

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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GEOLOGY OF CANADIAN TIN OCCURRENCES

R. Mulligan



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By

R. Mulligan

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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PREFACE

Canada, in common with the rest of North America, appears to be deficient in economic tin resources and is thus dependent on vulnerable overseas sources for this major industrial mineral.

In this report, all known Canadian occurrences of tin are described. The study was carried out to meet one of the objectives of the Geological Survey: the estimation of the potential abundances and probable distribution of the mineral and fuel resources available to Canada.

The number of known deposits is impressive, and certain areas favourable to the occurrence of tin are suggested. Little serious prospecting for tin has been done in the past; most of the known occurrences were found during the search for other minerals. The author presents a classification of Canadian and other tin deposits that should prove helpful in the search for new deposits.

Y. O. FORTIER, Director, Geological Survey of Canada

OTTAWA, April 25, 1972

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GEOLOGY OF CANADIAN TIN OCCURRENCES

Abstract

Tin occurrences, associated with granitic intrusions or rhyolitic complexes, are present in the Precambrian, Appalachian, and Cordilleran regions of Canada. A significant number of major groups of occurrences are in areas where late-stage muscovite-bearing granite is well developed. Such granite may contain 10 to 30 parts per million tin, whereas the ordinary biotite granite or quartz monzonite rarely contains more than 1 to 5 parts per million. Most occurrences are in areas underlain by chiefly quartzitic and argillaceous sedimentary rocks of low to moderate metamorphic grade, but some important tin-bearing massive sulphide deposits are in volcanic complexes. Tin deposits are rare in high-grade metamorphic complexes, but some tin-bearing massive sulphide deposits are strongly metamorphosed. Some of the largest deposits appear to be related to major faults.

In the Precambrian Shield, most of the occurrences are in the Archean Slave and Superior Provinces; the few in the younger Churchill, Grenville, and Southern Provinces are minor or insignificant. Some pegmatites and related albitites in the Yellowknife–Beaulieu River, Winnipeg River, and other districts have local concentrations of cassiterite associated with lithium, beryllium, and tantalum minerals. Several zinc-copper massive sulphide deposits in Superior Province contain appreciable concentrations of tin. Most of these are associated with rhyolitic volcanichypabyssal complexes, including the South Bay deposit and the Kidd Creek deposit of Ecstall Mining Limited (Texas Gulf). Recovery of tin from the Kidd Creek ores at the rate of 1.5 million pounds per year is expected to start by the end of 1973. However the Manitouwadge orebodies, which also contain tin in smaller but significant amount, are emplaced in dominantly metasedimentary rocks, associated with granite and abundant pegmatite.

In the Appalachian Region, where the major granitic intrusions are of late Devonian age, the tin occurrences are mainly related to late or post-orogenic muscovitic phases, and the most significant deposit (Mount Pleasant) is emplaced in rhyolitic rocks of probable early Carboniferous age. Most occurrences are quartzgreisen vein deposits with minor cassiterite, but the Mount Pleasant deposit is a "subvolcanic" type with fairly abundant metallic sulphides and some stannite superimposed on quartz-topaz-cassiterite greisen mineralization. Several greisen-type occurrences are essentially wolframite deposits. Some massive sulphide deposits in the Bathurst area contain appreciable concentrations of tin as cassiterite and stannite.

In the Cordilleran Region the granitic rocks are dominantly of late Mesozoic, probably Cretaceous age and most tin occurrences are related to them. However, one occurrence may be related to Devonian granite, a few to Tertiary hypabyssal intrusions, and one (the Sullivan mine) is apparently of Late Precambrian age. The occurrences are mostly concentrated in a belt that generally follows the northeastern limit of intrusive and metamorphic rocks, and two of the largest groups are on the fringes of major batholiths in areas of maximum deformation. Cassiterite in minor amounts occurs in many gold-placer deposits in the northern areas, and wood tin is characteristic of the Klondike District. Quartz-greisen vein deposits with cassiterite are fairly common in northern areas and several types of tin-bearing skarn occur in the Cassiar District. Wolframite is the main ore mineral in some tin-bearing quartzgreisen vein occurrences and scheelite is present in some of the skarns and vein deposits. Tin is concentrated in many lead-zinc-silver sulphide vein deposits, especially in the Kootenay (southernmost) District. Stannite is the only tin mineral recognized in most, and is found in massive concentrations in one deposit. Cassiterite is uncommon except at the Sullivan mine, which is a concordant lead-zinc massive sulphide deposit in Kootenay District, and is the only current tin producer in Canada. The ore as mined contains fine disseminated cassiterite in very small concentration, but some veins in a tourmalinized and pyrrhotite-impregnated footwall zone contain substantial amounts of moderately coarse cassiterite.

Résumé

On trouve des venues d'étain associées à des intrusions de granite ou à des complexes rhyolitiques dans les régions canadiennes du Précambrien, des Appalaches et de la Cordillère. Un certain nombre de venues importantes se trouvent dans des régions ou des granites à muscovite présentent une maturité avancée. Ces granites peuvent contenir de 10 à 30 parties par million d'étain, alors que le granite ordinaire à biotite ou la monzonite quartzifère en contiennent rarement plus de 1 à 5 parties par million. La plupart des venues reposent sur des roches sédimentaires surtout quartzitiques et argileuses à métamorphisme allant de faible à moyen, mais certains gisements massifs importants de sulfure qui contiennent de l'étain, sont comprise dans des complexes volcaniques. Les gisements d'étain sont rares dans les complexes qui ont subi un métamorphisme intense, mais certains gisements massifs de sulfure qui contiennent de l'étain sont fortement métamorphisés. Quelques-uns des gisements les plus importants semblent être reliés à des failles majeures.

Dans le Bouclier précambrien, les venues sont presque toutes concentrées dans les provinces archéennes des Esclaves et du lac Supérieur; les quelques venues dans les provinces plus jeunes de Churchill, Grenville et du Sud sont très peu considérables ou sans importance. Certaines pegmatites et albitites connexes dans les régions de Yellowknife-Rivière Beaulieu, de la rivière Winnipeg et autres régions renferment des concentrations locales de cassitérite associée à des minéraux de lithium, de béryllium et de tantale. Plusieurs gisements massifs de sulfure de zinc-cuivre dans la province du lac Supérieur renferment des concentrations appréciables d'étain. La plupart de ces gisements sont associés à des complexes rhyolitiques volcaniques hypabissaux, dont le gisement de South Bay et celui de Kidd Creek exploité par Ecstall Mining Limited (Texas Gulf). On prévoit commencer vers la fin de 1973 la récupération d'étain à partir du minerai de Kidd Creek, au rythme de 1.5 million de livres par année. Toutefois, le minerai de Manitouwadge, qui contient également de l'étain en quantité réduite mais appréciable, se trouve dans des roches principalement méta-sédimentaires associées au granite et à la pegmatite qui est en abondance.

Dans la région des Appalaches où les intrusions majeures de granite sont du Dévonien supérieur, les venues d'étain se rattachent principalement à des phases muscovitiques supérieures ou post-orogéniques, et le gisement le plus important (mont Pleasant) se trouve dans des roches rhyolitiques qui datent probablement du Carbonifère inférieur. La plupart des venues sont des gisements filoniens de quartzgreisen contenant de petites quantités de cassitérite, mais le gisement du mont Pleasant qui est de type "subvolcanique" contient des sulfures métalliques assez abondants et de légères quantités de stannite surimposée sur des minéralisations de quartz-topaz-cassitérite greisen. Plusieurs venues de type greisen sont essentiellement des gisements de wolframite. Certains gisements massifs de sulfure dans la région de Bathurst renferment des concentrations appréciables d'étain sous forme de cassitérite et de stannite.

Dans la région de la Cordillère, les roches granitiques sont principalement du Mésozoïque supérieur, probablement du Crétacé, et la plupart des venues d'étain leurs sont rattachées. Cependant, une venue peut être reliée à du granite du Dévonien, d'autres à des intrusions hypabissales du Tertiaire, et une (la mine Sullivan) date apparemment du Précambrien supérieur. Les venues sont surtout concentrées dans une zone qui suit en général l'extrémité nord-est des roches intrusives et métamorphiques, et deux des groupes les plus importants sont en bordure de batholithes majeurs dans des régions de déformation maximale. On trouve de petites quantités de cassitérite dans plusieurs gisements d'or placérien des régions septentrionales et l'étain de bois est commun dans le district du Klondike. Des gisements filoniens de quartz-greisen avec cassitérite sont assez communs dans les régions du nord et on trouve plusieurs types de skarns qui renferment de l'étain dans le district des Cassiars. La wolframite est le principal minerai dans quelques venues filoniennes de quartzgreisen stannifères, et on trouve de la scheelite dans quelques skarns et gisements filoniens. Il existe des concentrations d'étain dans plusieurs gisements filoniens de sulfure de plomb-zinc-argent, particulièrement dans le district de Kootenay (le plus au sud). La stannite est le seul minéral d'étain que l'on voit à peu près partout et on en trouve des concentrations massives dans un gisement. La cassitérite est rare sauf à la mine Sullivan qui exploite un gisement concordant de sulfure massif de plombzinc dans le district de Kootenay et est actuellement le seul producteur d'étain au Canada. Le minerai extrait renferme de la cassitérite fine en très petite concentration, mais certains filons situés dans une zone à paroi tourmalinisée et imprégnée de pyrrhotite renferment des quantités substantielles de cassitérite moyennement grossière.

Chapter I

INTRODUCTION

No deposits are now mined primarily for tin in Canada, nor have been to any appreciable extent in the past. Since about 1941, several hundred tons of tin, as metal or cassiterite concentrate, have been produced per year as a by-product from the lead-zinc-silver iron ores of the Sullivan mine (Cominco Ltd.), Kimberley, British Columbia. Some tin is also recovered as a lead-tin alloy from drosses at the smelter. The tin-tungsten-molybdenumbase metal deposit of Brunswick Tin Mines Ltd. (Mount Pleasant), in Charlotte County, New Brunswick, has been in an active exploration and development stage for several years. Small amounts of cassiterite have been recovered from gold placer operations in the Atlin area, British Columbia, and in the Yukon. Lode-mining operations have been attempted on small deposits in the Winnipeg River District, Manitoba, and the New Ross area, Nova Scotia, but no substantial production has been recorded. Tin has been concentrated with tantalum minerals in small operations in the Yellowknife-Beaulieu District, N.W.T.; tin is a substantial component of tantalum minerals being produced at the Chemalloy Mines property, Winnipeg River District, Manitoba, but the writer understands that the tin content is not paid for.

Tin is a minor constituent of several large base-metal sulphide deposits in addition to the Sullivan mine. These include several in the Bathurst District, New Brunswick, and in the Precambrian Shield. Recovery of tin at the rate of 1.5 million pounds per year from the massive sulphide ores of Ecstall Mining Limited at Kidd Creek, near Timmins, Ontario, is expected to start by the end of 1973. The South Bay deposit in Kenora District, Ontario, appears to have a higher concentration of tin than any other known massive sulphide deposit in Canada and this suggests that other and larger base-metal mines with economically recoverable tin content may be found.

Canadian tin deposits and occurrences are shown on the accompanying map (1352A), listed in Table 1, and described in Chapter IV. Some information on tin as a trace-element is also contained in Chapter II. All reported occurrences that have come to the attention of the writer up to 1971 are mentioned, although some are considered dubious. The notes are based on field observations and laboratory investigations by the writer, and on the references cited. The localities are described in approximate order of their distribution from west to east, as shown on Map 1352A; some overlapping in eastern Canada has resulted from the grouping of deposits according to the geological provinces in which they occur. Locality numbers correspond to those on the map and in Table 1.

