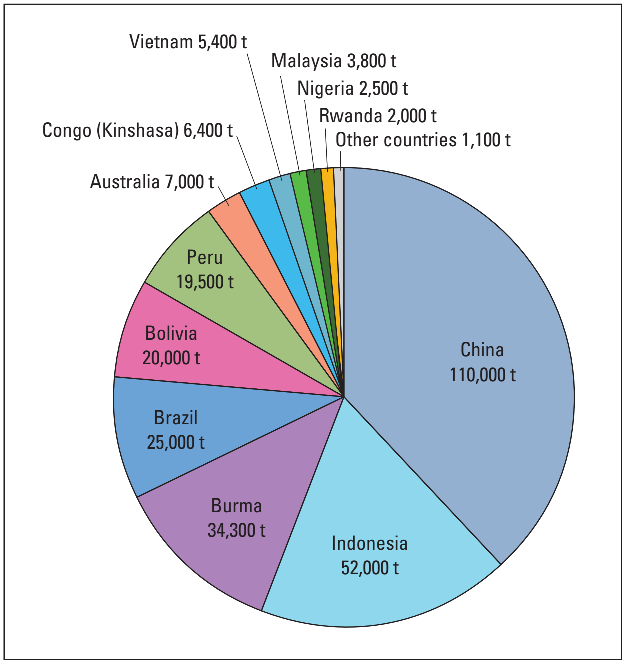


Figure S10. Pie chart showing estimated world mine production of tin in 2015, by country and amount (in metric tons [t]). The estimated world total was 289,000 t. Data are from Anderson (2017). Congo (Kinshasa) is a short-form name for Democratic Republic of the Congo.

Globally Important Mining Areas

Major tin deposits are confined to a comparatively small number of areas. More than one-half of the world's tin ore is mined in the great tin belt of Southeast Asia. Significant deposits also occur in South America.

Australia.—Granite-related tin deposits are present through much of Australia and include Neoarchean tantalum-tin pegmatite fields in western Australia and Paleozoic granite-related hydrothermal tin-tungsten deposits in the Tasmanides of eastern Australia (Solomon and Groves, 2000). A variety of deposit types are present in eastern Australia, including distal skarn tin deposits, proximal tin skarns, greisens, and quartz-cassiterite-wolframite systems. Eastern Australia has been a significant tin producer, with more than 683,000 metric tons of tin produced to the end of 1986 (Solomon and Groves, 2000). Tin was first discovered in Australia at Mount Bischoff in Tasmania in 1871.

Bolivia.—Bolivia has long been a significant producer of tin from primary deposits in the so-called Bolivian tin belt. The Bolivian tin belt extends for 1,100 km through the length of the Eastern Cordillera of Bolivia and is generally less than 100 km wide (Urquidi-Barrau, 1989). It extends from southern Peru, where tin is produced from the San Rafael Mine, to northern Argentina, where the Pirquitas Mine has been the major producer. In addition to tin, deposits in the Bolivian tin belt have produced important amounts of tungsten, silver, zinc, lead, antimony, bismuth, and gold. Most of the deposits in the northern segment of the belt are generally related to plutonic rocks of Late Triassic-Early Jurassic and Oligocene age, whereas those in the southern segment are related to subvolcanic porphyry stocks of Miocene age (Urquidi-Barrau, 1989). The northern tin-tungsten deposits occur as fissure-filling veins along fault and fracture systems in Paleozoic sedimentary rocks peripheral to granitic plutons and within these igneous bodies. The southern deposits are associated with high-level porphyry stocks and eruptive complexes with several of the largest tin deposits in Bolivia (Llallagua/Catavi, Huanuni, San José/Oruro, and Cerro Rico) occurring at or near the margins of the large Morococala and Los Frailes volcanic fields. It is suspected that additional large tin deposits occur buried beneath the volcanic fields (Urquidi-Barrau, 1989).

The Bolivian tin deposits are mostly confined to high altitudes in the rather inaccessible regions of the central Andes. As a result, access at times poses formidable infrastructure and logistical challenges. The primary hard-rock tin deposits are now relatively low grade, and Bolivian mines operate at the highest costs of all the world's primary tin mines (Urquidi-Barrau, 1989). In addition, the ores in the southern segment of the Bolivian tin belt have relatively high smelting and refining costs owing to their complex mineralogy.

Brazil.—In 2015, Brazil was the world's fourth-ranked producer of mined tin (Anderson, 2017). Almost 90 percent of the country's production is obtained from the Pitinga Mine, which is located about 300 km northeast of Manaus in the Mapuero region of the State of Amazonas (table S2; fig. S7). The Pitinga Mine produced about 230,000 metric tons of tin between 1982, when the mine opened, and January 2001 (Lenharo and others, 2003). Tin is produced mainly from alluvial deposits in and around two Paleoproterozoic granitic complexes, the Àgua Boa and Madeira igneous complexes. These complexes are composed of a variety of granitic rocks, including fine to coarse grained, equigranular to porphyritic rapakivi granite, biotite granite, topaz granite, and albite granite (Lenharo and others, 2003). In the Àgua Boa complex, primary tin mineralization occurs in cassiterite-topaz-mica-quartz greisens as well as disseminated cassiterite in biotite and topaz granites. In the Madeira complex, cryolite-zircon-cassiterite-pyrochlore-columbite-tantalite-xenotime mineralization occurs disseminated within the roof zone of the albite granite. Tin is produced from a saprolite developed on the albite granite.

Burma (Myanmar).—The tin deposits in Burma lie along the Thailand-Burma border and form the northern end of the Southeast Asian tin belt, a north-south elongate zone about 2,800 km long and 400 km wide, extending from Burma and Thailand to Peninsular Malaysia and the Indonesian Tin Islands (Schwartz and others, 1995). The Southeast Asian tin belt consists principally of Jurassic-Triassic biotite granites that host mostly simple tin-tungsten vein deposits and lesser stockwork, replacement, pegmatite, and breccia deposits (Schwartz and others, 1995). The tin deposits in Burma are similar to those in Thailand and Malaysia with both rock-hosted and placer deposits related to biotite granites. The tin belt in Burma extends from the Byingyi-Mawchi district in the north about 1,200 km south to the Mergui Islands. Although small placer tin deposits are present in Burma, the mountainous terrane is not favorable for the occurrence of large placer deposits such as those found in Thailand, Malaysia, and Indonesia (Sainsbury, 1969b).

China.—China has been the leading tin-producing country since 2003, when it surpassed Indonesia. The main producing area is the Gejiu district in Yunnan Province, which is the largest primary tin district in the world; it contains about 300 million metric tons of tin ore with an average grade of 1 percent tin (Cheng and others, 2013). Tin mineralization occurs in greisen, skarn, strata-bound cassiterite-sulfide (mostly oxidized), and vein deposits in extensive hydrothermal systems centered on shallow Late Cretaceous granitic cupolas (Cheng and others, 2013). Geologic characteristics, metal zoning patterns, and new geochronologic data all support that the tin-polymetallic deposits are genetically related to the nearby granite intrusions.

Principal tin smelter production from China was 148,000 metric tons in 2012 (Tse, 2013, p. 8.14). According to Carlin (2014, p. 77.2), the Guangxi Autonomous Region and Yunnan Province accounted for 53 percent of China's mine production of tin in 2011, but production was substantially lower in 2012 owing to mine closures caused by cadmium contamination and drought-related water shortages.

Indonesia.—Indonesian tin production comes mainly from placer deposits both onshore and offshore of the islands of Bangka, Belitung (Billiton), and Singkep in the Java Sea. Bangka Island is the major source of placer tin and is produced with seagoing dredges (Sainsbury, 1969b). The largest hard-rock tin deposit is the Klappa Kampit Mine on Belitung Island and consists of replacement bodies composed of cassiterite, magnetite, and sulfide minerals in shale (Sainsbury, 1969b).

Malaysia.—Historically, Malaysia furnished as much as 55 percent of the world's annual tin production (Sainsbury, 1969b). The tin deposits in Malaysia are part of the Southeast Asian tin belt and consist of both hard-rock and placer deposits, with placers being the dominant producers. The tin deposits extend through Malaysia in two north-trending belts that coincide with two mountain ranges that consist of Jurassic-Triassic batholiths and stocks of biotite granite and related rocks which intrude older sedimentary and metamorphic rocks (Sainsbury, 1969b). The two most productive tin-mining areas in Malaysia have been the Kinta Valley in the State of Perak (Rajah, 1979) and the Selangor River in the State of Selangor. Between 1876 and 1950, the Kinta Valley alone produced 1.2 million metric tons of tin (Sainsbury, 1969b).

Portugal and Spain.—An 800-km-long belt of tin- and tungsten-bearing deposits that extends southeastward through Portugal and Spain is associated with dominantly porphyritic biotite and biotite-muscovite granites (Sainsbury, 1969b). The deposits consist of veins, stockworks, and alluvial and eluvial placers. As in other tin districts, major tin deposits tend to occur within and near the borders of granite intrusions, whereas tungsten deposits tend to occur farther from the contacts in surrounding rocks. The Neves-Corvo deposit in Portugal—one of the largest and richest massive sulfide deposits in the Iberian pyrite belt—is unique because of its very high copper and tin grades. The Corvo orebody, which accounts for 95 percent of Neves-Corvo tin production of about 40 metric tons per year, has reserves of 20 million metric tons with grades of 5.20 percent copper, 3.07 percent zinc, and 0.30 percent tin (Relvas and others, 2006).

Thailand.—The modern commercial production of tin in Thailand began in about 1870, but it was not until the early part of the 20th century that the country became a significant producer. The tin deposits in Thailand, both hard-rock and placer, are a continuation of the deposits in Malaysia and are part of the Southeast Asian tin belt. As elsewhere in Southeast Asia, placer deposits have been the major tin producers in Thailand. The principal tin placers are located on Phuket Island and near Ranong to the north (Sainsbury, 1969b). Tin production from Phuket Island has mostly been from alluvial stream-channel deposits and their submarine extensions. In northwestern and western Thailand, hard-rock fissure vein, stockwork, and pegmatite tin deposits also contain wolframite and sulfide minerals (Sainsbury, 1969b).

United Kingdom.—Cornwall, England, has a long history as a leading producer of tin. Cornish tin deposits have been worked extensively for many centuries, dating back to at least Roman times; there is, in fact, strong evidence of tin working in Cornwall from the early Bronze Age (about 2100 to 1500 B.C.; Bancroft and Weller, 1993). Although the mines of Cornwall produced more than 2 million metric tons of tin during their operation, they are now largely exhausted (Sainsbury, 1969b). In 1860, more than 300 mines, employing 100,000 workers, were in operation in Cornwall, but by 1964, only 2 mines were still operating (Sainsbury, 1969b). The last mine, South Crofty, closed in 1998.

The tin deposits of Cornwall are principally zoned greisens and replacement deposits developed in and around Permian biotite-muscovite, tourmaline-bearing granites intruded into deformed and metamorphosed upper Paleozoic marine mudstone-sandstone sequences (Jackson and others, 1989). The tin deposits contain cassiterite and copper, arsenic, iron, tungsten, and zinc sulfide minerals. Because of metal zoning in the deposits, some mines produced principally copper ores; others produced lead-zinc ores; and others, tin, wolframite, and minor sulfide ores (Sainsbury, 1969b). Erosion of the primary tin deposits produced tin-bearing placer deposits that were the first source of tin in the region (Bancroft and Weller, 1993).

Tin Deposits in the United States

Tin deposits are quite rare in the United States and of relatively little economic value (Carlin, 2001). They are mentioned here because they are potential sources of tin in times of limited supply.

In 1948, a byproduct plant at the Climax Mine in Colorado was built to treat tailings from the molybdenite circuit to recover cassiterite and wolframite. In 1968, about 8,200 metric tons (about 18,000,000 pounds) of tungsten trioxide (WO_3) and about 360 metric tons (about 800,000 pounds) of cassiterite had been recovered (Wallace and others, 1968). The production of tin and tungsten ceased in 1982 when the Climax Mine closed (Maurice W. Ganster, Climax Mine, Climax Molybdenum Co., written commun., 1981). The Climax Mine was reopened by Freeport-McMoRan Inc. in 2012 as an open pit operation with a new mill, but tin and tungsten were not being recovered.