Chapter II deals with the geochemical distribution of tin in the natural environment, its physical-chemical characteristics, mineralogy, and identification. In Chapter III the main geological features of tin deposits are analyzed and an attempt made to classify Canadian

Original manuscript submitted: November 25, 1971 Revised version submitted and approved: May 31, 1973 and other deposits in terms of environment, petrology, mineral association, and conditions of formation.

The present study documents the existence of well-defined metallogenic provinces or "tin belts" in the Cordilleran and Appalachian regions, based on known occurrences, geochemical data, and geological environment, and of areas of significant tin concentration in widespread parts of the Canadian Shield. Within the belts certain districts are shown to be especially favourable, but the possibility of important deposits elsewhere should not be overlooked.

Resource Potential

Canada, in common with the rest of North America, appears to be deficient in economic tin resources. Excepting the currently producing Sullivan mine at Kimberley, British Columbia, and the Kidd Creek deposit of Ecstall Mining Limited (Texas Gulf) near Timmins, Ontario, few of the deposits listed here are potential tin producers.

However, the Sullivan mine has produced roughly 10,000 tons of by-product tin so far, with a value at present prices of more than 33 million dollars. The Mount Pleasant deposit in Charlotte County, New Brunswick, should become an important supplier of tin if brought into production. The Kidd Creek mine near Timmins, Ontario, is expected to yield 1.5 million pounds (750 tons) of tin per year from its massive zinc-copper-lead-silver deposit, starting about the end of 1973.

The Sullivan and Kidd Creek mines are large massive base-metal deposits, with very low tin concentrations. The recent discovery of relatively high tin concentration at the South Bay mine, in western Ontario, considerably enhances the possibility that other large basemetal mines with economically recoverable tin content may be found in the Canadian Shield or elsewhere.

Tin might be economically recoverable from one or more potential tungsten deposits of the wolframite-quartz-greisen type and also from gold placer deposits in some areas if they should become economic in the future.

The number of known occurrences is impressive, and they provide prima facie evidence of areas favourable for tin deposits. Very little serious prospecting for tin has been done in Canada. Most of the known occurrences have been discovered almost accidentally in the search for other metals or in mineralogical investigation of other ores. Some contain tin in unusual associations, and suggest the possibility of finding deposits of new types. Valuable tin deposits may easily be overlooked in the field. These facts illustrate the advisability of careful investigation for tin in various types of mineralization and of routine analysis for tin in geochemical and general exploration.

Tin is a major industrial metal and is indispensable in its main applications. Canada, in common with the rest of North America, is critically dependent on overseas supplies, which might be cut off in national emergencies, as in World War II. Special effort should therefore be made to find and develop domestic resources of tin.

Properties of Tin

Ordinary tin is a soft, malleable, silvery-white metal that is non-toxic and is resistant to corrosion by atmospheric agencies and most other materials except strong acids and bases. It is tetragonal, with a structure rare among metals (P.A. Wright, 1966). Its specific gravity is 7.29 and specific heat 0.056. Thermal conductivity is 0.15 compared with 0.91 for copper, and electrical resistivity is 11.5 compared with 1.77 for copper (Chemical Rubber Publishing

Company, *Handbook of Chemistry and Physics*). Tensile strength is 4,000 pounds per square inch, compared with about 55,000 for mild steel.

This ordinary or β -tin may deteriorate at low temperature ("tinpest") by changing to another allotropic form known as "grey tin," which is stable below 18°C, but the change does not ordinarily take place. Grey tin has a cubic diamond structure and is a semiconductor, but is not industrially important.

Tin melts at 232°C and boils at 2270°C but is somewhat volatile at temperatures below the boiling point. Its wide liquid range is exceeded only by tungsten and the platinum-group metals (P. A. Wright, 1966). Liquid tin has a low surface tension and readily spreads over the surfaces of other metals. On steel, copper, and some other metals it forms an intermetallic bonding layer at the interface. The low melting point, corrosion resistance, and non-toxicity of tin, together with its workability, resistance to fatigue, and ready solderability are the basis of its unique value in tinplate and other protective coatings, tubes, and foil. The low melting point of tin is of major importance in smelting and refining techniques.

The most important property of tin is its ability to alloy with numerous other metals, forming a wide range of useful products. In the solders and some other products the low melting point of tin is of paramount importance, but in general the function of tin in alloys is complex.

Some chemical properties of tin are: atomic number 50, atomic weight 118.69, atomic structure (electron shells) 2;8;18;18;4. As a member, with germanium and lead, of Group IVB of the Periodic Table (Cooper, 1964), tin is dominantly tetravalent, but also forms divalent compounds. As a tetravalent element, tin is amphoteric, and can form either stannic compounds or stannates. The ionic radii are $Sn^{+4} 0.71$, $Sn^{+2} 0.93$ (Jack Green, 1953). The electronegativities are $Sn^{+4} 1.80$, $Sn^{+2} 1.65$. Tin forms complexes with the halogens, and Sn Cl₄ in particular is quite volatile. The chemical properties of most importance in the geochemistry and geology of tin are discussed in Chapters II and III.

Uses

Tin has a wide variety of uses as pure metal, alloy ingredient, and inorganic and organic compounds, in which its characteristics are unique or unmatched by any other element. A good idea of its main applications as a metal or in alloys may be obtained from Table 2. The principal uses are discussed in "Materials Survey–Tin," published by the United States Department of Commerce, June 1953. New uses and improvements on existing ones are constantly being found by active research. They are described in the periodical "Tin and its uses" published by the Tin Research Institute, Fraser Road, Greenford, Middlesex, England.

Metallic

The largest single application of tin is as a protective coating on steel, copper, and some other metals, mainly as tinplate for cans. Tinplate is thin sheet steel coated with commercially pure tin by hot-dipping or electrolytic processes. In an older, similar application, still of considerable importance, sheet steel is coated with a lead-tin alloy, forming terneplate. Much tin is also used as a coating on copper wire and electrical connections to prevent corrosion and to facilitate soldering. The use of tin in pipe, tubing, collapsible tubes and foil has declined, but it is still preferred in many applications, especially where purity and non-toxicity are important. Among many other traditional and new uses for metallic tin are recent new applications in the production of "float glass," and in powder metallurgy. The use of tin in small amounts as a modifier in cast iron, including some automotive engine blocks, is another recent development.

TABLE 2

Consumption of tin in the United States, by finished products (long tons of contained tin) (from U.S. Bureau of Mines, Minerals Yearbook, 1969)

		1968			1969	
	Primary	Secondary	Total	Primary	Secondary	Total
Alloys (miscellaneous)	442	182	624	477	192	669
Babbitt	2,143	1,440	3,583	2,128	1.378	3.506
Bar tin	970	115	1,085	1,009	34	1.043
Bronze and brass	3,851	11,631	15,482	4,155	12,371	16,526
Chemicals, including tin oxide	1,744	1,423	3,167	1,857	1,250	3,107
Collapsible tubes and foil	1,114	55	1,169	1,114	29	1,143
Pipe and tubing	53	37	90	43	5	4 8
Solder	14,685	6,685	21,370	14,936	6,347	21,283
Terne metal	295	185	480	207	181	388
Tinning	2,105	55	2,160	2,238	51	2,289
Tinplate ¹	28,839	_	28,839	26,886	_	26,886
Tin powder	1,103	53	1,156	1,213	61	1,274
Type metal	108	1,109	1,217	116	994	1,110
White metal ²	1,330	66	1,396	1,266	118	1,384
Other	77	66	143	85	49	134
Total	58,859	23,102	81,961	57,730	23,060	80,790

Includes secondary pig tin and tin acquired in chemicals.

²Includes pewter, britannia metal, and jewelers' metal.

Alloys

Tin alloys readily with a large number of other metals, and alloys have accounted for most of the tin used in industry. The main alloys can be grouped as follows:

- (1) tin-lead: solders
- (2) tin-lead-bismuth: fusible metals
- (3) tin-lead-antimony: type metal, bearing metals
- (4) tin-copper-antimony: britannia metal, pewter, babbitt bearing metals
- (5) copper-base: bronzes, gun metal, bell-metal, brass
- (6) miscellaneous: tin-aluminum (bearings), tin-silver (dental amalgams), tin-mercury (mirrors), tin-nickel(electroplating, etc.), tin-titanium (aerospace industries), tin-niobium (superconductors).

Solders are the second largest users of tin. They contain from about 83 to more than 90 per cent tin. Tinplate containers and automotive radiators consume large quantities. Some fusible metals used for thermal safety appliances melt at temperatures below the boiling point of water. Babbitt and other bearing metals are major consumers of tin. The most important bronzes are casting bronzes, with more than 10 per cent tin and the wrought bronzes, with less than 10 per cent. Casting bronzes include gun metal, which is now widely used for gas-free, pressure-tight, and corrosion-resisting castings. The principal wrought bronzes are the phosphor bronzes, which have a wide variety of uses because they combine mechanical properties approaching those of steel with high corrosion resistance. Up to 5 per cent tin is added to brasses to improve their hardness and corrosion resistance.

Tin is also used as a major or minor ingredient with various metals (see "Miscellaneous") in traditional and newly developed alloys for special purposes.

Tin Compounds

Tin is used to a limited extent as oxide and inorganic salts in ceramics, glassmaking, and textile industries, in reagents, and in electroplating solutions. Recently developed organotin compounds are becoming increasingly important as fungicides, and biocides, stabilizers in plastics, and in other applications.

Mining, Concentration, Extraction: Secondary Tin

The important ore mineral of tin is cassiterite. Since it is a heavy, hard, inert mineral, it is concentrated in placer deposits, and the bulk of the world's supplies are recovered from placer deposits by dredging, hydraulicking, or mechanical methods. As the placer deposits are generally free of deleterious sulphide metals, they yield high-grade, nearly pure concentrates which can be direct-smelted by simple techniques and they command the highest prices on world markets.

Beneficiation of tin ores, whether from placer or hard-rock sources, is done almost entirely by gravity methods, using sluices, jigs, shaking tables, and similar devices. Separation of cassiterite from other heavy minerals is achieved partly by magnetic and electrostatic methods. Flotation, with or without roasting, is sometimes used to remove metallic sulphide minerals. Flotation methods for cassiterite have been developed with some success but are useful mainly for the recovery of fine tin which is lost by gravity methods.

Smelting of tin concentrates is carried out mainly in reverberatory furnaces at about 1200°C, using carbon to reduce the cassiterite, and generally limestone as a flux. Complex ores such as those from many Bolivian deposits require prior roasting to remove sulphur and arsenic. The tin and contaminating metallic sulphides are mostly oxidized and the latter can in part be removed by various leaching processes. The main smelting yields impure liquid tin and a tin-rich slag. This primary slag is resmelted with further limestone and carbon to produce a waste slag and an "irony" tin "hardhead" which is added to succeeding furnace charges. The impure tin is refined in successive stages involving liquation, agitation and aeration, with various additives, during which most of the impurities are removed in drosses. An alternative electrolytic process used in some plants yields high-purity tin but is more expensive. The commercial product ranges from 99.8 per cent to 99.99 per cent tin.

Alternative extraction processes that have been proposed are listed and described (P. A. Wright, 1966) as follows:

- (1) volatilization of sulphide or oxide
- (2) reduction below the fusion temperature of the gangue, followed by hydrometallurgical attack
- (3) chloride volatilization

So far none has proved commercially feasible.

An important part of the tin of commerce is recovered from secondary sources, mostly from alloys (see Table 2). Various methods for different alloys are described by P. A. Wright (1966). Reclamation of tin from cans is limited by the high cost of collecting and cleaning the cans. Detinning of scrap tinplate is usually by an alkaline leaching process, but chlorine detinning processes have been used to some extent.

World Production, Markets, Prices

Tin has been an important metal of commerce since prehistoric times. Its early use as an alloy with copper marked the "bronze age" of man's cultural development. Production and use of tin have not increased as fast as those of the major metals, but it remains fifth in world output among the non-ferrous metals, behind aluminum, copper, lead, and zinc (Shelton, 1965).

World production of primary tin in recent years is reported in Table 3.

Country ²	1967	1968	1969 (preliminary)
North America:			
Canada	195	160	120
Mexico	588	519	. 280
United States ¹		- not disclose	d —
South America:			
Argentina	802	701	700
Bolivia	26,890	28,945	29,489
Brazil	1,733	1,837	2,560
Peru (recoverable)	65	99	82
Europe:			
Czechoslovakia	150	162	140
France	461	343	263
Germany, East	1,000	1,000	1,000
Portugal	645	668	440
Spain	160	140	121
U.S.S.R. ²	25,000	26,000	27,000
United Kingdom	1,475	1,798	1,622
Africa:			
Burundi	45	116	83
Cameroon	50	41	29
Congo (Brazzaville)	71	24	20
Congo (Kinshasa)	4,664	6,895	6,718
Morocco	10	19	10
Niger	55	70	73
Nigeria	9,340	9,644	8,606
Rhodesia, Southern	500	600	500
Rwanda	1,393	1,272	1,150
South Africa, Republic of	1,761	1,837	1,847
South-West Africa, Territory of	720	730	/30
Tanzania	341	286	1/8
Uganda	111	228	146
Asia:			• • •
Burma	475	385	340
China, mainland	20,000	20,000	20,000
Indonesia	13,597	16,563	17,146
Japan	1,166	930	/29
Korea, South	40	44	40
Laos	222	482	72 167
Malaysia	72,121	13,009	12,107
Inalland	22,490	23,0/8	20,780
Oceania: Australia	5,586	6,650	7,873
Total	214,233	227,935	223,609

TABLE 3World mine production of tin (content of ore), by countries (long tons partly estimated),
from U.S. Bureau of Mines—Minerals Yearbook, 1969

¹United States production in 1969 less than 100 tons (Lewis, J. R., 1971). ²U.S.S.R. production from Europe and Asia.

Consumption by the United States of America, the largest market, is shown in Table 2.

Canadian production since 1960 has fluctuated between a high of 500 long tons in 1961 and a low of 120 tons in 1969, averaging 260 tons per year over the decade. Nearly all is in concentrate, and is exported. Consumption has varied within a narrow range from 3,880 to 4,972 tons per year. About 55 per cent is used in tinplate manufacture and 30 per cent in solder (Fraser, 1970).

Most tin production is from industrially underdeveloped countries with little consumption, and the industrially advanced countries that consume most of the tin generally have very limited resources. This has been a factor in the characteristically erratic fluctuations in the price of tin through the years. A mutual interest by producing and consuming countries in stabilization of prices and supplies led to formation of the International Tin Council in 1956. The participants include most of the main producing countries and a large number of major consumers, but have not included the U.S.S.R., China, U.S.A., or West Germany. The council, in agreements from time to time, establishes floor and ceiling prices. It attempts to support them by buying or selling tin which is held in a buffer stock, and is further empowered to impose and remove export controls on producing countries as necessary to balance supply and demand. Another important factor in the supply-demand picture is the stockpile of tin maintained by the U.S. Government. Initial buying to establish the strategic reserves had the effect of a sudden increase in demand, but adjustments by buying and selling have been in general accord with the objectives of the International Tin Council.

Prices of primary tin in ingot vary according to grade specifications, which are chiefly determined by brand names that indicate the smelter and source of the ore. Commercial grades range from about 99.8 to 99.99 per cent tin. One of the best known brands is Straits Tin, a product of Malayan smelters that averages about 99.9 per cent tin. The prices quoted in Table 4 are for Straits Tin for prompt delivery, New York.

Year	High	Low	Average
1960	104.7	98.9	101.4
1961	125.7	100.1	113.3
1962	124.2	107.4	114.6
1963	133.0	108.1	116.6
1964	211.0	131.4	157.7
1965	200.9	148.5	178.2
1966	183.0	153.5	164.0
1967	157.0	150.6	153.4
1968	167.7	141.0	148.1
1969	187.5	152.5	164.4

 TABLE 4
 Price of tin (cents per pound)

 (source: U.S. Bureau of Mines, Minerals Yearbooks)

According to the International Tin Council's *Report on the world tin position*, 1965, the average annual New York price quotation increased from $52 \notin$ in 1945 to 99.3 in 1949. From 1950 to 1959 it fluctuated between a low of 91.8 in 1954 and a high of 128.3 in 1951.

Chapter II

GEOCHEMISTRY, MINERALOGY, AND DETECTION METHODS

General Distribution of Tin

The geochemistry of tin has been discussed by Goldschmidt (1954), Rankama and Sahama (1950), and more recently by Wedepohl (1969). Wedepohl quotes a large number of analyses of chondrites, tektites, and iron meteorites, from which cosmic abundance data have been inferred. The tin contents reported for the meteorites vary widely from fractional to 2 or 3 parts per million with a few erratically higher values. An average value of 0.43 to 1.0 parts per million in chondrites and tektites seems to be accepted. An opinion is quoted that on the basis of comparative data for chondrites and iron meteorites, tin can be expected to be siderophile at high temperatures and lithophile at low temperatures.

The crustal abundance of tin, according to recent estimates quoted by Wedepohl and apparently accepted by him, is about 2 to 3 parts per million. This figure is about the same as the calculated averages for igneous rocks (Table 5), on which it appears to be based. The figures given by Goldschmidt (1954) and others are considered too high.

> Abundance of tin in rocks (ppm) (after Wedepohl 1969)

	Author				
Rock type	Onishi and Sandell (1957)	Hamaguchi <i>et al.</i> (1964)	Horn and Adams (1966)		
Igneous					
Silicic rocks	3.5	3.6)		
Intermediate	1.3	1.5	2.5		
Mafic	1.2	0.9			
Ultramafic	0.5	0.35	,		
Sedimentary					
Shale	4		4.12		
Sandstone			0.115		
Carbonate			0.166		
Oceanic clay			0.5		
Red clay (Pacific)		4.9			
Red clay (Japan Sea)		4.1			

TABLE 5

Tin in Igneous Rocks

The average tin content of various types of igneous rocks, according to several authors quoted by Wedepohl (1969) and included in Table 5, is about 2.5 ppm. A considerable number of analyses and averages for granitic, intermediate, mafic, and ultramafic rocks are listed by Wedepohl. Most of the available data are for granitic rocks, but those for the other types are sufficient to establish a definite increase in tin content from ultramafic to silicic (granitic) rocks. This increase, in conjunction with the worldwide association of tin with granitic rocks, is the main evidence for the conclusion that tin is concentrated in the late products of magmatic differentiation.

Intrusive Rocks

The intrusive rocks with which tin is commonly associated belong to the silicic (granitic) suite. Few data are available regarding tin in syenitic rocks. Tin occurrences are rare in alkaline regions, and those recorded are generally associated with quartz-bearing pegmatites or veins, but the rare tin mineral nordenskiolite was first found in a nepheline-syenite pegmatite in Norway. Another rare mineral, sorensenite (Na₄Sn Be₂Si₆(OH)₄), has been found as a hydrothermal mineral in the Ilimaussag alkali complex, Greenland. There the tin content of the nepheline syenites ranges from 35 to 370 ppm with a mean of 112 ppm, far higher than in the alkali granite (49 ppm). The tin content increases throughout the magmatic process, the highest content (370 ppm) being in the amphibole lujavrites, which were formed after the aegirine lujavrites (Gerasimovskiy and Borisenok, 1968). In alkaline intrusive rocks the tin content can be completely dispersed in alkaline ferromagnesian and accessory minerals. Gerasimovskiy and Borisenok reported 750–950 ppm in aegirine. Kovalenko et al (1968) stated that riebeckite, aegirine, and astrophyllite are the main carriers of tin in alkali granitoids. Aegirine from the Monteregion alkaline complex at St-Hilaire, Quebec, was found to contain 32 ppm tin (Mulligan and Jambor, 1968). The syenitic member of an alkali complex in the Teslin area, Yukon, was found to contain considerably more tin (25 ppm) than nearby granitic rocks (5 ppm).

Extrusive Rocks

The increase in tin content from basic to acidic rocks is mainly based on intrusive representatives, especially for the acidic types. Data in the literature on extrusive rocks are fragmentary and inconclusive in this respect.

A considerable amount of data on the tin content of volcanic rocks in several parts of the Canadian Precambrian Shield is contained in the Geodat records of the Geological Survey of Canada. Part of the data has been published (Baragar and Goodwin, 1968) and is summarized in Table 6.

The data from Baragar and Goodwin show a consistent increase in tin content from basic to salic volcanic rocks, although the levels and rates of increase are quite different in different greenstone belts.

These are all Archean volcanic belts; all are in the Superior Province except the Yellowknife belt (Slave Province). The comparative data for "Noranda and N.W. Quebec" are spatially most comparable with the Timmins–Noranda belt. The Keweenawan volcanic rocks northwest of Sault Ste. Marie belong to a younger structural–orogenic province generally characterized by basic lavas and intrusions. These data apply to only one small area, but suggest that the late Precambrian volcanic rocks may contain as much tin as any of the Archean ones.

TABLE 6

Tin content of volcanic rocks in the Canadian Precambrian Shield

	Basalt	Type A ³	Type B ⁴	Andesitic	Salic
Greenstone Belt ¹					
Birch–Uchi	$1.05 (44)^2$	1.56 (11)	1.94 (9)	2.18 (27)	3.44 (21)
Lake of the Woods-Shoal Lake	0.75 (36)	0.80 (12)	0.47 (3)	0.87 (17)	1.63 (9)
Timmins-Noranda	1.61 (66)	1.43 (33)	1.52 (28)	1.59 (44)	2.02 (22)
Yellowknife	1.18 (58)	0.89 (8)	0.57 (2)	1.19 (13)	1.38 (8)
Average	1.15	1.17	1.01	1.46	2.12
Comparative Data from Canadian Shield					
Noranda and N.W. Quebec				1.0 (28) Range 0.5-3.8	1.64 (10) Range 1.0-2.4
N.W. of Sault Ste. Marie				0.0 0.0	
(Keweenawan volcanics)	1.4 (33) Range 0.9-2.1				3.4 (15) Range
Other Data	0.7 2.1				1.2-0.0
Japan (Onishi and Sandell, 1957) Japan (Hamaguchi <i>et al.</i> 1964)	1.15			1 1.4	
North America (Onishi and Sandell, 1957)	1.4				

¹From Baragar and Goodwin, 1968 (Archean volcanics).

²Numbers of analyses in parentheses.

³Type A basaltic and /or andesitic.

⁴Type B andesitic and /or basaltic.