One of the few primary hard-rock tin deposits in the United States is the Lost River tin-tungsten-fluorine deposit in the Seward Peninsula, Alaska. In the region of the northwestern Seward Peninsula, tin mineralization is related to at least nine Late Cretaceous, highly differentiated, fluorine-rich granites that intruded massive Ordovician-age limestones (Dobson, 1982). Other igneous rocks present in the region are diabase dikes, lamprophyre dikes, and alkali basalt. The deposits of the Seward Peninsula, which were first reported in 1900 by A.H. Brooks, have produced ore containing more than 2,200 metric tons of tin and constitute the only known domestic deposits of economic grade and size (Sainsbury, 1964, 1969a, b). In most cases, the tin mineralization is evident primarily in placers that surround the exposed cores of the intrusions that host bedrock mineralization. The lodes were a major source of ore, however. The Lost River deposit is also enriched in F, W, Be, Zn, Pb, Cu, and Ag. Mineralization occurs in areas of intense greisenization of the intrusive granites and is characterized by the destruction of igneous textures and the replacement of feldspars and biotite by quartz with topaz, tourmaline, cassiterite, and sulfides, including galena, sphalerite, chalcopyrite, arsenopyrite, and stannite. Greisenization was apparently contemporaneous with a hydrous stage of alteration in the limestone; this alteration stage was characterized by fluorite-biotite ± hornblende with sulfides and cassiterite. Beryllium mineralization is hosted by fluorite-white mica veins. Beryllium-bearing minerals are also present and include chrysoberyl ($BeAl_2O_4$), euclase ($BeAlSiO_4(OH)$), phenakite (Be_2SiO_4), and minor amounts of other beryllium-bearing minerals. Tin was precipitated prior to and contemporaneous with the deposition of sulfide minerals; the mobilization and redeposition of tin liberated from early skarn minerals by later alteration was an important process in the formation of the economic tin skarns. Early andradite garnet contains up to 6 weight percent SnO_2, and idocrase and grossular contain 0.2 to 0.6 weight percent SnO_2 (Dobson, 1982).

Undiscovered Resources

Tin metallogenic provinces are quite well known; thus, most undiscovered tin deposits are expected to be located spatially close to known deposits or extensions of the same. Sainsbury and Reed (1973, p. 637) observed that "The worldwide geologic association of tin with acid granitic rocks and rhyolites is so well marked that speculation as to the likelihood of finding major tin resources in new geologic environments is without redeeming value." Since then, however, Hudson and Reed (1997) have documented more than 100 tin occurrences in Alaska in several relatively recently discovered tin-mineralized areas, and the high-grade cassiterite ore in the Neves-Corvo massive sulfide deposit of Portugal was a departure from conventional tin ore. Alaskan tin prospects occur from the central Alaska Range north to the Brooks Range and across interior Alaska, including the Yukon-Tanana upland, the Ruby geanticline, southwestern Alaska, and the Seward Peninsula (fig. S11). In all cases, the deposits are known or inferred to be associated with felsic igneous rocks that were generated by large-scale melting of continental crust. The widespread distribution of tin occurrences and their repeated development at different geologic times suggest that a large part of Alaska is a tin metallogenic province. Therefore, Alaska is prospective for future discoveries and eventual production, in the event that economic incentives are presented by market conditions (Hudson and Reed, 1997).

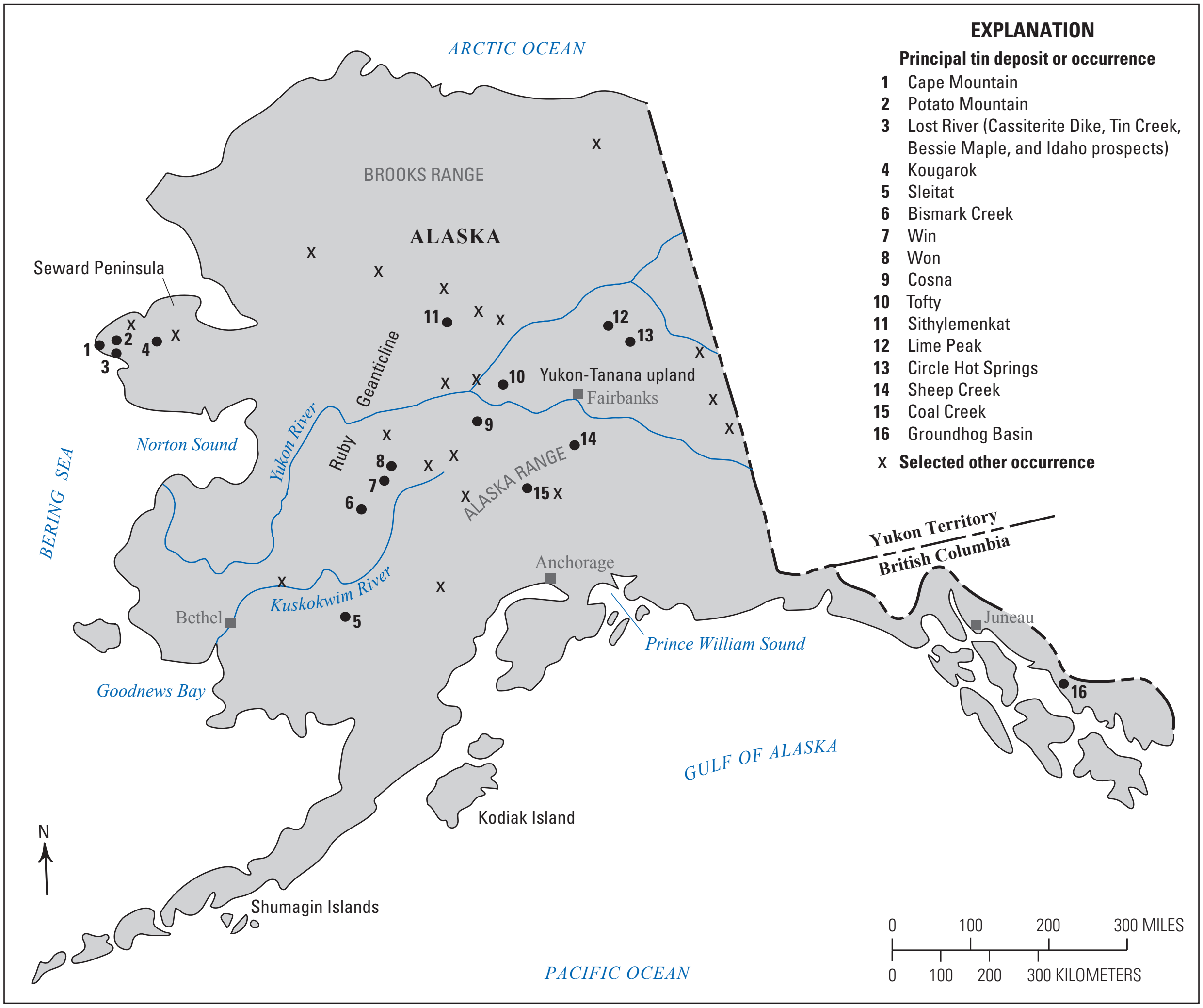


Figure S11. Map of Alaska showing the locations of selected tin deposits or occurrences. Modified from Hudson and Reed (1997).

Exploration for New Deposits

Historically, prospecting for tin has been carried out by the time-honored methods of panning, drilling, trenching, and assaying. As rich deposits were exhausted and the costs of exploration rose, the search for tin required more sophisticated methods. Geophysical and geochemical analyses have been employed to cover large areas more rapidly, isolating areas of possible tin deposits so that drilling can be more effective and less costly (Carlin, 1985).

Exploration for tin deposits is relatively simple, as the metal is invariably associated with highly differentiated, peraluminous granites or in downstream, downslope placer or alluvial deposits. As an example, the discovery of the East Kemptville deposit in Nova Scotia was based on a glacial till survey, as the deposit area is completely buried under several meters of till, and the discovery hole (EK–79–1) was centered on the highest tin content in tills (Daniel J. Kontak, Department of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada, written commun., 2014).

The tin content of residual soils and stream sediments and of vegetation has been used successfully as a guide to tin in the bedrock. The tin content of granitic rocks in the Malaysian alluvial tin fields is on the order of 60 ppm compared to the normal granitic background of 3 ppm. Boron, fluorine, lithium, rubidium, and thorium, as well as tin, are all enriched in late-stage granitic differentiates, and have been cited as local (but not universally applicable) ore guides (Rose and others, 1979).

At the Silsilah ring complex in Saudi Arabia, which contains peralkaline and peraluminous granites, the tin deposits are associated with the strongly greisenized peraluminous granites and pegmatites that have USTs containing euhedral quartz crystals, measuring up to 2 m, which have their *c* axes oriented perpendicular to the top of the granite cupolas (Kamilli and Criss, 1996). Nevertheless, strong albitization is associated with nonmineralized metaluminous granites that are intermediate in composition between the peralkaline and peraluminous granites. In summary, the strongest field indicators of economic tin deposits associated with granites are the presence of mica-bearing (biotite and [or] muscovite) pegmatites and especially zones of greisen alteration. These associations have been observed in other tin provinces worldwide.

The small, uneconomic deposits of cassiterite and wood tin that occur in Nevada, New Mexico, and Mexico are related to topaz rhyolite flow-dome complexes that are indicators of topaz granites that may host economic deposits of tin (or tungsten) in greisens or skarns at depth. Examples of these deeper formed deposits include those at East Kemptville, Nova Scotia, Canada, and at the Anchor Mine in Tasmania, Australia (Christiansen and others, 1986).

Trace-element characteristics of biotite granites can be useful in identifying individual intrusive complexes that are potentially ore bearing. Frequency distributions of tin in tin-bearing and mineralized granites are positively skewed and bimodal, with a relatively large proportion of values exceeding 25 ppm. Elemental concentrations and relationships of the lithophile elements, especially Rb, Li, K, Ba, Sr, Zr, Nb, Th, and Mn, are the most reliable chemical indicators of ore-forming processes and tin-bearing potential (Olade, 1980).

Finally, of course, the best places to find new orebodies or extensions of existing ones are in areas of known mining districts or metallogenic belts. Only four well-defined regions account for 80 percent of the cumulative historic tin mine output. They are as follows: (a) the Southeast Asian tin belt (Burma, Thailand, Malaysia, and Indonesia); (b) the Central Andean tin belt (southeastern Peru, Bolivia, and northwestern Argentina); (c) the south China tin belt; and (d) the Cornwall tin province (United Kingdom; Lehmann, 1990).

Environmental Considerations

Sources and Fate in the Environment

Tin commonly occurs in one of two oxidation states in weathering environments: Sn^{2+} and Sn^{4+}. As summarized by Séby and others (2001, and references therein), Sn(IV) is relatively insoluble and most commonly occurs in the mineral cassiterite, although dissolved Sn(IV) oxyhydroxide complexes (for example, $SnO(OH)_3$ and $SnO(OH)_2$) have been observed. Sn(II) may form dissolved complexes with hydroxide, chloride, sulfate, phosphate, carbonate, and organic species, or, more commonly, with solid Sn(II) oxide and sulfide minerals. Dissolved Sn(II) species may sorb to the surfaces of clays and manganese and iron oxide minerals. Sn(IV) forms the basis of organo-tin compounds with the general formula R_nSnX_{4-n}($n = 1$ to 4), where R is a hydrocarbon group and X is an anionic species, such as chloride, fluoride, oxide, hydroxide, carboxylate, or thiolate (Anger, 2004).