Data for corresponding intrusive rocks in the Shield are fragmentary, but the data given for Superior Province seem significant. From these it appears that the volcanic rocks contain as much tin as the intrusive rocks, if not more.

Tin Content of Granitic Rocks

Reported values for the tin content of granitic rocks vary widely. In part they reflect broad regional differences, as reported tin contents of granites from regions rich in tin deposits are generally higher than those from tin-poor regions.

However, a wide variation in the tin content of different granitic bodies within tin-rich regions has been noted in many places. Those that have tin deposits associated with them are referred to as "tin-bearing granites." They contain several times as much tin as "non-tin-bearing" granites. For example, Barsukov and Durasova (1966) reported 16–30 ppm tin in granites with associated tin deposits, compared with 3–5 ppm in those without. Rattigan (1963) reported 20 ppm tin in stanniferous granites of Australia, compared with 3.1 ppm in non-stanniferous granites. Others generally report smaller differences.

Abnormal tin contents are common in leucocratic, muscovitic granites, but these are commonly altered and tin may have been introduced. Tourmaliniferous granites commonly contain more tin than ordinary granites. Lyakhovich (1965) reported 15 times as much but this is probably an extreme case.

Wedepohl (1969) listed a considerable amount of analytical data for granites and selected the following averages as probably representative.

No. of samples	Source	Author	Average Sn (ppm)
42	South Africa	Kolbe (1965)	2.4-4.4
35	Australia	Kolbe (1965)	2.0-4.1
8	Dzhida, USSR	Petrova and Legeydo (1965)	2.5
27	Dzhida, USSR	Petrova and Legeydo (1965)	2.4

These are considered to justify the values of 3.5 and 3.6 ppm shown in Table 5 as compared with much higher older estimates.

Tin Content of Canadian Granitic Rocks

Very little information has been published on the tin content of Canadian granitic rocks. The data in Table 7 are, except as noted, spectroscopic analyses by the Geological Survey of Canada of samples collected by the writer. Most of the samples are composites of small chips taken along traverses commonly several miles long, and therefore represent averages of a considerable volume of material.

The samples from the Appalachian Region are mostly from areas where tin and (or) beryllium occurrences were known or suspected. Many are muscovitic granites, which are commonly present in such areas, and are generally rich in tin. Ordinary biotite granites generally range from 2 to 6 ppm tin, and may be somewhat above the world average (see above).

For the Bear, Slave, and Churchill Provinces of the Precambrian Shield, the data are scattered and erratic. Hidden, Blaisdell, and Sparrow Lakes are in the western part of the Yellowknife–Beaulieu River District (loc. 24), and suggest that the late muscovite granite there may be considerably enriched in tin. The samples from Superior Province were collected along main highway routes from Timmins, Ontario, to the Manitoba Lowlands. Excepting pegmatites, post-Superior syenite west of Marathon, and unusual granitic rocks near tin occurrences, which are generally higher, the rocks are uniformly low in tin, averaging about 1.5 ppm. The composition of the rocks has not been determined. The typical rock sampled consisted of medium to dark, more or less gneissic, granitoid rock cut by reddish leucocratic granite, aplite, and pegmatite. These data suggest that the granitoid rocks of the central southern part of Superior Province are lower in tin content than the world averages, although tin occurrences are fairly numerous in the greenstone belts. The samples from Grenville Province taken by the writer are nearly all pegmatites. They are highly erratic, but a surprising number are relatively rich in tin, for a province in which tin occurrences are virtually unknown.

The samples from the Cordilleran Region are mostly from the "tin belt," and many of them are from areas where tin and (or) beryllium occurrences were known or suspected. Ordinary granites from the northern part of the belt contain generally from 3 ppm up to about 15 ppm tin and appear to be richer in tin than the world average. Those from the southern part of the belt, and from south and central British Columbia generally ("Miscellaneous"), are much lower. Those from Kootenay District, except the Precambrian Hellroaring and Lightning Creek pegmatites and the Skookumchuck pegmatites, are notably low in tin, although the district contains a significant number of tin deposits and occurrences.

It would seem that a relatively high tin content in granitic rocks, even if the variation is high, implies the possibility of tin concentrations in the vicinity. However, a low tin content does not rule out the possibility of tin deposits in surrounding rocks. Indeed the low tin content of granitoid rocks in Superior Province (Table 7), compared with that of volcanic

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rocks in some greenstone belts (Table 6), suggests that tin may have been driven out of preexisting volcanic-sedimentary rocks during granitization processes (see under "Physical-Chemical processes," Chapter III).

TABLE 7	Tin content of Canadian granitoid and pegmatitic rocks (Analyses by Geological Survey of Canada spectrographic laboratory) (values reported as <1.5 ppm are shown as 1 ppm)

Sample			l Tin						
number	NTS Block*	Locality identification	Remarks	(ppm)					
		APPALACHIAN REGIO	N						
Nova Scotia									
Z 75	21 A/14	South of Nictaux	granite (av. of 6)	4.0					
457	11 E/8	West of St. Mary's	muscovitic	11					
New Ross are	ea, N.S.								
130	21 A/9	Nevertell Lake	muscovitic	12					
137.1+136.1	21 A/9-16	NW of New Ross	muscovitic	27					
136.2+137.2	21 A/9-16	NW of New Ross	biotitic	6					
138.1	21 A/9-16	SE of New Ross		21					
119.1	21 A/9-16	Windsor Road South	biotitic	9					
C 119.2	21 A/9-16	Windsor Road south	muscovitic	38					
+131 138	21 A/9-16	Leminster	muscovitic	21					
121.1+.4	21 A/9-16	Wallaback	pegmatite	56					
121.2	21 A/9-16	Wallaback	muscovitic	69					
121.3	21 A/9-16	Wallaback	pit (mineralized)	1900					
121.5	21 A/9-16	Wallaback	greisen	200					
122	21 A/9-16	Wallaback	red muscovitic	40					
124	21 A/9-16	NW Wallaback	DIOTITIC	4					
130	21 A/9-16	Lurner Lin	altered muscovitic	12					
L /3. /, 8	21 A/14	12 miles in. of inew Ross	coarse muscovitic	18, 15					
Southern Nev	v Brunswick								
116.1	21 G/2	N. St. George	red	25					
102	21 G/7	McDougall Lake		3					
116.2	21 G/7	McDougall Lake		5					
117.1	21 G/8	Square Lake	greisen	400					
117.3	21 G/8	Square Lake	greisen fluorite	42					
115	21 G/8	wirral-inerepis		30					
651	21 G/6		muscovitic	20					
652	21 G/6	Tower Hill	histitic	20					
033	21 G/0	Peech Hill	oltarad	10					
662	21 G/7	True Hill	shuelite perphyru	10					
452	21 G/7	Fagle Pock	red	12					
452	$21 \text{ G/}{3}$	Pokiok	lea	6					
114	21 U/14	Keswick	muscovitic	20					
7.72/1-4	21 G/03	Potters Lake	musc -bi gr	4.3-7.9					
L (L/1 ⁴	21 0/05	I OTIOIS LARC	muse01. gr.	ч.J=7.J					
Burnt Hill M	line area, $N.B$.	Manadaaaa		12					
113.3	21 J//	Napadogan	pegmatitic	12					
113.1	21 J/7	Napadogan		0					
109	21 J/10	Clearwater		10					
140	21 J/10 21 J/10	riayesville		10					
104.2	21 J/10	BUTHT HIII BROOK	araiaanized	24					
104.3	21 J/10 21 J/10	Durnt Hill Brook	greisenized	150					
105.1	21 J/10	Burnt Hill Mine	greisen	100					

Sample Number	NTS Block*	Locality identification	Remarks	Tin (ppm)
Burnt Hill Min	e area. N.B. (co)	nt.)		
139	21 J/10	McLean-Burnthill (D.D.core)		6
106.1+2	21 J/10 .	E. Rocky Brook	greisenized	6
107	21 J/10	E. Rocky Brook		10
108.1+2	21 J/10	W. Rocky Brook (Trout L.)		9
Bathurst Area,	N.B.			
59-10	21 P/12	Pabineau Lake	near Be occur.	12
x 457	21 P/5	S. of Pabineau Lake	muscovitic	14
Z 77/1–/3	21 P/12	Nicholas Denys	granite	1.7-4.5
Newfoundland				
Y 19	1 M/11	Rencontre	molybdenum	68
Y 21	1 L/14	St. Lawrence	access. fluor.	8
Y 22	1 L/14	St. Lawrence	access. Q-veined	10
~ ~ .		PRECAMBRIAN SHIELD		
Bear Province	96 C 17	Goodati		14
	80 C/7	Geodat		14
	85 0/13	Geodal		3.0
Bear or Slave	Province	0.1.		10
	85 N/16	Geodat		12
	86 B/14	Geodat		1.4
Slave Province				
	85 H/14	Geodat		1.2
	76 K/13	Geodat		1.4
159	85 I/11	Hidden Lake		1
141.6	85 I/12	Blaisdell Lake	near Be–Li pegmatites	61
Y 25, 26	85 I/12	Sparrow Lake East	F-0.	5,93
Y 27–29	85 I/12	Sparrow Lake West		10
Churchill Prov	ince			
	75 O/8	Geodat		.76
	65 B/14	Nueltin Lake ²	access. fluorite	3.4
				(3)
62 x 3	64 N/13/12	Kasmere Lake	access. fluorite	14
	54 E/5	Churchill River ³	access. fluorite	N.D.
	54 E/14	Portage Chute ³	abund. zircon	2.9
	54 L/5	S. of Knife River ³	biotite-musc.	2.8
	54 L/12	N. of Knife River ³	bi-musc. (fluor. veins)	1.7
	54 L/10	N. of Knife River ³		N.D.
	54 L/18	N. of Knife River ³	muscbi.	N.D.
	54 L/15	N. of Knife River'	muscchlor.	N.D.
Y 20	64 O/13	Munroe Lake	access. fluorite	70?
56-108, 144	63 J/18	Herb Lake	Li-Be pegmatite	52
Superior Provi	nce			
Z 05	42 A/12	Canadian Jamieson	hypabyssal?	6.8
Z 06	42 A/12	Canadian Jamieson	granite dykes	1.3
Z 07.2	42 A/05	Star Lake road	granodi.?	1
Z 07.2	42 A/05	Star Lake road	granodi.?	1.6
Z 08	42 B/01	Scorch Creek	granodi.?	1.0

GEOLOGY OF CANADIAN TIN OCCURRENCES

Sample Number	NTS Block*	Locality identification	Remarks	Tin (nnm)
PRECAMBRI	AN SHIELD (cont.)			
Z 00 1	rovince (com.)	West of Folevet	aranadi ?	1
Z 09.1 Z 09.2	42 B/02	West of Folevet	granodi 2	1
Z 09.2 Z 10	42 B/02	West of Folevet	granodi 2	1
Z 10 Z 11	41 0/14 41 N/16	West of Chapleon	granodi ?	1.0
Z 11 Z 12 1	41 K/10	Geo	permatite	1.1
Z 12.1 Z 13	42 E/04	Geco	pegmatite	1.4
Z 13 Z 14 4	42 F/04	Geco	pegmatite	8.0
Z 15	42 F/04	Geco	granodi	3.8
Z 16	42 F/04	Willroy	pegmatite	7.9
$\overline{\mathbf{Z}}$ 17	42 C/13	South of Manitouwadge	granodi.?	0.2
Z 18	42 D/09	West of Marathon	augite sy.	2.5
Z 19	42 D/15	West of Marathon	hornbl. sv.	2.6
\overline{Z} 20	42 D/14	West of Terrace Bay	granodi.?	1.2
$\overline{\mathbf{Z}}$ $\overline{21}$	42 D/14	West of Schreiber	granodi.?	1.3
Z 22	42 D/13	West of Rossport	granodi.?	1.3
Z 23	52 H/01	Kama Bay	granodi.?	2.1
Z 24	52 A/10	Nipigon-Thunder Bay	granodi.?	2.6
Z 25	52 A/12	South of Raith	granodi.?	1.5
Z 26	52 G/02	West of Upsala	granodi.?	0.5
Z 27	52 G/06	East of Ignace	granodi.?	1.2
Z 28	52 G/09	Revell	granodi.?	1.4
Z 29	52 F/15	Zealand Tp.	pegmatite	1.4
Z 29.2	52 F/15	Zealand Tp.	granodi.?	2.6
Z 30	52 F/14	Red Lake Road	granodi.?	1.7
Z 31	52 K/03	Cliff Lake	granodi.?	1.3
Z 32.7	52 N/02	South Bay	granodi.?	7.5
Z 32.8	52 N/02	South Bay	granodi.?	2.5
Z 43	52 K/15	South Bay road	granodi.?	1.2
Z 44.1	52 F/13	Medicine Lake	granpeg.	2.7
Z 44.2	52 F/13	Medicine Lake	Be-peg.	3.6
Z 44.3	52 F/13	Gordon Lake	granodi.?	2.2
Z 45	52 E/09	East of Kenora	granodi.?	1.1
Z 46	52 E/10	West of Kenora	granodi.?	0.5
Z 47.2	52 E/14	west Hawk-Caddy L.	granodi.?	2.5
Z 47.3	52 E/12	East of winnipeg	granodi. ?	1.6
Grenville P	21 E/11	Kearney	negmotite	2
165.2	31 E/11	Kearney (Mt. Baldy)	pegmatite	2
840	31 E/11	Spain mine (Mo)	pegmatite	1
840	31 F/7	Hunt mine (Mo)	granopegmatite	2
301 x	31 G/13	Pednaud	negmatite	1
501 X	32 B/9	Geodat	pegmatte	0.5
	22 J/15	Goodal		6.2
	$\frac{1}{22} J/10$			4.3
	22 J/10			3.9
59201	31 C/6	Moira Lake	fluorite veins cut	6.7
59202	31 C/6	Moira Lake	fluorite veins cut	9.4
5912	31 F/5	Craigmont	syenite	26
	31 J/12	Lac des Iles	Be-pegmatite	4.7
141.6	32 O/14	Bellecombe	pegmatite	4.7
019	22 O/12	Taché Tp.	Be-pegmatite	0.8
019.2	31 J/16	Maisonneuve	Be-pegmatite	21
013.3	31 I/13	Rivière du Poste	pegmatite	19
013.4	31 I/13	Rivière du Poste	pegmatite	130

Sample Number	NTS Block*	Locality identification	Remarks	Tin (ppm)
Grenville Provi	ince(cont.)			
013.5	31 I/13	Rivière du Poste	pegmatite	13
021.1	21 M/16	Lacoste	pegmatite	13
021.1	21 101/10	Lucosto	poginarito	10
Kara Dia	1.4	CORDILLERAN REGION		
Koolenay Dist	rici	Creater Calma		2
402.1	02 F/2 92 F/2	Creston-Sanno	normatita	2
.2	82 F/2	Malaan	pegmatite	4
405	02 F/0	Nelson		1
313	02 F/0	Nelson		1
319.1	02 F/0	Nelson	pagmatita	1
319.2	82 F/0	Nelson	pegnatite	1
319.3	82 F/0 82 E/10	Crawford Pay	syenite	1
234	82 F/10 82 E/10	Crawford Bay		0
235	82 F/10 82 C/12	Crawford Bay	pegmatite	1
502.1	82 G/13 82 E/7	Estella		2
502.1	82 F/7	KUSKONOOK		2
502.2	02 F//	Sanca Troup (Junction)	fluor acour	2
508	82 F/11 92 E/7	A kokli	nuor. occur.	2
002	82 F/1 82 E/0	Hallroaring Crook	Re regrestite	22
240.2	82 F/9	Lightning Creek	Be pegmatite	220
011.1	82 F/9		Tentienu	330
500 D 01	02 F/4	Coryell	Pe permetite	20
P 01 D 07	82 F/10	Mount Pachia		20
P 07	82 L/10	Mount Begole	Persported	4
		Pavalatoka	be reported	1
		Reveisione	pegmanie	I
Miscellaneous,	British Columb	ia		
828	82 E/1	Volcanic Creek	pegmatite	1–5
225	82 L/11	Fly Hill		1
451.1	83 D/13	Mica Mountain	pegmatite	5
004	83 D/13	Mica Mountain	Be reported	6-15
216	93 M/4	Rocher Déboulé	W deposits associated	1
217	93 M/4	Rocher Déboulé		1
602	82 F/7	Bugaboo		1
450.8	82 M/11	Bischoff Lakes	Be occur.	2
Y 01	82 N/04	Albert Canyon	grpeg.	4.1
Y 02	82 K/12	Shelter Bay	musc.–bi. gr.	2.1
Y 03	82 F/03	Emerald (W occur.)	musc.–bi. gr.	1.9
Y 04	82 F/03	Emerald (W occur.)	muscbi. gr.	1.5
Y 05	82 F/03	Emerald (W occur.)	musc.–bi. gr.	1.7
Y 06	82 F/03	Lost Creek	musc.–bi. gr.	2.2
Y 07	82 F/03	New Gordon (Mo occur.)	granodi. (Mo)	4.9
818	93 K/03	Endako (Mo deposit)	granite	7.5
781	93 A/02	Brynnor Mine (Mo deposit)	granite	2.3
Cassiar Distric	ct			
304.5	104 O/8	Ash Mountain	near Sn skarn	5
305.2	104 O/8	Ash Mountain	composite granite	2
306.2	104 O/8	Ash Mountain	muscovite-tourmaline granite	4
214.3	105 B/3	Topaz Mt. (Seagull)	•	8
213	105 B/2	Cassiar batholith		6
307	105 B/1	Cassiar batholith	pegmatite	1
512-533	104 O, P	Cassiar batholith		4-5
(6 samples)	-			

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Sample Number	NTS Block*	Locality identification	Remarks	Tin (ppm) l
CORDILLERAN ((cont.)			
Cassiar Distric	ct (cont.)			
611–621	104 O	Atsutla Range		10-15
(6 samples)	104 105	Consider the distribution		
(5 samples)	104–105	Cassiar batholith		1
(5 samples) 767_768	104 O	Simpson Peak		1
769	104 O/2	Klinkit batholith		8
001.1, .6	104 O/13	Logjam stock	Be, W, Bi occur.	8, 13
611	104 O/13	Logjam stock		10
612	104 O/09	Blue Light (W, Be occur.)	pegmatite	11
608	105 B/07	Ice Lake	Be pegmatite	10
625	104 O/07	Ash Mountain S.E.	biotite granite	6
Atlin District				
210.4	104 N/11	Boulder Creek, Atlin	near W-Sn deposit	7
809		Boulder Creek, Atlin	altered	9
446	104 N/11	Mount Munro, Atlin		1
477	104 N/11	Atlin Ruffner	altered	9
806-808	104 N/11	Boulder Creek area	greisen-gran.	5-500
Z 67.8	104 N/11	Black Diamond (W, Sn)	altered gran.	36
Z 69.2	104 N/11	Ruby Creek (Mo)	alaskite	6.6
Z 69.3	104 N/11	Ruby Creek	alaskite	4.0
McMillan Pas.	s-Cantung			
Z 60.2	105 O/08	Amax (scheelite)	granite	4.6
Z 60.9	105 O/08	Amax (scheelite)	granite	5.0
Z 50.6, .7	105 H/16	Cantung (scheelite)	aplite	9.2, 10
Z 53	105 H/16	Cantung (scheelite)	granite	9.7
Z 34.1 7 54 2	105 H/16	Cantung (scheelite)	granite	3.5
Z 54.2 7 54 3	105 H/16	Cantung (scheelite)	granite	0.4
Z 54.5	105 H/16	Cantung (scheelite)	granite	31
Z 54 5	105 H/16	Cantung (scheelite)	granite	8.8
Z 48	105 A/15	Cantung (seneente)	granite	3.5
MaQuastan M	ano Hang Pinar	eannang tour	Branne	5.5
207 A	106 D/4	Dublin Gulch		1
207.4	100 D/4	Dublin Gulch	quartz-veined	3
406	106 D/4	Lynx-Snowshoe	quartz venieu	1
421	105 M/15	Roop Lakes		5
433.1	115 P/16	Highet Creek		4
905.2	105 N/5	Mount Armstrong		. 3
906.2	105 N/3	Mount Armstrong		5
908.1	105 O/11	Emerald Lake		3
909.1	105 O/11	Emerald Lake		3
	115 P to 105/I	McQuesten-Nahanni belt,		1.9
		Yukon—average of 34 plutons, (R. Garrett, pers. com.)	,	
Klondike Distr	ict			
63 x 2	115 O/9	Mount Barnham	tourmaline pegmatite	12
204.1	116 B/2	Hunker Creek	quartz-porphyry	7
204.3	116 B/2	Unexpected mineral claim	quartz-porphyry	7
124.2	11 () ()		(fluoritic)	
436.2	116 B/2	Germaine Creek	altered quartz-	21
912	116 B/2	Germaine Creek	altered rhyolite	100
714	110 0/2		porphyry	100

Sample	NTS Block*	Locality identification	Bomorka	Tin (nnm)
	NTS BIOCK	Locality Identification	Keinarks	Tin (ppin)
CORDILLERA	N (cont.)			
Miscellaneo	us, Yukon			
911.1	115 P/7	Stewart Crossing		6
911.2	115 P/7	Stewart Crossing	altered	3
801	105 F/7	Sheep Creek (Canol)		2
802	105 L	Little Salmon Lake		3
211	105 C/11	Canol road		4
P 53	105 C/10	Teslin	syenite	26
P 50	105 F/3	Quiet Lake	tourmaline pegmatite	95
435.2	115 J/10	Canadian Creek	altered	6
Z 71.4	115 J/10	Canadian Cr. (Casino)	altered Klotassin Gr.	8.7
Z 71.5	115 J/10	Canadian Cr. (Casino)	fresh Klotassin Gr.	1.5
Z 71.7	115 J/07	Canadian Cr. (Casino)	Nisling granite	2.8
Z 71.8	115 J/07	Canadian Cr. (Casino)	Nisling granite	3.1
M 318	105 C/01	Teslin–Deep Lake	granite	4.6
B 121	105 C/01	Teslin-Morley Mountain	granite	12
M 361	105 C/02	Teslin–Morley Bay	granite	3.3
M 462, 3	105 C/08	Teslin–Englishmans Range	granite	2.2, 6.0
M 464	105 C/09	Teslin-S. of Thirty Mile L.	granite	6.6
M 653	105 C/15	Teslin-North Boundary	hornblende granodi.	0.4

*National Topographic Survey map system.

Geodat Records, Geological Survey of Canada.

²K. Eade (pers. com.).

³H. H. Bostock, 1969.