Examples of natural concentrations of tin in rocks, soils, waters, and air are given in table S4. The tin content in soils generally ranges from less than 0.1 to 5 ppm (which is equivalent to milligrams per kilogram), with higher tin concentrations occurring in more organic soils (Kabata-Pendias and Pendias, 2001). The mean tin concentration at a depth of 20 centimeters in soils in the Western United States is 0.9 ppm (Shacklette and Boerngen, 1984), but topsoil concentrations can be as high as 8.6 ppm (Smith and others, 2005) in the Eastern United States. Topsoil in Sweden can be equally as concentrated in tin, but deeper soils exhibit a maximum tin concentration of nearly 3.0 ppm (Eriksson, 2001). In North Atlantic seawater, tin concentrations range from below the detection limit (that is, less than 0.2 nanogram per liter [ng/L]) to about 2.0 ng/L, with the highest concentrations occurring at depths of from 50 to 200 m (Byrd and Andreae, 1986b). Dissolved and colloidal (that is <0.45 micrometer [μm]-sized) concentrations of tin in rivers range from 0.1 to 8.4 ng/L, whereas particulate (that is, >0.45 μm) concentrations of tin in rivers range from 0.1 to 109 ng/L (Byrd and Andreae, 1986c). Considered together, the average concentration of tin in the suspended sediment of world rivers is 4.6 ppm (Viers and others, 2009). Tin occurs naturally in the atmosphere as part of mineral dust particles, and ranges from 0.3 to 53 picograms per cubic meter (pg/m^3) in more remote areas of the world (Byrd and Andreae, 1986a).

Mining and industrial activities can lead to above-background concentrations of tin in the environment (table S4). The common association of tin with organic material, clays, and metal oxide minerals increases the likelihood that tin will become enriched in soils, but above-background concentrations of tin in soils are not well documented. Tin mobilized from rocks tends to concentrate in particulate matter and sediments in aquatic environments. Byrd and Andreae (1986c) studied Tasmanian and European rivers and, as noted above, found that the concentration of tin in suspended particulates was greater than dissolved concentrations of tin (table S4). Likewise, unfiltered water samples from industrial European countries contain tin concentrations that are orders of magnitude greater than dissolved tin concentrations observed in more remote regions (table S4; Byrd and Andreae, 1986c; Reimann and de Caritat, 1998; Neal and Robson, 2000).

Much of the previous research on tin in aquatic environments focused on organo-tin compounds. Tributyltin (TBT) has been a common additive in paint for ships and barges to prevent the growth of mollusks, algae, and barnacles (Evans and others, 1995). As a result, concentrations of butyltin compounds in North American and European harbors were observed to range from below the detection limit to 1,500 ng/L tin (Dirkx and others, 1993, and references therein). Because TBT also negatively affects nontarget organisms, such as mussels and fish, many countries banned the use of TBT-based paints on boats of less than 25 m in length in the late 1980s and early 1990s (Evans and others, 1995).

Table S4. Tin concentrations in rocks, soils, waters, and air.

[DOE, U.S. Department of Energy; EPA, U.S. Environmental Protection Agency. Units of measure: cm, centimeter; ng/L, nanogram per liter; ng/m^3, nanogram per cubic meter; pg/L, picogram per liter; pg/m^3, picogram per cubic meter; ppm, part per million; µg/L, microgram per liter; µm, micrometer]

Environment and (or) location	Tin concentration	Unit	Notes	Reference(s)
		Rocks		
Upper continental crust	5.5	ppm	Average	Taylor and McLennan (1995)
Bulk continental crust	2.5	ppm	Average	Taylor and McLennan (1995)
Lower continental crust	1.5	ppm	Average	Taylor and McLennan (1995)
		Soils		
Conterminous United States	0.2 to 3.7	ppm	Range for 0 to 5 cm depth	Smith and others (2005)
Conterminous United States	1 to 1.9	ppm	Range for O horizon, if present	Smith and others (2005)
Conterminous United States	0.3 to 8.6	ppm	Range for A horizon	Smith and others (2005)
Conterminous United States	0.2 to 4.2	ppm	Range for C horizon	Smith and others (2005)
Western United States	0.90	ppm	Mean for 20 cm depth	Shacklette and Boerngen (1984)
Eastern United States	0.86	ppm	Mean for 20 cm depth	Shacklette and Boerngen (1984)
Topsoil, Sweden	0.4 to 8.6	ppm	Range; mean is 1.8 ppm	Eriksson (2001)
Subsoil, Sweden	0.4 to 3.0	ppm	Range; mean is 1.5 ppm	Eriksson (2001)
Proposed DOE benchmark	50	ppm	Screening benchmark for terrestrial plants	Efroymson and others (1997)
Soil quality guideline	5	ppm	Canadian agricultural soil guideline	Canadian Council of Ministers of the Environment (2007)
		Waters		
North Atlantic	<0.2 to 1.2	ng/L	Range; mean is 0.3 ng/L	Byrd and Andreae (1986b)
Seawater, Sargasso Sea	<0.2 to 1.0	ng/L	Range; mean is 0.4 ng/L	Byrd and Andreae (1986b)
Seawater, The Bahamas	<0.2 to 1.9	ng/L	Range; mean is 0.8 ng/L	Byrd and Andreae (1986b)
World rivers	4.57	ppm	Average suspended sediment	Viers and others (2009)
North American rivers	0.5 to 8.4	ng/L	Range of dissolved and colloidal (<0.45 µm)	Byrd and Andreae (1986c)
North American rivers	0.5 to 109	ng/L	Range of particulates (>0.45 µm)	Byrd and Andreae (1986c)
South American rivers	0.5 to 4.0	ng/L	Range of dissolved and colloidal (<0.45 µm)	Byrd and Andreae (1986c)
European rivers	0.6 to 5.5	ng/L	Range of dissolved and colloidal (<0.45 µm)	Byrd and Andreae (1986c)
European rivers	4.4 to 18	ng/L	Range of particulates (>0.45 µm)	Byrd and Andreae (1986c)
River water, Tasmania, Australia	0.1 to 0.6	ng/L	Range of dissolved and colloidal (<0.45 µm)	Byrd and Andreae (1986c)
River water, Tasmania, Australia	0.1 to 2.0	ng/L	Range of particulates (>0.45 µm)	Byrd and Andreae (1986c)
River water, Azores, Portugal	1.1 to 1.4	ng/L	Range of dissolved and colloidal (<0.45 µm)	Byrd and Andreae (1986c)
River water, Azores, Portugal	1.1 to 1.4	ng/L	Range of particulates (>0.45 µm)	Byrd and Andreae (1986c)
River water, Senegal	2.1	ng/L	Dissolved and colloidal (<0.45 µm)	Byrd and Andreae (1986c)
River water, eastern United Kingdom	100 to 600	ng/L	Range of means for 18 rivers in rural and industrial areas	Neal and Robson (2000)
Stream water, Germany	<0.01 to 1.3	µg/L	Unfiltered; median is 0.03 µg/L	Compiled by Reimann and de Caritat (1998)
Stream water, eastern India	0.55 to 4.12	µg/L	Dissolved (<0.2 µm); median is 1.2 µg/L	Compiled by Reimann and de Caritat (1998)

Table S4. Tin concentrations in rocks, soils, waters, and air.—Continued

[DOE, U.S. Department of Energy; EPA, U.S. Environmental Protection Agency. Units of measure: cm, centimeter; ng/L, nanogram per liter; ng/m^3, nanogram per cubic meter; pg/L, picogram per liter; pg/m^3, picogram per cubic meter; ppm, part per million; µg/L, microgram per liter; µm, micrometer]

Environment and (or) location	Tin concentration	Unit	Notes	Reference(s)
Waters —Continued				
Stream water, Romania	5 to 170	ng/L	Unfiltered; median 5 ng/L	Compiled by Reimann and de Caritat (1998)
Lake water, Norway	<0.04 to 3.52	µg/L	Unfiltered; median is 0.061 µg/L	Compiled by Reimann and de Caritat (1998)
Rainwater, United States	775	pg/L	Volume-weighted mean	Byrd and Andreae (1986a)
Groundwater, southern Norway	<0.005 to 2.33	µg/L	Unfiltered; median is <0.005 µg/L	Compiled by Reimann and de Caritat (1998)
Proposed EPA benchmark	2,700	µg/L	Tier II secondary acute value	Suter and Tsao (1996)
Proposed EPA benchmark	73	µg/L	Tier II secondary chronic value	Suter and Tsao (1996)
Air				
Polluted air	1.5 to 800	ng/m^3	None	Compiled by Reimann and de Caritat (1998)
Northern Atlantic Ocean	2.11 ± 1.97	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)
Pacific Ocean	1.64 ± 2.14	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)
Europe	397 ± 267	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)
Cape Grim, Australia	0.26 ± 0.16	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)
The Bahamas	52.6 ± 22.1	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)
New Zealand	1.55 ± 0.76	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)
Tallahassee, Florida, United States	134 ± 139	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)
Rhode Island, United States	850 ± 71	pg/m^3	Mean and standard deviation	Byrd and Andreae (1986a)

The primary inputs of tin to the atmosphere are through mining and ore processing, combustion of fuel oil and coal, and production and use of tin products. Total anthropogenic emissions of tin to the atmosphere were estimated to be 6.14 million grams in 1983 (Nriagu and Pacyna, 1988). Tin concentrations in air over urban and industrial regions range from 134 to 850 pg/m^3 (Byrd and Andreae, 1986a). The general range of tin concentrations reported for "polluted air" is orders of magnitude higher at 1.5 to 800 nanograms per cubic meter (Reimann and de Caritat, 1998, and references therein).

Tin continues to be an important component in industrial society, so the need for tin continues to increase. Unlike many metals, tin recycling is relatively efficient. The recycled content (or the proportion of scrap) used in tin production is between 10 and 25 percent, and the fraction of tin in discarded products that get recycled is greater than 50 percent (Graedel and others, 2011, figs. 3 and 4). The factors that contribute to the economic and technologic feasibility of tin recycling are as follows: (a) tin is used in large quantities, and (b) it occurs in alloys in relatively pure form, making it easier to remelt and recover (Reck and Graedel, 2012).

Mine Waste Characteristics

Tin deposits are mined by open pit and underground methods. The mine waste generated is generally considered to be the material that originates and accumulates at the mine site that has no current economic value (Lottermoser and Ashley, 2006) and includes both solid and liquid waste. The character of mine waste varies according to the deposit type and the methods used to extract the ore. Most available information about tin mine waste relates to lode deposits. Mining of the Cerro Rico de Potosí lode deposits in Bolivia since 1545 has generated large amounts of mine waste. Two mine waste impoundment failures at Bolivia's Porco Mine in 1996 released approximately 235,000 cubic meters of tailings and fluid into the Río Pilaya (Pilaya River) (Hudson-Edwards and others, 2001). Tailings at the Jumna mill in northern

Queensland, Australia, come from various mines in the Irvinebank lode tin deposits in the area. The mill closed in 1989, and the tailings repository on site contains an estimated 150,000 t of tailings (Garrad and Bultitude, 1999).

The mineralogy of solid mine waste from tin mining is similar to that of the mined deposit, but the proportion of tin ore minerals is smaller. Tailings at the Porco Mine in Bolivia contain small amounts of cassiterite as well as other minerals, such as sulfides (arsenopyrite, galena, pyrite, sphalerite, and tetrahedrite), quartz, illite, and gypsum; trace metals in these tailings include Ag, As, Cd, Cu, Hg, Pb, Sb, Tl, and Zn (Hudson-Edwards and others, 2001). The Jumna mill tailings in Australia consist of quartz, microcline, plagioclase, muscovite, chlorite, kaolinite, sulfides (pyrite, chalcopyrite, galena, and arsenopyrite), magnetite, and small amounts of hornblende, beryl, fluorite, and expanding clays (Lottermoser and Ashley, 2006). Some of these tailings are cemented together with secondary hydrous ferric oxides (HFO) known as hardpans; the hardpan layers contain significantly higher As, Ca, Cd, Co, Cu, Fe, In, Mn, Mo, S, Th, U, Y, and Zn contents than the actual tailings because of mobilization and subsequent sorption of these elements by the HFO (Lottermoser and Ashley, 2006). Tin-bearing skarns and replacement deposits, such as those at Lost River (Alaska) and Dachang (China), are hosted in carbonate rocks. Gangue minerals in these deposits may include calcite and dolomite, may have generally lower sulfide mineral contents, and (or) may include the trace metals Ag, As, B, Be, Cs, Cu, F, Li, Pb, Re, Rb, W, and Zn (Hammarstrom and others, 1995).