Distribution of Tin in Minerals of Granitic Rocks

Table 8 presents data from the most comprehensive survey found in the literature on the distribution of tin among the minerals of granitoid rocks. The data appear to be generally compatible with other less complete accounts. The figures confirm the widely held opinion that the bulk of the tin is carried by the ferromagnesian minerals and sphene. The theoretical basis for this opinion is explained in a later section.

The high tin content of hornblende and sphene throws some doubt on the validity of comparing the tin content of granitic rocks on the basis of biotite content. However, other data report much higher tin concentration in biotite, especially in granites associated with tin deposits. Barsukov and Durasova (1966) reported 30 to 50 ppm tin in biotite from tin-free granites, and 100 to 300 ppm from tin-bearing granites.

Table 8 shows that important amounts of tin are also contained in feldspars (especially plagioclase); some is not accounted for, and is probably largely in other accessory minerals not listed in the table. Some tin may be in the form of finely dispersed cassiterite or complex tin silicates. In leucogranites, much of the tin is probably contained in muscovite, as it commonly is in pegmatites. For example, the muscovite-rich fraction of a sample of berylliferous pegmatites in the Horseranch complex (Cassiar District, British Columbia) was found to contain 62 ppm tin, whereas the residue contained only 1.8 ppm. At Hellroaring Creek, in Kootenay District, a sample of muscovite from berylliferous pegmatite was found to contain 42 ppm tin compared with 22 ppm in a composite sample. In a number of lithiumbearing pegmatites from the Canadian Shield, muscovite was found to contain several times as much tin as the whole-rock samples. Barsukov (1957) reported that the tin content of muscovite decreased during centrifuging of the finely powdered sample, whereas that of

I

biotite remained constant during the same treatment. He concluded that tin in muscovite is in the form of fine cassiterite, whereas in biotite it is held isomorphously in lattice sites.

TABLE 8	Tin co	ontent of	minerals	of the D	zhida gra	nitic roc	ks(after 1	Petrova d	and Legey	do, 1965)
	Quartz (Sn co 5.4 p	diorite ntent, pm)	Granoo (Sn co 5.4 p	diorite ntent, opm)	Quartz (Sn co 4.0 p	syenite ntent, pm)	Porphyrit (Sn co 3.8 p	ic granite ntent, pm)	Leucocra (Sn co 3.8 p	tic granite ntent, opm)
Mineral	Sn in mineral, ppm	% of total tin	Sn in mineral, ppm	% of total tin	Sn in mineral, ppm	% of total tin	Sn in mineral, ppm	% of total tin	Sn in mineral, ppm	% of total tin
K-feldspar	1.0	3.9	1.4	4.08	1.0	7.25	1.3	11.06	1.1	9.70
Plagioclase	2.0	18.3	2.3	18.50	1.7	20.50	1.9	17.9	1.5	11.30
Quartz	0.5	1.3	1.0	0.20	0.5	1.75	0.5	2.63	0.7	6.00
Biotite	6.0	8.5	5.5	9.25	4.0	2.25	5.0	8.95	10.0	4.30
Hornblende	7.0	17.8	10.0	24.30	6.8	7.25	10.3	8.70	_	_
Sphene	120	42.3	400	37.00	310	54.30	440	46.31	475	61.00

Tin Content of Sedimentary Rocks, Soils, Water, and Plants

Little information is available regarding the tin content of sedimentary rock. The data given in Table 5 for shales appear to be representative of analyses quoted by Wedepohl (1969), which range from 2.5 to 19 ppm tin. An average of 4 to 6 ppm appears to be acceptable. Parker (1967) listed the tin content of clays and shales as 10 ppm. A sample of shale collected by the writer in the Cassiar District, British Columbia, was found to contain 2 ppm tin. Composites of samples collected by R. Kretz in the Yellowknife-Beaulieu River District of Northwest Territories (loc. 24) were found to contain tin as follows:

Samples	Range	Mean
4	3.8-18	11.6
2	9.4–19	14.2
	Samples 4 2	Samples Range 4 3.8–18 2 9.4–19

Boyle (1972) reported the tin content of rocks of the lower (?) Mississippian Horton Bluff Formation of Walton-Cheverie area, Nova Scotia as follows:

	Samples	Range	Mean
grey to black carbonaceous shale	34	1.3-40	6.3
carbonaceous shale, phosphorite shale, etc.	4	3.2-6.1	4.45
guartzite and sandstone	21	0.5-5.3	2.6
argillaceous and arenaceous dolomite	14	0.5-3.6	1.8

For the overlying lower(?) Mississippian Cheverie Formation the data are:

grey and green shale, siltstone, and argillite	18	-1-13	5.2
red shale and argillite	10	0.9-7.4	3.6
sandstone	26	-1-13	4

For calcareous rocks, anhydrite, and sandy shale of the overlying (upper?) Mississippian Windsor Group, tin contents reported are all less than 1 ppm. For unconformably overlying Triassic rocks the data are:

Wolfville Formation-conglomerate, sandstone, etc. diabase	7 2	-0.5-2.7 2.0-4.4	1.1 3.2	
				-

According to Boyle, tin was reported "not found" in the ores, from production records. From Boyle's data, tin was not found in samples of galena, sphalerite, tennantite, and proustite, but he reported 10 to 100 ppm tin in pyrite from the bedded rocks.

The data on tin in soils are conflicting. Evidently residual soils over and near cassiterite deposits are enriched but dispersal patterns are uncertain. According to Goldschmidt (1954), tin is concentrated in bauxite in about the same proportion as aluminum, but is not concentrated in sedimentary iron ores.

The biogeochemistry of tin is likewise uncertain. Goldschmidt (1954) reported enrichment in forest litter and also in coal ashes that contain concentrations of other uncommon elements. Ivashov and Bardyuk (1967) reported up to 0.3 per cent tin in the ashes of concentrator plants over orebodies, or 5 times higher than its content in anomalous soils. However, Millman (1957) found only 1.2 to 1.4 ppm tin in dried samples of leaves and twigs, compared with 250 ppm in residual soil.

The concentration of tin in natural waters, according to two averages by Wedepohl (1969), is from 0.03 to 0.09 parts per billion. For Japanese hot springs, it is from 0.1 to 0.5 parts per billion. The few data on tin concentration in sea water range from 0.3 to 1.22 parts per billion and average 0.72.

Physical-Chemical Considerations

Many features of the geochemical behaviour and association of tin are explicable by its position in the Periodic Table (see Table 9). Tin is essentially a lithophile element. The lithophile elements tend to be bound to oxygen and form silicates and other oxygen-bearing minerals (Ahrens, 1966). Thus tin occurs predominantly with the alkali metals, alkaline earths, silicon, and aluminum which, in combination with O, CO_2 , F, OH, etc., predominate in the common rock-forming minerals of the lithosphere, or outer crust of the earth. Tin also has a dual nature, to some extent. Although it occurs predominantly as the dioxide, associated with other lithophile elements, tin also occurs as sulphide minerals and enters into sulphides and sulphosalts in sulphide metal deposits. In this respect it behaves as a chalcophile element.

The reason some metals have lithophile, and others have chalcophile tendencies relates to their bonding characteristics. Bonding in the silicate minerals is usually regarded as predominantly ionic, whereas in sulphide minerals it is predominantly covalent (Ahrens, 1966, p. 16). In ionic bonding, ionic radius plays a dominant role in controlling distribution of elements, because it determines whether ions may substitute for each other in the silicate minerals of igneous rocks (Ahrens, 1966, p. 17). The ionic radius of tetravalent tin (the Sn^{+4} ion) is 0.71 (Jack Green, 1953), based on a radius of 1.40 for O^{-2} . In accordance with ionic radius-ratio rules, it therefore occurs in sixfold (octahedral) co-ordination with oxygen. Because of its ionic radius and co-ordination, tin can substitute to some extent for a variety of elements having similar radii; for example, tungsten (in wolframite), tantalum and niobium (in columbite and tantalite) where it is associated with these elements. Presumably for similar reasons, tin is commonly associated with molybdenum in lithophile deposits, and also with lithium. In the case of lithium, some form of coupled substitution may take place in micas. Barsukov and Durasova (1966, p. 102) suggested that tin substitutes for tervalent iron in biotite and, simultaneously, lithium replaces part of the magnesium. Coupled substitutions may also involve the co-participation of fluorine in place of oxygen. Fluorine minerals are very common in tin deposits, and fluorine complexes are commonly considered to be the main transporting agents of tin in the lithophile environment.

ΤA	BI	LΕ	9

Valence and ionic radii of tin (Sn^{+4}) and some associated elements (approximately) according to their arrangement in the Periodic Table

Valence state	+1	+2	+3	4	-3	-2
Symbol	Li	Be	В			
Ionic radius	0.68	0.35	0.23			
Co-ordination number	6	4	3			
Symbol	Na	Mg	Al	Si		
Ionic radius	0.97	0.66	0.51	0.42		
Co-ordination number	6-8		4–6	4		
Symbol	K	Ca	Fe	Ti		
Ionic radius	1.35	0.99	0.64	0.68		
Co-ordination number	10-12		(Note 2)	6		
Symbol	hali hali			Zr	Nb	Mo
Ionic radius				0.79	0.69	0.62
Co-ordination number				6	6	6
				C -		
Symbol				0.71		
Ionic radius				0.71		
Co-ordination number				0		
Symbol					Та	W
Ionic radius					0.68	0.62
Co-ordination number					6	6

Note 1: Some of horizontal groups omitted (double horizontal lines).

Note 2: Fe does not belong in this position; shown here (as Fe+3) for compactness.

Note 3: Heavy vertical lines denote boundary between dominantly cationic and dominantly anionic elements.

As a tetravalent ion, tin is listed among the network-forming elements in silicate melts (Ringwood, 1955, p. 244). Such elements tend to be tightly bonded to oxygen in polyhedral groups, and form three-dimensional frameworks by sharing of corner oxygen ions. However, as a six-co-ordinated ion, the bond strength of tin with oxygen is less than that of silicon, whose smaller ionic radius (0.43) is such that it is in four-co-ordination with oxygen. Because of this and its relative abundance, silicon is the dominant network-forming element. It is

followed in dominance by aluminum, whose ionic radius (0.51) is such that it can enter into four-co-ordination with oxygen, as it does in feldspars. As it cannot substitute for the larger single-valence alkali ions or calcium (Table 9), tetravalent tin is therefore excluded from the feldspar structure. Divalent tin (Sn^{+2}) has nearly the same radius (0.93) as calcium (0.99) and might be expected to substitute for it in plagioclase, but it can do so only sparingly, presumably because of its greater electronegativity (Hamaguchi, *et al.*, 1964, p. 1046). Presumably for similar reasons, Sn^{+2} cannot substitute appreciably for Mg^{+2} and Fe^{+2} in the early-formed ferromagnesian minerals.

 Sn^{+4} is also a complex-forming ion (Ringwood, 1955, p. 246), as evidenced by its amphoteric nature (e.g., formation of stannates in alkali solutions). However, its ionic potential is too low for stability and an appreciable amount of dissociation takes place (Ringwood, 1955) resulting in the tendency for tin to persist as a free ion in magmas. Tin is therefore excluded from the early crystallates of magmas and tends to accumulate in residual fluids.

As Sn^{+4} , tin has nearly the same radius as Fe^{+3} (Table 9), and the possibility of substitution arises. The degree of substitution possible is again limited by the requirement of electroneutrality in a total structure, so that it is only in the later-formed amphiboles and biotite, with their complex structures and compositions, that appreciable substitution can take place. This offers an explanation for the observed concentration of tin in biotite, and amphibole in intermediate and acid rocks. Titanium (Ti⁺⁴) has the same valence and nearly the same radius, and Sn^{+4} can substitute rather freely for Ti⁺⁴, as is shown by the relatively high concentration of tin found in sphene. Other common accessory minerals, such as ilmenite, rutile, magnetite, apatite, and allanite, also carry much of the tin present in igneous rocks.