In weathering environments, trace metals in tin deposits are expected to remain immobile under oxic, near-neutral pH conditions ($5 < \text{pH} < 8$), especially in the presence of iron-rich solids (Smith and Huyck, 1999). Under anoxic and (or) acidic conditions, however, minerals and associated trace metals may dissolve. In those deposits with sulfide minerals (for example, pyrite and arsenopyrite), generation of acid effluents is possible if sulfide dissolution is not balanced by the acid-neutralizing capacity of carbonate minerals (for example, calcite and dolomite). Dissolution of sulfide minerals releases metals and sulfuric acid, and the acidic pH values allow higher concentrations of metals to be dissolved in solution—potentially causing the environmental problem known as acid mine drainage (AMD). Mining of hydrothermal tin lode deposits increases the potential for AMD.

Little information about mine wastes from placer tin deposits is available, particularly for the placer deposits in Southeast Asia. Because placer deposits form as a result of chemical weathering and physical erosion of lode tin deposits, many of the potentially deleterious constituents originally present in lode deposits, such as sulfide minerals, are absent from or reduced in placer deposits (Sainsbury and Reed, 1973, p. 644). Heavy and less reactive minerals that commonly occur with cassiterite in tin placer deposits include columbite-tantalite, wolframite, ilmenite, monazite, zircon, and xenotime (Sutphin and others, 1990, p. 10). Monazite and zircon may include radioactive elements, such as thorium and uranium. Mine tailings in the Jos Plateau tin placer deposit in Nigeria contain above-background levels of thorium and uranium, and radioactivity dose rates measured in the tailings were approximately 100 times those measured in nearby control sites (Ibeanu, 2003). Based on a preliminary model of tin-gold placer deposits, Bliss and Menzie (1995) showed that grades of tin do not correlate with deposit volumes, and 80 percent of the studied deposits had volumes of between 8,800 and 91,000,000 cubic meters. These volumes can be viewed as the minimum volume of rock that would be disturbed during mining of a deposit.

Human Health Concerns

The Agency for Toxic Substances and Disease Registry (2005) provides a useful summary of the human toxicology of tin and tin compounds. The general public is most likely to be exposed to tin through consuming food directly from tin-lined cans (though currently many cans are lined with epoxy resins to protect against this), breathing tin-bearing dust, and eating seafood or using household products that contain organo-tin compounds. Occupational exposure to tin usually results from inhaling or touching tin-bearing dust at industrial and hazardous waste sites. The average human diet includes an intake of about 10 milligrams per day of tin (Anger, 2004). Exposure to oral doses of tin much greater than this amount may lead to stomach ache, anemia, and liver and kidney problems. Exposure to some organo-tin compounds can interfere with brain and nervous system function and, in severe cases, can cause death. Those exposed to extended inhalation of tin oxide—an issue mainly of concern to people who work in the tin industry—have a higher potential to develop stannosis, which is a mild disease of the lungs caused by inhalation of tin-bearing dust (Anger, 2004). Inorganic tin is poorly absorbed by the body, and no evidence exists for the carcinogenicity of metallic tin and tin compounds in humans (Agency for Toxic Substances and Disease Registry, 2005). Long-term exposure to certain organo-tin compounds, however, has been shown to cause cancer in animals (Smith and Huyck, 1999, and references therein).

Primary and secondary drinking water regulations for tin currently do not exist in the United States. Likewise, the World Health Organization has not set a recommended guideline for inorganic tin in drinking water because of the generally low concentrations of tin in aquatic systems and its minor toxicity to humans (World Health Organization, 2004). The Occupational Safety and Health Administration has set an exposure limit of 2.0 milligrams per cubic meter (mg/m^3) for inorganic tin dust (Occupational Safety and Health Administration, 2013a) and 0.1 mg/m^3 for organo-tin dust (Occupational Safety and Health Administration, 2013b) in workplace air over an 8-hour workday.

Ecological Health Concerns

Many studies focus on the ecological impacts of tin in the environment. Because fish tend to be sensitive to low concentrations of dissolved metals, they are commonly useful indicators of contamination in aquatic systems. One of several useful endpoints used in toxicity tests is the concentration that leads to 50 percent mortality (LC_{50}) after exposure to a substance for a certain amount of time. Chronic toxicity tests (that is, lower doses over longer times) with dissolved tin (as tin chloride, or $SnCl_2$) and developing rainbow trout (*Salmo gairdneri*) revealed a mean LC_{50} value of 0.42 milligram per liter (mg/L) after 28 days of exposure (Birge and others, 1980). Acute toxicity tests (that is, higher doses over shorter times) with tin and two marine fish species were attempted by Taylor and others (1985), but upon addition of dissolved tin chloride to seawater, most of the tin precipitated, so the highest concentration of dissolved tin that could be maintained was 0.03 mg/L, a concentration that caused no mortalities over 4 days. Chronic toxicity tests with juvenile rainbow trout (*Oncorhynchus mykiss*) and bis(tri-*n*-butyltin) oxide (TBTO) (at a concentration of 0.5 or 2.0 micrograms per liter [µg/L]) showed that after 21 days, weight gain was significantly lower in TBTO-treated specimens relative to control specimens, and internal tin accumulation in TBTO-treated specimens increased between 7 and 21 days (Triebskorn and others, 1994). Rüdel and others (2007) show that over the two decades following Germany's ban on using organic tin compounds on small boats in 1989, concentrations of TBT and triphenyltin (TPT) decreased in the muscles of bream (*Abramis brama*) collected from river and lake samples. Some regions of the United States have adopted secondary acute and chronic screening benchmarks of 2,700 µg/L tin and 73 µg/L tin, respectively, for aquatic freshwater life, as recommended by the Oak Ridge National Laboratory (Suter and Tsao, 1996).

Relatively few studies focus on tin accumulation and toxicity in plants. Peterson and others (1976) surveyed the tin contents in different plant species in Malaysia and found that: (a) different plant species accumulate tin to varying levels (1.5 to 32 ppm dry weight) at control sites, and (b) plants near a tin smelter accumulated higher tin concentrations (8.4 to 2,165 ppm dry weight) than those plants in control areas. Experiments with relatively low concentrations of tributyltin chloride (TBTCl) and cells from three different vascular plant species revealed that tin concentrations within plant cells increased with increasing incubation time, which has implications for tin accumulation in the food chain (Caratozzolo and others, 2007). Some regions of the United States have adopted a soil screening benchmark of 50 ppm tin for terrestrial plants, although the confidence in this benchmark is low because of sparse datasets (Efroymson and others, 1997). The Canadian agricultural soil quality guideline for tin is lower, at 5 ppm (Canadian Council of Ministers of the Environment, 2007).

Mine Closure

Most recent and new mining operations include closure plans that address issues related to the mine footprint. A mine's footprint includes the waste left on site and in locally affected soil and water, as well as ecological impacts, such as habitat destruction and loss of biodiversity. Mining of both placer and lode tin deposits may generate mine waste piles. Wind-blown dust from unprotected mine waste piles may enter the atmosphere and surrounding soil and aquatic environments. In addition, these waste piles have the potential to become unstable. If using mine waste as backfill into dry mine workings is not an option, mine waste pile stability and dust-generating issues can often be addressed through grading and covering piles with vegetation.

Many lode tin deposits have the potential to generate AMD. For example, water draining from mine workings and tailings at the Ervedosa tin mine in Portugal displays a pH range of 3 to 6, and high dissolved metal and arsenic concentrations (Gomes and Favas, 2006). Common methods for treating AMD include active water treatment facilities or passive limestone-lined channels or constructed wetlands (Plumlee and Logsdon, 1999). The end result of both active and passive approaches is eventual precipitation of dissolved metals. Precipitated metals in passive wetland systems tend to be more stable under the prevailing anoxic conditions, whereas the metal-rich precipitates that result from active treatment facilities form a sludge that, if not responsibly disposed of, can cause environmental problems. When the potential for AMD exists at a mine site, a common preventative measure includes conducting water quality surveys before, during, and after mining.

Placer tin deposits tend to be mined by open pit and (or) dredging methods. Mining of alluvial placers in modern stream and riverbeds is less likely to increase dissolved salt loads but is more likely to increase the amount of sediment delivered downstream. This, combined with potential diversion of rivers and streams, may negatively affect downstream ecosystems. Many of the placer deposits located in Burma, Indonesia, Malaysia, and Thailand are located offshore below sea level. Some of these deposits have been mined, whereas others may become more economical to mine in the future (United Nations, 2004). Much of the processing of tin from offshore deposits takes place on land, so many of the same mine waste issues mentioned for onshore tin deposits also apply to offshore tin deposits. Additionally, most offshore placer tin deposits are mined by dredging methods, which have the potential to negatively affect benthic, midwater, and pelagic ecosystems. Such marine ecosystem disruption could, in turn, also negatively affect the fishing industry. Future developers will need to consider all environmental and social issues that could result from the mining of offshore placer tin deposits, as well as the relevant mitigation measures that address such issues.

Problems and Future Research

Supply Issues

Tin has not been mined or smelted in the United States since 1993 and 1989, respectively. Most tin deposits in the United States would be uneconomic to mine, even assuming higher prices for the metal. The only potentially economic deposits at present are the Lost River and Sleitat Mountain districts in Alaska (table S2, deposits 96 and 97; and fig. S11, deposits 3 and 5). The DOD recommends that material mitigation strategies for shortfalls include extra emergency purchases, substitutions, export reductions, Federal inventorying, and stockpiling. An additional strategy would be for the United States to develop its own (minimal) identified tin resources and (or) to explore for and find a major tin deposit. According to Sainsbury (1968), any future tin mining in the Seward Peninsula, Alaska, would have to mine ores with less than 2 percent tin.

Large-tonnage operations might be established on lower-grade disseminated ores, as occur in greisen-type deposits (for example, East Kemptville, Nova Scotia, Canada). To be profitable, such mines would probably also need to recover cassiterite, stannite, wolframite, and base-metal sulfides, as well as beryllium minerals and fluorite.

Research Issues

Whereas the mechanism of transport and deposition of tin is fairly well understood, the processes by which tin is incorporated into the parent magma at the points of magma generation and ascent are topics of investigation. As pointed out by Sainsbury and Reed (1973, p. 650–651), “alkali rocks in many parts of the world contain tin in amounts equal to or greater than the so-called tin-granites, yet no commercial tin lodes are ever associated with them. In a way, this fact refutes the possibility that the tin granites derive their tin from the surrounding rocks invaded by the magma or that tin deposits are formed by circulating meteoric waters.”

A promising advancement concerning research into the origin of tin deposits is the recent development of a reliable method for the analysis of tin isotopes in cassiterite (Haustein and others, 2010; Yamazaki and others, 2013). The ability to fingerprint cassiterite from various deposits or regions also shows great potential for identifying the source of tin in bronze archeological artifacts, a conundrum that has plagued archaeologists for many decades, if not centuries. Isotopic variations as large as 0.77‰ (per mil) in ^{124}Sn/^{120}Sn were observed in samples from Japan and China using multiple collector-inductively coupled plasma-mass spectrometer (MC–ICP–MS) techniques. The isotopic fractionation of all the sample studies was dependent on isotope mass. McNaughton and Rosman (1991) proposed the following three possible mechanisms for tin isotopic fractionation: (a) equilibrium fractionation between cassiterite and tin-sulfide minerals; (b) kinetic fractionation, which could take place during dissolution of tin in a source region and precipitation of tin in an ore deposit; and (c) multistage enrichment processes of tin from crustal material to ore, in which each step introduces kinetic fractionation. Yamazaki and others (2013) concluded from the samples that they studied, however, that the presence of tin-sulfide minerals does not play an important role in tin isotope fractionation; they also concluded that the temperature during ore formation was not the main cause of the tin isotope fractionation in the samples studied. Although the isotopic variation seen by Yamazaki and others (2013) was smaller than those observed in cassiterite from Europe by Haustein and others (2010), the mechanism of isotopic fractionation is still unclear. This is similar to the state of knowledge for stable isotopes of carbon, oxygen, silicon, and sulfur in the late 1940s and 1950s after the development of a precise mass spectrometer by Nier (1947). The technique is reliable and constantly being improved; the field of study is promising. Nevertheless, many tin deposits occur in regions where there is much shale or slate in the country rock, as in Cornwall and Bolivia. Stable isotope research using ^{124}Sn/^{120}Sn values and variations may go a long way towards improving understanding of the mechanism of tin isotopic fractionation.

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Note: All Web links listed were active as of the access date but may no longer be available.

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Table S2

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.

[WGS 84, World Geodetic System of 1984; negative values for latitude indicate that the deposit is in the Southern Hemisphere; negative values for longitude indicate that the deposit is in the Western Hemisphere. Elements: B, boron; F, fluorine; Fe, iron; Sn, tin. Dating method: Ar-Ar, argon-argon; K-Ar, potassium-argon; Rb-Sr, rubidium-strontium; U-Pb, uranium-lead. Abbreviations: ca., circa; Ga, giga-annum, or billion years before present; ID, identification; kg/m^3, kilogram per cubic meter; m, meter; Ma, mega-annum, or million years before present; NA, not applicable; n.d., no data; NNE-WSW, north-northeast—west-southwest; SHRIMP, sensitive high-resolution ion microprobe; wt. %, weight percent]

Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude	Longitude	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
				(decimal degrees WGS 84)						
1	Pirquitas Mine	Argentina	Jujuy	–22.72	–66.48	Hydrothermal	Lode, subvolcanic vein	Underground	Inactive since 1991	n.d.
2	Ardlethan	Australia	New South Wales	–34.33	146.85	Hydrothermal	Lode, breccia	Mine closed in 1986; reprocessing tailings in 2013	Additional underground mining being considered in 2013	0.420
3	Doradilla	Australia	New South Wales	–30.33	146.35	Hydrothermal	Skarn (F- and B-poor)	n.d.	Preliminary economic analysis	0.280
4	Taronga	Australia	New South Wales	–29.45	151.53	Hydrothermal	Lode, stockwork/sheeted veins	n.d.	Prefeasibility study	0.150
5	Maranboy/Yeuralba	Australia	Northern Territory	–14.53	132.79	Hydrothermal	Fissure veins associated with quartz-mica greisen, tourmalite, and topazite	Underground; operated from 1913 to 1952	Exploration	2.030
6	Mt. Wells	Australia	Northern Territory	–13.51	131.72	Hydrothermal and placer/alluvial	Veins, stockworks, and alluvial	n.d.	n.d.	0.970
7	Collingwood	Australia	Queensland	–15.77	145.25	Hydrothermal	Lode, greisen	n.d.	Closed in 2008	0.730
8	Gillian (Herberton area)	Australia	Queensland	–17.72	145.05	Hydrothermal	Lode, skarn	n.d.	n.d.	0.810
9	Mt. Garnet (Consolidated Tin Mines)	Australia	Queensland	–17.58	145.17	Hydrothermal	Fe-rich skarn	Open pit	Prefeasibility study	0.600
10	Mt. Garnet (MGT Resources)	Australia	Queensland	–17.58	145.17	Hydrothermal	Fe-rich skarn	Unknown	n.d.	0.780

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

[WGS 84, World Geodetic System of 1984; negative values for latitude indicate that the deposit is in the Southern Hemisphere; negative values for longitude indicate that the deposit is in the Western Hemisphere. Elements: B, boron; F, fluorine; Fe, iron; Sn, tin. Dating method: Ar-Ar, argon-argon; K-Ar, potassium-argon; Rb-Sr, rubidium-strontium; U-Pb, uranium-lead. Abbreviations: ca., circa; Ga, giga-annum, or billion years before present; ID, identification; kg/m^3, kilogram per cubic meter; m, meter; Ma, mega-annum, or million years before present; NA, not applicable; n.d., no data; NNE-WSW, north-northeast—west-southwest; SHRIMP, sensitive high-resolution ion microprobe; wt. %, weight percent]

Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
n.d.	n.d.	Schist	n.d.	n.d.	n.d.	n.d.	n.d.	Ross (1941); Velasco (1988); Sutphin and others (1990)
3.025 (2013)	n.d.	Granitic breccia	Biotite-rich, S-type granite	417±2.5 Ma	n.d.	n.d.	n.d.	Ren and others (1995); Clarke and others (1985); Sutphin and others (1990); Australian Tin Resources Pty Ltd. (2016); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
7.81 (2013)	n.d.	Marble, mica schist—Ordovician	Leucoadamellite, greisenized quartz-feldspar porphyritic dikes (F- and B-poor)	Early Devonian	n.d.	13,000 x 40 to 110 x 200	Stratform, near-vertical	Kwak (1987); Plimer (1984)
37.589 (2013)	n.d.	Metamorphosed mudstone, siltstone, sandstone	Adamellite	Late Triassic	n.d.	n.d.	n.d.	Offenberg (1982); Sutphin and others (1990); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
0.722 (2013)	n.d.	Greywacke, sandstone, conglomerate, shale, basalt—Neoproterozoic to Middle Cambrian; sandstone, conglomerate, shale and siltstone—Lower Cretaceous	Adamellite, quartz porphyry, and adamellite porphyry	n.d.	n.d.	Main lode—3,950 x 2 to 7.5 x?; Stannum King lode—1,000 x 3.6 x?	n.d.	Walpole (1958); Outback Metals Ltd. (2014a); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
1.137 (2013)	n.d.	Burrell Creek Formation: greywacke, siltstone, shale, biotite-sericite quartzite—Early Proterozoic (1862 ±3 Ma)	Muscovite-biotite granite and hornblende granite, unfoliated	1804 ± 50	U-Pb	2,400 x 300 x?	n.d.	Mookhey (1971); Outback Metals Ltd. (2014b); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
4.0 (1984)	n.d.	Greisen	Granite	Permian	n.d.	n.d.	n.d.	Krosch (1985)
2.3 (1982)	n.d.	Sedimentary rocks, basalt, chert, granite, granodiorite	Granite	Permian	n.d.	n.d.	n.d.	Brown and others (1984); Sutphin and others (1990)
7.3 (2013)	About 0.15 to 0.25	Chillagoe formation (sandstone, siltstone, limestone, carbonates, chert, basalt)—Silurian	Granite	Carboniferous-Permian	n.d.	6,000 x 4 to 20 x ?	Strata-bound, tabular; three distinct orebodies	De Lacey (2012); Consolidated Tin Mines Ltd. (2013); Michael Hicks, Consolidated Tin Mines Ltd., written commun., July 22, 2013
0.793 (2013)	n.d.	Chillagoe formation (sandstone, siltstone, limestone, carbonates, chert, basalt)—Silurian	Granite	Carboniferous-Permian	n.d.	n.d.	Strata-bound, tabular	Kettle (2012); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

[WGS 84, World Geodetic System of 1984; negative values for latitude indicate that the deposit is in the Southern Hemisphere; negative values for longitude indicate that the deposit is in the Western Hemisphere. Elements: B, boron; F, fluorine; Fe, iron; Sn, tin. Dating method: Ar-Ar, argon-argon; K-Ar, potassium-argon; Rb-Sr, rubidium-strontium; U-Pb, uranium-lead. Abbreviations: ca., circa; Ga, giga-annum, or billion years before present; ID, identification; kg/m^3, kilogram per cubic meter; m, meter; Ma, mega-annum, or million years before present; NA, not applicable; n.d., no data; NNE-WSW, north-northeast—west-southwest; SHRIMP, sensitive high-resolution ion microprobe; wt. %, weight percent]

Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude (decimal degrees WGS 84)	Longitude (decimal degrees WGS 84)	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
11	Cleveland (Aberfoyle and Rossarden)	Australia	Tasmania	–41.66	147.75	Hydrothermal	Greisenized calcic skarns and carbonate replacements of calcareous sandstone and mudstone	Closed in the 1970s	In exploration (2013)	0.680
12	Heemskirk (Queen Hill) (Zeehan tin project)	Australia	Tasmania	–41.88	145.32	Hydrothermal	Stockwork and strata-bound carbonate replacement (three separate orebodies)	UG	Prefeasibility study	1.140
13	Mount Bischoff	Australia	Tasmania	–41.41	145.52	Hydrothermal	Lode, carbonate replacement; alteration of quartz-orthoclase porphyry dikes	Open pit	n.d.	1.100
14	Mount Lindsay	Australia	Tasmania	–41.75	145.36	Hydrothermal	Greisenized calcic skarns and carbonate replacements of calcareous sandstone and mudstone	n.d.	Bankable feasibility study	0.200
15	Renison-Bell	Australia	Tasmania	–41.78	145.78	Hydrothermal	Lode, carbonate replacement	n.d.	n.d.	1.460
16	Rentails	Australia	Tasmania	–41.78	145.78	Tailings	NA	Tailings from the mill associated with the Renison-Bell deposit	n.d.	0.450

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
6.119 (2013)	0.35	Crimson Creek formation (interbedded, volcaniclastic turbiditic wacke, siltstone-mudstone, and tholeiitic basalt lava horizons and intrusive sills)—Neoproterozoic to Eocambrian; Sandstone, basalt, dolorite, argillite, chert, limestone, greywacke turbidite—Cambrian to Devonian	I-type biotite granite; composed of adamellite to alkali-feldspar granite	350 Ma	K-Ar, Rb-Sr	100 x 100 x 300	n.d.	Collins (1981); Blissett (1959); Mikyla Hickey, Venture Minerals Ltd., written commun., July 22, 2013
6.280 (2013)	0.6	Quartzite, shale, sandstone, dolostone, Crimson Creek Formation (Interbedded, volcaniclastic turbiditic wacke, siltstone-mudstone and tholeiitic basalt lava horizons and intrusive sills)—Neoproterozoic and Cambrian	I-type biotite granite; composed of adamellite to alkali-feldspar granite	Devonian	n.d.	Severn—536 x 223 x 192; Queen Hill—446 x 134 x 346; Montana—312 x 89 x 38	n.d.	Sutphin and others (1990); Blight (2012); J.A. Anderson, Aberfoyle Ltd., unpub. data, 1986; Stellar Resources Ltd., unpub. data, 2013; Peter Blight, Stellar Resources Ltd., written commun., July 1, 2013
10.54 (2013)	n.d.	Dolomite, dolomitic shale, quartzite—Pre-Cambrian; graywacke, mudstone, chert, basalts—Cambrian; quartz-orthoclase porphyry dikes and sills	Quartz-orthoclase porphyry dikes	349±4 Ma	Rb-Sr (whole rock)	n.d.	n.d.	Halley and Walshe (1995); Mikyla Hickey, Venture Minerals Ltd., written commun., July 22, 2013
45 (2013)	ca. 0.10	Success Creek Group (fluviatile deposits—siliceous sandstone; siliceous siltstone, mudstone, dolomite and stromatolite clast-bearing, oolitic, chert breccia) and Crimson Creek formation (interbedded, volcaniclastic turbiditic wacke, siltstone-mudstone, and tholeiitic basalt lava horizons and intrusive sills)—Neoproterozoic	I-type biotite granite; composed of adamellite to alkali-feldspar granite	Devonian	n.d.	950 to 2,150 long, 15 to 35 thick, 4.75 cross-strike width of individual skarn layers	n.d.	Radonjic (2012); Mikyla Hickey, Venture Minerals Ltd., written commun., July 22, 2013
26.0 (2013)	n.d.	Dolostone, quartzite, siltstone, shale, sandstone	n.d.	Devonian	n.d.	n.d.	n.d.	Sutphin and others (1990); R. Morland, Renison Associated Tin Mines, unpub. data, 1986; Mikyla Hickey, Venture Minerals Ltd., written commun., July 22, 2013
20.461 (2013)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Peter Kettle, International Tin Research Institute, written commun., April 8, 2013