If the concentration of tin in primary magma were sufficiently high, the excess over that accommodated in the ferromagnesian and accessory minerals would precipitate as independent tin minerals such as cassiterite. This evidently is rare, although disseminations in granite are known in the Jos/Bukuru and Odigi fields in northern Nigeria. Otherwise pegmatites represent the first stage of deposition of tin as an independent mineral in the magmatic environment. The further concentration of tin as a lithophile element depends on the course of late and postmagmatic processes in particular environments, and is discussed in connection with various types of deposits in Chapter III.

It has been mentioned that tin also behaves as a chalcophile element, in compound sulphides and sulphosalts of sulphide deposits. The dual behaviour of tin is seen also in the elemental state. The ordinary or beta form is paramagnetic, whereas alpha-tin is diamagnetic, which is characteristic of chalcophile elements (see under "Properties," Chapter I). In ionic form, tin is usually quadrivalent, but as Sn^{+2} its second ionization potential (14.63 V) indicates sufficient covalency to enter the sulphide minerals (Ahrens, 1964). The electronegativity, generally given as 1.65 compared with 1.8 for Sn^{+4} , is another criterion of the bonding character of ions, but its effects may conflict with those of radius and valence (Nockolds, 1966). The electronegativities of tin and some associated elements, according to Pauling and others, were quoted by Ahrens (1964) as follows:

Ca²	1.00	Ge	1.7
Fe ²	1.65	Ag	1.8
Sn²	1.65	S n ²	1.65
Sn⁴	1.8	Cu ¹	1.8
Fe ³	1.8	Cu ²	2.0
Ti⁴	1.60	Pb ²	1.6
W ⁶	2.1	Pb⁴	1.8

GEOLOGY OF CANADIAN TIN OCCURRENCES

Nockolds (1966) has considered the relative lithophile and chalcophile tendencies of elements in terms of bonding energy, a quantity which involves charge, radius, and electronegativity in a single function. In Table IV (Nockolds, 1966), he lists the metals according to the ratio of their single-valence bonding energies to oxygen and to sulphur. Tin falls in an intermediate range between the strongly lithophile elements, with the highest ratios, and the strongly chalcophile ones, with the lowest ratios. The ratio for Sn^{+2} is lower than that for Sn^{+4} , and divalent tin should therefore be the more chalcophile. F. G. Smith (1963, p. 421) has suggested that when the oxidization potential is high, tin is present mostly in tetravalent form, probably in oxy-complexes from which it can precipitate as cassiterite (SnO_2) or enter oxy-minerals. When the oxygen potential is low, tin is present in divalent form, probably in soluble sulpho-complexes, and is precipitated in sulpho-minerals of divalent elements and in sulphostannites.

Rarely, tin shows siderophile tendencies, as in its occurrence as native metal and in intermetallic compounds with platinum-group metals.

Little appears to be known about the behaviour of tin in the sedimentary process. It is clear that the chief mineral, cassiterite, being highly stable, refractory, and insoluble, is concentrated largely in the heavy residues in the vicinity of primary deposits. In this form, it provides the main commercial source of tin. It seems to be generally believed, and reasonable, that tin in sulphide minerals, being acid-soluble, would pass readily into solution in the weathering process, perhaps in the form of a colloidal stannate (Millman, 1957). However, according to Goldschmidt (1954), these minerals are subject to quick oxidation, and the product of weathering and hydrolysis is tin dioxide.

However, some tin is dissolved in natural water. The chemistry of solution of tin is very complex. The subject has been reviewed briefly by Wedepohl (1969). It is believed that the bulk of dissolved tin is precipitated into hydrolysate along with aluminum. Some enrichment is noted in bauxites. The absorptive capacity of aluminum hydroxide for tin (Durasova, 1967) may partly explain tin accumulation in argillaceous sediments.

The concentration of tin in sea water is considered high, relative to aluminum, manganese, and iron (Hamaguchi *et al.*, 1965) and it is believed that tin in solution is transported to the ocean and remains in solution in sea water. According to Goldschmidt (1954), it may be stabilized in solution in the form of a chlorostannic ion. According to Durasova (1967), one of the causes of accumulation of tin in pelagic sediments may be its absorption from sea water by illite.

Mineralogy

Tin Minerals

A fairly complete list of the essential tin minerals, with their composition, ordinary physical properties, and typical occurrence, is given in Table 10. They are grouped according to chemical types. Most of these are described in standard mineralogy texts. A few references to other literature are given. A few other unusual and rare minerals are mentioned below.

Of the known tin minerals, only the oxide cassiterite and the compound sulphide stannite have wide distribution. A number of other compound sulphides are fairly common in parts of Bolivia, and a few have been identified elsewhere. Of these, franckeite, canfieldite, kesterite, and hexastannite have been recognized in Canada. Other tin minerals known to occur in Canada are the tin tantalate wodginite and native tin.

Cassiterite is by far the most important ore mineral and is recovered from placer, pegmatite, quartz-cassiterite and sulphide-cassiterite deposits. The hydrated tin oxides are locally important, and souxite is a major constituent of some Bolivian ores. No information has been found on the amount of tin actually recovered from the sulphosalt minerals. Although considerable amounts of some of these minerals have been mined in Bolivia, most of the concentrate exported is dominantly a cassiterite concentrate. According to Wedepohl (1969), some deposits of this type in the U.S.S.R. are being mined, but any references found in the literature on producing areas are to "cassiterite–sulphide" deposits. According to T. Watanabe (pers. com.), tin is recovered from sulphide minerals in Japanese deposits.

Native Tin and Natural Alloys

Native tin occurs in pitchblende at Beaverlodge, Saskatchewan (loc. 26). This is one of the very few if not the only known occurrence.

Native alloys or intermetallic compounds with platinum-group metals are very rare. Niggliite, PtSn, occurs with insizwaite and parkerite in veins at Waterfall Gorge, Insizwa, South Africa. In reflected light it has very high bireflectance from pink-cream to pale blue. The anisotropism is intense, from bright pinkish cream to very dark blue or black. Composition in weight per cent is approximately Pt, 61; Sn, 30; Bi, 2.5; Sb, 5.5. The powder pattern is similar to that of synthetic PtSn (Cabri and Harris, 1972). Stannopalladinite, and some unnamed tin-palladium and tin-platinum minerals have been reported. Zvyagintsevite, $(PdPt)_3(Pb,Sn)$ was discovered in polished sections of pentlandite-chalcopyrite-cubanite ore from the hanging-wall of veins in the Noril'sk deposit. The mineral forms inclusions up to 0.3 mm in diameter in pentlandite and is surrounded by rims of ferroplatinum. It is isotropic; microhardness is 316 kg/mm²; and reflectivity is lower than that of ferroplatinum. Zvyagintsevite formed after crystallization of pyrrhotite (Genkin, et al., 1966).

Oxides

Cassiterite (ordinary, crystalline)

Structure. Tetragonal, rutile type; crystals usually short prismatic to pyramidal, twinning on 011 very common, often genicular. Long prismatic (acicular or "needle tin") comparatively rare and thought to be of late low-temperature or secondary origin.

Optical. Uniaxial positive, refractive indices (1.99–2.09) and birefringence conspicuously high.

Physical. Very refractory, insoluble in acids, unaffected by weathering. Cleavage poor, lustre adamantine to splendent; colour variable from light yellow to red to black, mostly brown due to impurities. In crystals, variable in zones or growth bands parallel to faces. Generally not, or only weakly magnetic and separable from wolframite by this quality, but both ferromagnetic and paramagnetic varieties have been found. *Chemical*: commonly contains iron, up to Fe:Sn = 1:6; also Ti, Ta, Nb, rarely W, Mn, etc.

Tests. Reducible to metallic tin on charcoal with soda.

In contact with zinc in dilute hydrochloric acid becomes coated with metallic tin which becomes bright on polishing.

Wood tin is an extremely fine grained or cryptocrystalline variety of cassiterite with colloform structure marked by concentric banding and radial fractures. Colour generally brown in varying shades between bands, according to impurities, mostly iron oxides. Common in Canada only in the Klondike gold-placer deposits (loc. 3) and possibly locality 8.¹ It has been observed in the oxide zones of sulphide-tin deposits and considered a product of secondary processes, but also occurs in deep-seated veins and in pockets in rhyolitic lavas as a hypogene mineral, perhaps of fumarolic origin.

¹See Map 1352A.

TABLE 10	Some essential tin mine	rals						
Name	Chemical composition	Tin content (%)	Specific gravity	Hardness	Colour	Form	Typical occurrence and locality ¹	Reference
NATIVE TIN							Canada, loc. 26.	Silman, 1954
INTERMETALLIC COMPOUND Niggliite Stannopalladinite	PtSn (rod bo) or c.	30			pink-blue	anisotropic	Insizwa, South Africa	Cabri and Harris, 1972
Zvyagınısevile	(ru,ru)1(u,u)					Isotropic	NOTI SK, U.S.S.K.	Genkin, et al., 1900
oxides Cassiterite	SnO ₂	78.6	6.8–7.1	67	various light to dark, gen- erally brown	tetragonal crys- tals, pyramidal, rarely prismatic; wood tin	quartz-cassiterite, cassiterite-sulphide —common, Canada, loc. 3 (wood tin)	
Wickmanite	MnSn(OH)6			3.5	yellow	rounueu, panaeu octahedra	Sweden, Norway,	Moore and Smith,
Varlamoffite	?(hydrated tin oxide)				yellow	amorphous	rare Congo, Bolivia	1900 Deer, <i>et al</i> ., 1962
Souxite	hydrated oxide				yellow	powuer amorphous	Bolivia	Nickel, 1962
compound sulphil and sulphides Stannite	DES Cu2FeSnS4	27.1–27.8	4.3-4.52	3.5	steel grey to black, occas. black tarnish	Tetragonal, generally massive	Canada loc. 22a,46 etc.—fairly common	

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Hexastannate	related to							Springer, 1968
Mawsonite	variable					variable		
Kesterite Franckeite	Cu2ZnSnS4 Pb5Sn3Sb2S14	17.1(calc.)	5.9	2.5-	greyish black	orthorhombic, generally	Canada, loc. 22a Canada, loc. 14, Bolivia, Tasmania	Levy, 1967
Teallite	PbSnS ₂ (+Ge,B)	30.5	6.36	1.5	greyish	orthorhombic,	common only in	
Cylindrite	6PbS.6SnS2.Sb2S3	26.5	5.46	2.5	black grey-black	unin, taoular massive, in	Bolivia, rare	
Canfieldite isomorphous	(complex) Ag ₈ SnS ₆	10.1	6.1–6.3	2.5	grey-black with bluish	cyundrical forms Isometric, massive, and botryoidal	Bolivia, also Freiberg and Tasmania	Harris and Owens, 1971
with Argyrodite	AgsGeSs				tones		Canada, (loc. 22a), (loc. 45)	Boorman and
Herzenbergite	Tin sulphide				black	massive	Bolivia, rare	11000
tantalate-niobate: Thoreaulite	SnTa2O7	20±	7.6-7.9	9	brown	monoclinic, rough,	Pegmatite, Monono,	
Wodginite	(SnMn, tantalate)	7.0 (Wod- gina, Aust.)	7.2-7.36	63	reddish brown to	prismatic monoclinic	pegmatic, Wodgina, +Canada, loc. 30,	Nickel, et al., 1963
Ixiolite	(FeMn,Sn)(CbTa) ₂ 0 ₆	10.4 Bernic L	. 7.2–7.366		Dlack		okogoole, rinland	
sillicates Stokesite Malayaite	H4CaSnSi3O11(?) CaSnSiOs	28(calc.) 45(calc.)	3.2	9	colourless	orthorhombic ?	Cornwall, very rare Malaya, Cornwall	Vorma, 1963 Alexander and
Arandisite	Hydrated tin silicate	50+	4.12	5	green	partly colloidal ?	South-west Africa, very rare	runuer, 1905 Gevers, 1929
BORATES Nordenskioldine	CaSn(BO ₃) ₂	43(calc.)	4.2	5.5	yellow	rhombohedral	Norway, South-West	
Hulsite	complex Fe-Sn		4.3	3	black	orthorhombic,	Seward Pen., Alseks rare	
Paigeite	borates					laUulai	Maska, Ial	
1 Canadian loca	lity numbers refer to N	fap 1352A and	1 Table 1.					