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude	Longitude	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
				(decimal degrees WGS 84)						
17	Greenbushes	Australia	Western Australia	–33.83	115.98	Hydrothermal	Lode, pegmatite, placer	Surface placer	n.d.	0.1175 (lode); 0.0268 (placer)
18	Colquiri tailings	Bolivia	La Paz Department	–17.38	–67.12	Tailings	Sn-polymetallic vein	Tailings from the mill associated with the Colquiri tin mine	Uncertain	0.600
19	Central (Llallagua, (San Jose/ Oruro, Huanuni)	Bolivia	Oruro Department	–18.00	–67.00	Hydrothermal	Lode, subvolcanic	n.d.	n.d.	0.550
20	Bolivian placers	Bolivia	Potosi Department	–18.00	–65.00	Placer/alluvial	Placer, alluvial	n.d.	n.d.	0.021
21	Catavi tailings	Bolivia	Potosi Department	–18.43	–66.57	Tailings	NA	Catavi is a mill that served numerous mines in the Potosi district	n.d.	0.350
22	Southern (Cerro Rico, Chorolque)	Bolivia	Potosi Department	–19.00	–66.00	Hydrothermal	Lode, subvolcanic	n.d.	n.d.	0.550
23	Northern (Chojlla, Colquiri)	Bolivia	San Jose Department	–16.00	–67.00	Hydrothermal	Lode, vein	n.d.	n.d.	0.780
24	Mapuero tin district (Pitinga Mine is the largest producer, accounting for about 90% of Brazil's production)	Brazil	Amazonas State	–0.75	–60.12	Placer/alluvial	Placer	Onshore dredge	n.d.	n.d.
25	Serra Branca	Brazil	Goias State	–13.62	–48.07	Hydrothermal and placer/ alluvial	Placer, lode, massive greisen	n.d.	n.d.	1.250
26	Brascan Group (Rondonia tin province)	Brazil	NA	–9.00	–63.00	Hydrothermal and placer/ alluvial	Placer, lode, massive greisen,	n.d.	n.d.	0.425
27	Mocambo	Brazil	Pará State	–6.83	–51.95	Hydrothermal and placer/ alluvial	Placer, lode, massive greisen	n.d.	n.d.	0.061
28	Rhodia-Espeng	Brazil	Pará State	–6.03	–53.72	Placer/alluvial	Placer	Gravel pump	n.d.	0.034
29	Brumadinho Group	Brazil	Rondonia and Goias States	–9.55	–62.42	Hydrothermal and placer/ alluvial	Placer and lode	n.d.	n.d.	0.093

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
39.0 (lode); 8.812 (placer) (1985)	n.d.	Pegmatite, laterized gravel and sand	Pegmatite	2.53 Ga	n.d.	n.d.	n.d.	Blockley (1980); Sutphin and others (1990)
11.0 (2013)	n.d.	Shale, sandstone, slightly metamorphosed—Devonian	Only dikes seen; significance unknown	Miocene	Stoping	3,000 x 100 x 500	Tabular	Campbell (1947); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
7.116 (1982 and 1984)	n.d.	Slate, metasediment, volcanics	n.d.	Tertiary	n.d.	n.d.	n.d.	Fox (1971); Sillitoe and others (1975); Sutphin and others (1990)
57.709 (1982)	n.d.	Sediments	n.d.	n.d.	n.d.	n.d.	n.d.	Fox (1971); Sillitoe and others (1975); Sutphin and others (1990)
40.0 (2013)	n.d.	Slightly metamorphosed shale—Devonian	n.d.	n.d.	n.d.	n.d.	n.d.	Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
7.1176 (1982)	n.d.	n.d.	n.d.	Tertiary	n.d.	n.d.	n.d.	Fox (1971); Sillitoe and others (1975); Sutphin and others (1990)
8.667 (1982)	n.d.	Granodiorite, quartzite, shale	n.d.	Tertiary	n.d.	n.d.	n.d.	Fox (1971); Sillitoe and others (1975); Sutphin and others (1990)
0.500 contained Sn (1987)	n.d.	“Apogranite,” rhyolite and tuffs	“Apogranite,” rhyolite and tuffs	“Apogranite” 1.9 to 1.5 Ga; rhyolite and tuffs—mid-Proterozoic	n.d.	n.d.	n.d.	Mareno (1986); Thorman and Drew (1988); Sutphin and others (1990)
0.551 (1982)	n.d.	Metasediments	Greisenized granite	Precambrian	n.d.	n.d.	n.d.	Sutphin and others (1990)
73.833 (1982)	n.d.	Granite, Rapakivi granite, paleovalley sediments	Greisenized granite	Precambrian	n.d.	n.d.	n.d.	Mareno (1986); Sutphin and others (1990)
13.000 (1982)	n.d.	Metasediments	Greisenized granite	Precambrian	n.d.	n.d.	n.d.	Sutphin and others (1990)
26.647 (1982)	n.d.	n.d.	Granite	Precambrian?	n.d.	n.d.	n.d.	Sutphin and others (1990)
65.428 (1982)	n.d.	Granite, Rapakivi granite, paleovalley fill	Granite	n.d.	n.d.	n.d.	n.d.	Mareno (1986); Sutphin and others (1990)

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude	Longitude	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
				(decimal degrees WGS 84)						
30	Best Group	Brazil	Rondonia and Pará States	–9.45	–65.13	Placer/alluvial	Placer	Gravel pump	n.d.	0.023
31	C–75 Garimpo	Brazil	Rondonia State	–9.90	–63.43	Hydrothermal and placer/alluvial	Placer, eluvial, lode, greisen and vein	n.d.	n.d.	n.d.
32	Mawchi Mine	Burma (also referred to as Myanmar)	Kayah Province	18.82	97.17	Hydrothermal	Lode, vein	n.d.	n.d.	0.070
33	Tenasserim Valley, Southeast Asian tin belt	Burma (also referred to as Myanmar)	Taninthayi region	12.00	99.00	Placer/alluvial	Placer (alluvial)	n.d.	n.d.	n.d.
34	Mount Pleasant	Canada	New Brunswick Province	45.43	–66.82	Hydrothermal	Lode, subvolcanic vein/porphyry	n.d.	Prefeasibility study	0.370
35	East Kemptville	Canada	Nova Scotia Province	44.10	–65.68	Hydrothermal	Lode, greisen	n.d.	Preliminary economic analysis	0.165
36	Dachang	China	Guangxi Province	24.83	107.83	Hydrothermal	Lode, carbonate replacement	n.d.	n.d.	0.5 to 1.0
37	Cuomolong	China	Sichuan Province	30.50	99.37	Hydrothermal	Skarn	n.d.	n.d.	0.22 to 1.38
38	Datongchang	China	Yunnan Province	25.53	98.73	Hydrothermal	Vein, strata-bound, skarn	n.d.	n.d.	0.016 to 0.26
39	Diantan	China	Yunnan Province	25.65	98.43	Hydrothermal	Skarn	n.d.	n.d.	n.d.
40	Gejiu district	China	Yunnan Province	23.33	103.33	Hydrothermal	Lode, carbonate replacement, some vein-type skarn	Surface-underground	n.d.	1.000
41	Lailishan	China	Yunnan Province	24.92	98.27	Hydrothermal	Vein, strata-bound	n.d.	n.d.	0.63 to 1.58
42	Laopingshan	China	Yunnan Province	25.00	98.37	Hydrothermal	Greisen	n.d.	n.d.	n.d.
43	Xiaolonghe	China	Yunnan Province	25.45	98.43	Hydrothermal	Greisen	n.d.	n.d.	0.18 to 0.42

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
24.386 (1982)	n.d.	Paleovalley sediments	Greisen	Precambrian	n.d.	n.d.	n.d.	Bettencourt and others (1981); Sutphin and others (1990)
0.100 contained Sn (1987)	n.d.	Granite, gneiss, basement rocks	Granite	1,150 t 925 Ma	n.d.	n.d.	n.d.	Thorman and Drew (1988); Sutphin and others (1990)
0.7 (1983)	n.d.	Clastic and carbonate metasediments, granite	Granite	Late Mesozoic–Early Tertiary	n.d.	n.d.	n.d.	U Khin Zaw and Daw Khin Myo Thet (1983); Sutphin and others (1990)
n.d.	n.d.	Eluvial and alluvial sediments, granite (tourmaline-rich)	Granite	Late Mesozoic–Early Tertiary	n.d.	n.d.	n.d.	Sutphin and others (1990)
15.2 (2013)	n.d.	Granite and quartz-feldspar porphyry	Granite	340 to 330 Ma	K-Ar	n.d.	n.d.	Kooiman and others (1986); Sutphin and others (1990)
56.0 (1984)	n.d.	Granite and metasediments	Granite	295±5 Ma	Ar-Ar	n.d.	n.d.	Richardson and others (1982); Sutphin and others (1990)
50–100 (1985)	n.d.	Shale, marl, limestones, granite	Granite	97 Ma	K-Ar	n.d.	n.d.	Premoli (1986); Sutphin and others (1990)
11.5 (2007)	n.d.	Triassic sandstone	Granite	n.d.	n.d.	Length: to 442; thickness: 1.40 to 8.58	Lenticular, strata-bound	Hou and others (2007)
<10.0 (2007)	n.d.	Dolomite, limestone, arenaceous mudstone, sandstone	Biotite granite	Mesozoic	n.d.	n.d.	Vein, strata-bound	Hou and others (2007)
n.d.	n.d.	Dolomitic limestone, arenaceous mudstone, sandstone	Biotite granite	Mesozoic	n.d.	n.d.	Lens, strata-bound	Hou and others (2007)
100 (1985)	n.d.	Limestone and dolomite, minor argillite, tuff and basalt, gneiss and schist, biotite granite	Granite	Porphyritic biotite granite, 115 to 84 Ma; Equigranular biotite granite, 80 to 64 Ma	K-Ar	n.d.	n.d.	Kwak (1987); Sutphin and others (1990)
42.6 (2007)	n.d.	Metamorphosed feldspathic sandstone, argillaceous siltstone, dolomite	Alkali-feldspar granite	n.d.	n.d.	Length: 40 to 600; width: 0.89 to 23.8	n.d.	Hou and others (2007)
n.d.	n.d.	Sandy slate	Biotite granite	Mesozoic	n.d.	n.d.	Vein, strata-bound	Hou and others (2007)
26,200 (2007)	n.d.	Sandy slate	Biotite granite	Mesozoic	n.d.	Length: 30 to 300; thickness: 1 to 20	Irregular	Hou and others (2007)

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Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude (decimal degrees WGS 84)	Longitude (decimal degrees WGS 84)	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
44	Cinovec (Zinnwald)	Czech Republic	Teplice District	50.73	13.77	Hydrothermal	Greisen	n.d.	n.d.	0.370
45	Kivu mines	Democratic Republic of the Congo (Congo [Kinshasa]) (formerly Zaire)	North Kivu Province	–6.50	27.50	Placer/alluvial	Placer	Gravel pump	n.d.	n.d.
46	Abu Dabbab	Egypt	Al Bahr al Ahmar Governorate	25.34	34.54	Hydrothermal and placer/alluvial	Skarn and greisen veins (primarily a tantalum deposit); associated tin placers	Open pit planned	Feasibility study	0.09 (0.13%, according to Roskill Information Services, Ltd., 2015)
47	Antonsthal district in the Westerzgebirge (Western Ore Mountains)	Germany	Saxony	50.51	12.74	Hydrothermal	Skarn ± schist replacement	n.d.	Exploration	0.190
48	Auersberg-Wildenthal district in the Westerzgebirge (Western Ore Mountains)	Germany	Saxony	50.46	12.64	Hydrothermal	Greisen veins	n.d.	Exploration	0.300
49	Breitbrunn district in the Westerzgebirge (Western Ore Mountains)	Germany	Saxony	50.48	12.77	Hydrothermal	Skarn ± schist replacement	n.d.	Exploration	0.250
50	Elbenstock-Sosa district in the Westerzgebirge (Western Ore Mountains)	Germany	Saxony	50.49	12.63	Hydrothermal	Greisen veins	n.d.	Exploration	0.260

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
28.1 (2013)	n.d.	Granite	Alkali-feldspar granite, rhyolite	330 to 295 Ma	n.d.	n.d.	Flat-lying, subhorizontal veins form regular domal structures that mimic the upper granite cupola contact	Schwarz-Schampera and Herzig (2002); Porter GeoConsultancy Pty Ltd. (1995); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
0.265 contained Sn (1986)	n.d.	Alluvium and eluvium, granite, metasediments	Granite	Precambrian	n.d.	n.d.	n.d.	Angermeier and others (1974); Sutphin and others (1990)
44.5 (2013)	n.d.	Quartz-bioite and quartz chlorite schists with intercalated beds of tuff and agglomerate, diabase—Neoproterozoic	Muscovite aplite leucogranite	Neoproterozoic	n.d.	400 x 200 x 480	Ellipsoidal and tabular	Amin (1947); Sabet and others (1971); Sarin and others (1976); Roskill Information Services, Ltd. (2015); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
14.7	n.d.	Cambrian-Ordovician sediments, mainly pelitic, but with some limestone beds (now marble/ calc-silicate and skarn)	Granite	Hercynian	n.d.	2,500 x 1,300 x variable thickness	Veins	Antony Truelove, Indo Gold Ltd., written commun., September 8, 2013
10.8	n.d.	Cambrian-Ordovician sediments, mainly pelitic, but with some limestone beds (now marble/ calc-silicate and skarn)	Granite	Hercynian	n.d.	500 x 500 x unknown depth	Veins	Antony Truelove, Indo Gold Ltd., written commun., August 8, 2013
22.3	n.d.	Cambrian-Ordovician sediments, mainly pelitic, but with some limestone beds (now marble/ calc-silicate and skarn)	Granite	Hercynian	n.d.	2,000 x 1,400 x variable thickness	Strata-bound	Antony Truelove, Indo Gold Ltd., written commun., August 8, 2013
2.3	n.d.	Cambrian-Ordovician sediments, mainly pelitic, but with some limestone beds (now marble/ calc-silicate and skarn)	Granite	Hercynian	n.d.	200 x 5,000 x unknown depth	Veins	Antony Truelove, Indo Gold Ltd., written commun., August 8, 2013

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude	Longitude	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
				(decimal degrees WGS 84)						
51	Geyer-Southwest	Germany	Saxony	50.62	12.90	Hydrothermal	Skarn	Sublevel stoping or more selective mining being considered	Prefeasibility	0.370
52	Gottesberg	Germany	Saxony	50.42	12.48	Hydrothermal	Greisen stockwork and breccia pipes	Sublevel, open stoping planned	Prefeasibility	0.270
53	Hammerlein-Tellerhauser district in the West-erzgebirge (Western Ore Mountains)	Germany	Saxony	50.45	12.87	Hydrothermal	Skarn, greisen veins, replacements in schist below skarn	n.d.	Exploration	0.570
54	Muhlleithen district in the West-erzgebirge (Western Ore Mountains)	Germany	Saxony	50.41	12.45	Hydrothermal	Breccia pipe	n.d.	Exploration	0.300
55	Sauschwemme, West-erzgebirge (Western Ore Mountains)	Germany	Saxony	50.44	12.66	Placer/alluvial	Alluvial	n.d.	Exploration	0.040
56	P.T. Koba Tin	Indonesia	Bangka Island	–2.58	106.40	Placer/alluvial	Placer	Gravel pump, dredge	n.d.	n.d.
57	P.T. Tambang Tamah	Indonesia	Bangka Island	–2.00	106.00	Placer/alluvial	Placer	Gravel pump, onshore dredge	n.d.	0.220
58	Kelapa Kampit	Indonesia	Belitung Island	–2.75	108.08	Tailings	Lode, vein	n.d.	n.d.	1.670
59	P.T. Tambang Belitun	Indonesia	Belitung Island	–2.67	107.83	Placer/alluvial	Placer	Gravel pump, onshore dredge	n.d.	0.013
60	Pt Timah Singkep Mine	Indonesia	Singkep Island	–2.00	114.00	Placer/alluvial	Placer	Gravel pump, onshore dredge	n.d.	n.d.
61	Akenobe	Japan	Hyogo Prefecture, Honshu Island	35.22	134.68	Hydrothermal	Lode, polymetallic veins	n.d.	n.d.	n.d.
62	Suzuyama	Japan	Kyushu Island	31.50	130.43	Hydrothermal	Lode, pegmatite and quartz veins	n.d.	n.d.	1.250

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
11.6 (2013)	0.150	Cambrian-Ordovician schists, dolomite and calcite-dolomite sediments	Granite	Hercynian	n.d.	2,600 x 400 x ?	n.d.	Lehmann (1990); Kettle (2012)
42.1 (2013)	0.150	Granite and granite porphyry	Granite	Hercynian	n.d.	800 x 400 x 900	Pipe	Beyschlag and others (1914); Lindgren (1933); Lehmann (1990); Kettle (2012)
25.3 (2013)	n.d.	Cambrian-Ordovician sediments, mainly pelitic, but with some limestone beds (now marble/ calc-silicate and skarn)	Granite	Hercynian	n.d.	about 5,600 x 0.5 x 2 to 3 (seams)	Strata-bound	Truelove, 2012; Antony Truelove, Indo Gold Ltd., written commun., September 8, 2013
0.75 (“Soviet” estimates)	n.d.	Cambrian-Ordovician sediments, mainly pelitic, but with some limestone beds (now marble/calc-silicate and skarn)	Granite	Hercynian	n.d.	30 x 30 x ≥ 200	Pipe	Antony Truelove, Indo Gold Ltd., written commun., September 8, 2013
6.5 (“Soviet” estimates)	n.d.	Alluvium/stream sediment	n.d.	Alpine orogeny(?) to Holocene	n.d.	≥1,000 x 30	Alluvium	Antony Truelove, Indo Gold Ltd., written commun., September 8, 2013
0.0467 contained Sn (1982)	n.d.	Formed in current and ancient channels	n.d.	n.d.	n.d.	n.d.	n.d.	Prijono (1986); Sutphin and others (1990)
2.259 (1982)	n.d.	Alluvial and eluvial sediments	n.d.	Post-Triassic	n.d.	n.d.	n.d.	Sutphin and others (1990)
1.390 (1982)	n.d.	Quartzite, sandstone, slate, granitoids	Granite	Lower Triassic	n.d.	n.d.	n.d.	Omer-Cooper and others (1974); Sutphin and others (1990)
23.381 (1982)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Prijono (1986); Sutphin and others (1990)
n.d.	n.d.	Bedrock is alternating beds of sandstone and shale intruded by stocks that range from gabbro to granite	Biotite granite	n.d.	n.d.	n.d.	n.d.	Sainsbury (1969b)
0.04 contained Sn (1980)	n.d.	Basalt, basaltic tuff, phyllite	n.d.	Tertiary?	n.d.	n.d.	n.d.	Sato and Akiyama (1980); Sutphin and others (1990)
0.448 (1982)	n.d.	Granite, pegmatite, shale, and sandstone	Granite and pegmatite	Tertiary	n.d.	n.d.	n.d.	Saito and others (1960); Sutphin and others (1990)

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude	Longitude	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
				(decimal degrees WGS 84)						
63	Syrymbet	Kazakhstan	North Kazakhstan Province	53.48	67.98	Hydrothermal	Vein stockwork, skarn, endogreisen	n.d.	Feasibility study	0.840
64	Malaysian dredges	Malaysia	NA	4.00	103.00	Placer/alluvial	Placer	Onshore dredge	n.d.	n.d.
65	Malaysian gravel pump mines	Malaysia	NA	4.00	103.00	Placer/alluvial	Placer	Gravel pump	n.d.	n.d.
66	Sungai Lembing	Malaysia	Pahang State	3.87	103.08	Hydrothermal	Lode, vein	n.d.	n.d.	0.710
67	Kinta tin field	Malaysia	Perak State	4.28	101.17	Mostly placer/alluvial and minor hydrothermal lode	Placer and lode	Gravel pump, dredge	Almost completely played out	n.d.
68	Kuala Langat Mining Sdn Bhd	Malaysia	Selangor State	2.82	101.62	Placer/alluvial	Placer	Dredge	Proposed	0.190 kg/m^3
69	Oortsog Ovoo	Mongolia	Dundgovi Province	45.57	108.10	Hydrothermal	Skarn	Open pit	Initial metallurgical study	0.007
70	Narsiin Khundlen (Amerilangui Ujin)	Mongolia	Khentii (or Hentiy) Province	48.74	112.53	Hydrothermal	Greisen veins	Open pit and underground	Feasibility study completed, but construction not yet started as of 2010	0.450
71	Achmmach	Morocco	Meknes	33.32	–5.45	Hydrothermal	Veins and disseminated in alteration envelopes	n.d.	In development as of 2013	0.85 (combined measured, indicated, and inferred)
72	Bou El Jaj	Morocco	Meknes	33.28	–5.48	Hydrothermal	Veins and disseminated in alteration envelopes	n.d.	In development as of 2014	NA
73	Achmmach	Morocco	Meknes-Tafilalet region	33.32	–5.45	Hydrothermal	Veins and disseminated in alteration envelopes	Long-hole stoping	Drilling and prefeasibility (expected startup in 2016)	0.850

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
12.0 (2013)	n.d.	Neoproterozoic sediments	Leucocratic granite	Middle Devonian	n.d.	n.d.	Stockwork veins	Velichkin and others (2000); Rubinstein and Barsky (2002); Syrymbet Mining Co. (2016); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
0.509 contained Sn (1985)	n.d.	Alluvium, granite, sediments	Granite	Mesozoic	n.d.	n.d.	n.d.	Govett and Robinson (1980); Sutphin and others (1990)
0.900 contained Sn (1985)	n.d.	Alluvium, granite, limestone, sandstone, metasediments	Granite	Mesozoic	n.d.	n.d.	n.d.	Govett and Robinson (1980); Sutphin and others (1990)
1.073 (1982)	n.d.	n.d.	Granite	Carboniferous	n.d.	n.d.	n.d.	Sutphin and others (1990)
n.d.	n.d.	Mostly calcareous rocks and some shale, phyllite, and schist	Granite	Probably Triassic to Jurassic	Mapping and stratigraphy	48 km	Multiple deposits	Rajah (1979)
n.d.	n.d.	Mainly sedimentary terrane, middle Paleozoic	n.d.	n.d.	n.d.	6.6 km	n.d.	Bliss and Menzie (1995); U.S. Geological Survey (2016)
3.700	0.003	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
7.8 (2013)	n.d.	Devonian volcanics and Jurassic granites	Granite	Jurassic	n.d.	Five prospects with ore bodies 60 to 500 m long and 0.8 to 2.5 m thick	n.d.	Amerilangui Ujin LLC (2010); Dandar (2009); Jargalsaikhan (1996); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
15.3 (combined measured, indicated, and inferred)	n.d.	Interbedded sandstone and siltstone (315 to 325 Ma)	Granite at depth presumed	Presumed Hercynian	Planned long-hole stoping	about 600 x 1,600	NNE-WSW-striking vertical mineralized structures in a fold and thrust belt	Blight (2012); Pierre Chaponniere, Kasbah Resources Ltd., written commun., July 11, 2013
NA	n.d.	Interbedded sandstone and siltstone (315 to 325 Ma)	Granite at depth presumed	Presumed Hercynian	n.d.	n.d.	NNE-WSW-striking vertical mineralized structures in a fold and thrust belt	Blight (2012); Pierre Chaponniere, Kasbah Resources Ltd., written commun., July 11, 2013
15.3 (2013)	n.d.	Interbedded sandstone and siltstone (315 to 325 Ma)	Granite assumed	Late Hercynian	n.d.	1,600 x 600 x 400	NNE-WSW vertical mineralized strucures	Bramwell (2012); Wayne Bramwell, Kasbah Resources Ltd., written commun., July 11, 2013

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

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Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude (decimal degrees WGS 84)	Longitude (decimal degrees WGS 84)	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
74	Bou El Jaz	Morocco	Meknes-Tafilalet region	33.28	–5.48	Hydrothermal	Veins and disseminated in alteration envelopes	n.d.	Drilling	Unpublished as of July 2013
75	Uis tin mine	Namibia	Southern Damaraland	–21.22	14.87	Hydrothermal	Lode, altered pegmatite	n.d.	n.d.	0.260
76	Jos Plateau deposits (Bauchi, Benue, Kano, and Zaria States)	Nigeria	Bauchi, Benue, Kano, and Zaria States	9.75	8.87	Placer/alluvial	Placer	n.d.	n.d.	n.d.
77	San Rafael	Peru	Puno Department	–14.20	–70.47	Hydrothermal	Lode (veins and breccias)	Open stope	n.d.	10.100
78	San Rafael tailings	Peru	Puno Department	–14.20	–70.47	Tailings	NA	Tailings from the mill associated with the San Rafael Mine	n.d.	1.300
79	Neves-Corvo District. Four principal individual deposits: Graca, Corvo, Neves, Zambujal and Lombador	Portugal	Baixo Alentejo Province	37.60	–7.97	Hydrothermal	Lode, volcanic-hosted massive sulfide	Underground	Active	Graca: 0.17; Corvo: 0.30; Neves: 0.17; Zambujal and Lombador: 0.07 (0.25 overall, with grades up to 60)
80	Southern mining regions of the former Soviet Union	Russia	Chita, Khabarovsk	53.00	124.00	Hydrothermal	Lode	n.d.	n.d.	n.d.
81	Pyrkakay	Russia	Chukotskiy Avtonomnyy Okrug	65.28	175.78	Hydrothermal	Porphyry tin	Proposed open pit	Prefeasibility	0.250
82	Pravourmiyskoe	Russia	Khabarovsk Kray	50.43	134.25	Hydrothermal	Tin greisen	n.d.	n.d.	1.000

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
Unpublished as of July 2013	n.d.	Interbedded sandstone and siltstone (315 to 325 Ma)	Granite assumed	Late Hercynian	n.d.	n.d.	n.d.	Blight (2012); Wayne Bramwell, Kasbah Resources Ltd., written commun., July 11, 2013
16.7 (1977)	n.d.	Quartzite schist, pegmatite	Pegmatite	Unknown	n.d.	n.d.	n.d.	Richards (1986); Sutphin and others (1990)
0.111 contained Sn (1969)	n.d.	Alluvium and eluvium, granites, basalt	Granite	Jurassic	n.d.	n.d.	n.d.	MacLeod and others (1971); Sutphin and others (1990)
0.223 (1980)	n.d.	Metapelites and metapsammites—Ordovician to Devonian; psammites and carbonates—late Paleozoic; red beds and intercalated volcanics—mid-Permian–Triassic; psammites and carbonates—Cretaceous; felsic ignimbrites and red beds—Miocene–Pliocene	Polyphase intrusion of granite, leucogranite, and granodiorite	22.7±0.7 to 21.9±0.2 Ma	Ar-Ar on hydrothermal adularia and muscovite	3,000 x 2 to 50 x 1,300	n.d.	Mlynarczyk and others (2003); Wagner and others (2009)
7.7 (2013)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
Graca: 3.45; Corvo: 20.47; Neves: 28.72; Zambujal and Lombador: 32.34 (300 total)	n.d.	Volcanics, granite	Granite	Carboniferous	n.d.	Graca: 700 x 500 x 80; Corvo: 600 x 1,100 x 92; Neves: 1,200 x 700 x 55; Zambujal: 550 x 600 x 53; Lombador: 600 x 1,350 x 100	Massive sulfide; fissure; stockwork	Mining Journal (1988); Sutphin and others (1990); Relvas and others, 2006
0.150 contained Sn (1989)	n.d.	Quartz porphyry granite, volcanic quartz porphyry tuff	Granite	97 to 91 Ma	n.d.	n.d.	n.d.	Smirnov (1977); Sutphin and others (1990)
93.0 (2013)	n.d.	n.d.	n.d.	Late Cenozoic sedimentary rocks	n.d.	n.d.	n.d.	Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
10.7 (2013)	n.d.	Felsic volcanic rocks	Granite and leucogranite (75 to 85 Ma, K-Ar; 95 to 83 Ma, Rb-Sr)	Late Early Cretaceous	n.d.	6,750 x 375 x 2,250	n.d.	Nokleberg and others (2005); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013

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Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude	Longitude	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
				(decimal degrees WGS 84)						
83	Northern mining regions of the former Soviet Union	Russia	Magadan, Oblast and Sakha Republic	69.00	140.00	Hydrothermal	Lode, vein	n.d.	n.d.	n.d.
84	Lendakhskaya	Russia	Western Siberia	59.33	92.85	Hydrothermal	Cassiterite greisen	n.d.	n.d.	0.830
85	Kuils River	South Africa	Cape Province	–33.93	18.73	Hydrothermal	Lode, greisen veins	n.d.	n.d.	2.440
86	Van Rooi's Vley	South Africa	Cape Province	–28.50	20.88	Hydrothermal	Lode, vein stockwork and replacement pipes	n.d.	n.d.	0.210
87	Rooiberg tin mines	South Africa	Transvaal	–24.75	27.75	Hydrothermal	Lode	Closed in 1993	n.d.	n.d.
88	Union tin mine	South Africa	Transvaal	–24.48	28.50	Hydrothermal	Lode, vein	n.d.	n.d.	n.d.
89	Zaaiplaats tin mine	South Africa	Transvaal	–24.05	28.75	Hydrothermal	Lode, veins, pipes and disseminated ores	n.d.	n.d.	0.165
90	Oropesa	Spain	Cordoba Province	38.00	–5.48	Hydrothermal	Veins, disseminated ore associated with shear zones and breccias. Type unclear. Post-orogenic system of the deep subvolcanic type?	Open pit	Preliminary economic assessment completed in 2014	0.470
91	Thai dredging operations, Southeast Asian tin belt	Thailand	NA	9.00	99.00	Placer/alluvial	Placer	Dredge	n.d.	0.024
92	Thai gravel pump operations, Southeast Asian tin belt	Thailand	NA	8.00	99.00	Placer/alluvial	Placer	Gravel pump	n.d.	0.015
93	Thai hard-rock and open pit operations, Southeast Asian tin belt	Thailand	NA	13.87	99.12	Hydrothermal	Lode	n.d.	n.d.	0.136

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Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
0.150 contained Sn (1989)	n.d.	Sandstone and siltstone, granite	Granite	143 to 148 Ma	K-Ar	n.d.	n.d.	Smirnov (1977); Sutphin and others (1990)
3.1 (2013)	n.d.	Granite	Granite	880 to 864 Ma	SHRIMP U–Pb zircon	n.d.	Granite intrusion contacts	Khiltova and Pleskach (1997); Vernikovsky and others (2007); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
0.705 (1973)	n.d.	Cape granite suite	Granite	553±8 Ma	n.d.	n.d.	n.d.	Hill and Brunker (1981); Sutphin and others (1990)
2.5 (1984)	n.d.	Paragneiss	n.d.	940±50 Ma	n.d.	n.d.	n.d.	van Backström (1950); Sutphin and others (1990)
n.d.	n.d.	Arkosic quartzite, shaley quartzite	n.d.	ca. 1,960 Ma	n.d.	n.d.	n.d.	Rozendal and others (1986); Sutphin and others (1990)
n.d.	n.d.	Indurated tuff, felsite	Tuff?	2,050 Ma	n.d.	n.d.	n.d.	Pringle (1986); Sutphin and others (1990)
5.0 (1986)	n.d.	Leucogranite to mildly alkali granite, granophyre, microgranite	Granite	ca. 1.96 Ga	n.d.	n.d.	n.d.	Zaaiplaats Tin Mining Co. (1983); Sutphin and others (1990)
5.787 (2013)	0.1	Devonian to upper Carboniferous quartzite, slate, conglomerate of shale, arenite and quartzite pebbles and cobbles, sandstone, greywacke, shale	Foliated granite(?)	Unknown (post-Carboniferous)	n.d.	1,300 x 185 x 200	n.d.	Baker (2012)
2,583.743 (1982)	n.d.	Alluvial and eluvial sediments, granite	Granite	Cretaceous	n.d.	n.d.	n.d.	Sutphin and others (1990)
1,630.500 (1984)	n.d.	Detrital sediments, granite	Granite	Tertiary and Cretaceous	n.d.	n.d.	n.d.	Nutalaya and others (1979); Sutphin and others (1990)
54.220 (1982)	n.d.	Granite	Granite	Cretaceous	n.d.	n.d.	n.d.	Sutphin and others (1990)

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

[WGS 84, World Geodetic System of 1984; negative values for latitude indicate that the deposit is in the Southern Hemisphere; negative values for longitude indicate that the deposit is in the Western Hemisphere. Elements: B, boron; F, fluorine; Fe, iron; Sn, tin. Dating method: Ar-Ar, argon-argon; K-Ar, potassium-argon; Rb-Sr, rubidium-strontium; U-Pb, uranium-lead. Abbreviations: ca., circa; Ga, giga-annum, or billion years before present; ID, identification; kg/m^3, kilogram per cubic meter; m, meter; Ma, mega-annum, or million years before present; NA, not applicable; n.d., no data; NNE-WSW, north-northeast—west-southwest; SHRIMP, sensitive high-resolution ion microprobe; wt. %, weight percent]

Deposit ID	Deposit or mine	Country	State, Territory, or Province	Latitude (decimal degrees WGS 84)	Longitude (decimal degrees WGS 84)	Deposit class	Ore type	Operation type and (or) comments	Development status	Grade Sn (wt. % unless otherwise noted)
94	Geevor	United Kingdom	Cornwall	50.15	–5.68	Hydrothermal	Lode, vein	n.d.	n.d.	0.570
95	Redmoor	United Kingdom	Cornwall	50.50	–4.31	Hydrothermal	Stockwork and sheeted veins	Shrinkage methods—overhand shrinkage	Scoping study	0.210
96	South Crofty	United Kingdom	Cornwall	50.23	–5.28	Hydrothermal	Lode, vein	Shrinkage methods—overhand shrinkage	n.d.	0.440
97	Wheal Jane	United Kingdom	Cornwall	50.23	–5.12	Hydrothermal	Lode,vein	n.d.	n.d.	0.890
98	Lost River district	United States	Alaska	65.48	–167.13	Hydrothermal	Lode, vein, greisen skarn	n.d.	n.d.	1.300
99	Sleitat Mountain	United States	Alaska	60.05	–157.08	Hydrothermal	Sheeted greisen veins	n.d.	n.d.	0.300
100	Kamativi tin mines	Zimbabwe	Matabeleland North Province	–17.50	27.12	Hydrothermal	Lode, pegmatite	n.d.	n.d.	0.114

Table S2. Location, grade, tonnage, and other data for selected tin deposits of the world with greater than 1,000 metric tons of contained tin.—Continued

[WGS 84, World Geodetic System of 1984; negative values for latitude indicate that the deposit is in the Southern Hemisphere; negative values for longitude indicate that the deposit is in the Western Hemisphere. Elements: B, boron; F, fluorine; Fe, iron; Sn, tin. Dating method: Ar-Ar, argon-argon; K-Ar, potassium-argon; Rb-Sr, rubidium-strontium; U-Pb, uranium-lead. Abbreviations: ca., circa; Ga, giga-annum, or billion years before present; ID, identification; kg/m^3, kilogram per cubic meter; m, meter; Ma, mega-annum, or million years before present; NA, not applicable; n.d., no data; NNE-WSW, north-northeast—west-southwest; SHRIMP, sensitive high-resolution ion microprobe; wt. %, weight percent]

Resource tonnage (million metric tons) (Year determined)	Cutoff grade (wt. %)	Host rock	Mineralizing rock-type	Mineralization age	Dating method	Deposit dimensions (in meters unless otherwise noted)	Deposit shape/ mineralization style	Primary references
0.696 (1986)	n.d.	Slate, granite	Granite	270±5 Ma, 215±5 Ma	K-Ar, Rb-Sr, U-Pb	n.d.	n.d.	Dines (1956); Sutphin and others (1990)
9.1 (2013)	n.d.	Killas slate—Devonian	Granite	Middle Permian	n.d.	500 x 80 x 400	n.d.	Dines (1956); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
1.331 (2013)	n.d.	Granite, slate	Granite	270±5 Ma, 215±5 Ma	K-Ar, Rb-Sr, U-Pb	n.d.	Lenticular	Dines (1956); Sutphin and others (1990); Peter Kettle, International Tin Research Institute, written commun., April 8, 2013
2.380 (1987)	n.d.	Slate, quartz porphyry dikes	Quartz porphyry dikes	270±10 Ma, 215±5 Ma	n.d.	n.d.	n.d.	Dines (1956); Sutphin and others (1990)
0.0024 contained Sn (1963)	n.d.	Rhyolite porphyry dikes, limestone, granite	Granite	80.2 Ma	K-Ar on biotitie	n.d.	n.d.	Dobson (1982); Sainsbury (1968); Sutphin and others (1990)
25.9 (2013)	n.d.	Mid-Cretaceous siltstones of the Kuskokwim Group	Biotite-muscovite granite	56.8±2.8 Ma	K-Ar on muscovite	n.d.	n.d.	Burleigh (1991); Hudson and Reed (1997)
100.00 (1962)	n.d.	Pegmatite, schist	Pegmatite	Precambrian	n.d.	n.d.	n.d.	Bellasis and van der Heyde (1962); Rijks and van der Veen (1972); Sutphin and others (1990)

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