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Varlamoffite (Congo) and souxite (Bolivia) are amorphous earthy materials of secondary origin that occur in oxidized zones of tin deposits, locally in substantial amounts. Varlamoffite has been described as partly hydrated stannic oxide (Deer, et al., 1962).

Compound Sulphides and Sulphides

The sulphide minerals of tin are rather soft, dark grey to black, generally in massive or very fine crystalline aggregates, and are difficult to recognize or distinguish by ordinary physical means. Ore microscopy and microchemical tests, as described in standard texts, are useful. The minerals are readily fusible and amenable to blowpipe tests, but are not positively identifiable by such methods. They are fairly soluble in acids, but with concentrated nitric acid, the tin is oxidized to SnO_2 .

Stannite (see Fig. 18)

Physical. Sphalerite structure, tetragonal, scalenohedral, pseudotetrahedral, but rarely crystalline. Generally massive or granular and disseminated. Twinning lamellar and polysynthetic, commonly seen in polished section (see Oelsner, 1966, p. 30–32). Cleavage indistinct, fracture uneven, lustre metallic, streak black. In polished section, stannite is generally distinguishable from the ordinary associated sulphide minerals by anisotropy and light brown colours. HNO₃ stains iridescent to black; fumes tarnish. HCl, KCN, FeCl₃, KOH, and HgCl₂ negative.

Chemical. Stannite has a fairly constant chemical composition but in some "related" minerals, the tin content is much lower and in some, it is much higher (see Fig. 18). Some zinc is commonly present. The pure zinc analogue kesterite occurs in Canada at loc. 22a. A zinc-rich variety, "stannoidite," $Cu_5(Fe, Zn)_2SnS_8$, has been described from Japan (Kato and Fujiki, 1969).

Occurrence. In hydrothermal quartz veins associated chiefly with sphalerite, galena, chalcopyrite, tetrahedrite, pyrite, arsenopyrite, etc. Most commonly seen in exsolution lamellae and blebs in sphalerite, often with chalcopyrite. In Canada this mineral is fairly widespread in Cordilleran tin-bearing zinc-lead sulphide deposits, notably the Snowflake-Regal Silver deposit (loc. 22a) where it occurs in masses a foot or more across. Kesterite, Cu_2Zn Sn S₄, the pure zinc analogue of stannite, also occurs there in exsolution relationship with stannite (Harris and Owens, 1972). Stannite is common also in the Appalachian region, especially at Mount Pleasant (loc. 46), and has been reported at Brunswick Mines, Nigadoo, and other deposits in Bathurst area (loc. 45). Some hexastannite has been reported at Mount Pleasant (Boorman and Abbott, 1967). Stannite occurs in massive sulphide deposits at Lac Dufault (loc. 37) and elsewhere in the Precambrian Shield.

Franckeite

Crystal structure. Orthorhombic, thin tabular plates, usually in aggregates or massive. Physical. Cleavage o/o perfect; flexible, slightly malleable. Lustre metallic or tarnished iridescent, streak greyish black. In polished section, anisotropic in light to dark grey colours. HNO₃ stains differentially iridescent, fumes tarnish. HCl fumes tarnish slowly, doubtful. FeCl₃ doubtful. KOH slowly stains brown to iridescent. HgCl₂ negative. Strong cleavage one direction.

Chemical. Lead-tin-antimony sulphide. Fe and Zn common impurities. Ge, Cu, Ag, Bi reported spectrographically. Decomposed in HNO_3 with separation of oxides of Sn, Sb.

Occurrence. A common mineral in silver-tin veins of Bolivia, sometimes in large amounts. Also reported from Tasmania. In Canada at Coal River (loc. 14) as chief tin mineral, intimately associated with sphalerite, geocronite, minor stannite and galena in calcite vein in argillite.

Teallite

Teallite occurs in thin tabular plates, usually as massive aggregates of thin graphite-like folia. It is very soft with metallic lustre and black streak. In polished section, distinctly anisotropic in white to light golden tints. It occurs, sometimes in large amounts, in the silvertin veins in Bolivia. Also reported at the Himmelsfurst Mine, Freiberg, Saxony.

Cylindrite

Unknown in crystal form, it occurs as massive aggregates distinguished by cylindrical forms which separate under pressure into smooth concentric shells. Colour and streak black, with metallic lustre. In polished section, anisotropic in grey-white colours. Composition uncertain. Found only in a few mines in Bolivia.

Canfieldite

An end-member of the argyrodite series with which it forms an isomorphous series from Ag_8GeS_6 to Ag_8SnS_6 . Octahedral and dodecahedral forms most common, also massive, compact, in botryoidal crusts with crystalline surface or as radiating crystal aggregates. Brittle; streak greyish black. In polished section, grey-white with a violet tint; isotropic. A rare mineral, canfieldite, occurs in Canada at Snowflake–Regal Silver (loc. 22a) (Harris and Owens, 1971) and in silver-rich galena at Nigadoo (loc. 45) (Boorman and Abbott, 1968).

The series best illustrates mutual substitutions of tin and the chemically similar element, germanium. The germanium mineral renierite also commonly contains some tin, and germanium is associated with stannite in various places, including Mount Pleasant, N.B. (loc. 46).

Colusite

A complex tin-bearing sulphosalt Cu_3 (As, Sn, V, Fe, Te) S₄ with H 3–4, G 4.8, bronze colour, black streak, metallic lustre, has been reported from Butte, Montana, and Red Mountain, San Juan Co., Colorado.

Herzenbergite

The only commonly recognized simple tin sulphide, it occurs as fine-grained material with colour and streak black and a metallic lustre. Composition Sn_2S_3 according to imperfect analysis. Found in the Maria-Teresa Mine near Huari, Bolivia.

We depohl (1969) mentioned the reported finding of two natural tin sulphides Sn_2S_3 and SnS_2 .

Tantalate-Niobates

Thoreaulite

A tin-tantalate found with cassiterite in pegmatite at Monono, Katanga, Republic of the Congo. It occurs as rough prismatic crystals and lamellar twins with perfect 100 cleavage. Brown with yellow-greenish streak and resinous to adamantine lustre. Optically biaxial positive, $2V 25^{\circ}$, mean index 2.38^{\pm} and birefringence 0.039 on 100 cleavages. Monoclinic structure inferred from optical properties.

Wodginite

Essentially a tin-manganese tantalate, with minor niobium, titanium and iron, wodginite was confirmed as a distinct mineral species (Nickel *et al.*, 1963). The material from Bernic Lake is higher in tin and contains little niobium, compared with the originally described material from Wodgina, Australia. Both contain about 70 per cent Ta_2O_5 . At Bernic Lake (loc. 30) where it is the main tantalum ore mineral, wodginite occurs in an albitite unit of a complex pegmatite rich in lithium and caesium minerals.

Ixiolite

A complex iron-manganese niobate-tantalate. Nickel *et al.* (1963) found that ixiolite represents a substructure of columbite-tantalite, with the cations in disordered arrangement. They found an SnO_2 content of 12.27 per cent.

Sukulaite

Sukulaite, $Ta_2Sn_2O_7$, and wodginite occur as inclusions in cassiterite in a granite pegmatite in Sukula, Tammela, in South West Finland (Vorma and Siivola, 1967).

Silicates, Borates, etc.

Known occurrences of tin-silicate minerals are quantitatively insignificant. However, their existence suggests possible forms in which tin may be dispersed in rock minerals, particularly calcic plagioclase and sphene.

Vorma (1963) reported the composition of *stokesite* as 4 (CaSnSi₃O₉·2H₂O) and the structure as (SiO₃)_n chains bound by eight-co-ordinated Sn⁺⁴ and eight-co-ordinated Ca⁺².

Alexander and Flinter (1965) stated that *malayaite*, found as a yellow coating on cassiterite crystals, was "isostructural with sphene." No details are given and no authoritative structural study is known to the writer.

The tin-borate minerals are also extremely rare, but *hulsite* and *paigeite* occur as small crystals and macroscopic tabular masses in metamorphosed limestone at a granite contact at Brooks Mountain, Seward Peninsula, Alaska.

Wickmanite, Mn Sn(OH)₆, has been reported from Langban, Sweden (Moore and Smith, 1966). It occurs as translucent yellowish octahedra up to 2 mm on the edge. It has good cleavage, a white streak, and hardness of 3.5. Wickmanite has also been recently reported from Norway (Amli and Griffin, 1972).

Tin as an Accessory Constituent in Minerals

Tin in appreciable amounts has been detected in a large variety of minerals, only the most important examples of which are mentioned here.

Silicates

Sphene may be considered as an accessory-tin mineral because of its importance as a collector of tin in primary igneous rocks (see Table 8). A sample of sphene provided by D. Hogarth from the Evans-Lou pegmatite, about 25 miles north of Ottawa, was found to contain 0.16 per cent tin by spectroscopic analysis. It also contains Nb and 5.5 per cent yttrium (Miles *et al.*, 1971).

Takenouchi (1971) found an immiscible region between malayaite and sphene at temperatures below 615°C. The peak of the solvus was at $Ca(Sn_{1/4}Ti_{1/4}) O SiO_4$. Rutile and ilmenite are also collectors of tin.

In skarns, *andradite garnet*, *epidote*, and *ferroactinolite* contain tin in amounts approaching one per cent in Canada at locality 16(u) (Table 1). Tin-rich andradite has also been reported from Czechoslovakia (Dadák and Novák, 1965); Devonshire, England; Thailand (Hosking, 1965); and the U.S.S.R. (Nekrasov *et al.*, 1965).

Tourmaline (a complex borosilicate) from Canadian lithium-bearing pegmatites was found to contain from 36 ppm tin in black schorl to more that 150 ppm in pink tourmaline from a tin-bearing unit at the Chemalloy deposit (loc. 30).

Dark blue *apatite*, a characteristic accessory in many Canadian lithium-bearing pegmatites was found to contain generally from 18 to 57 ppm tin. One sample was reported to contain 0.043 per cent tin, but it was from a specimen that contained cassiterite, from Sproule Lake (loc. 24a), and may have contained fine cassiterite inclusions. However, an apatite with the composition $Sn_9Ca(PO_4)_6(OH,Cl,F)_2$ has been synthesized (McConnell and Foreman, 1966).

Borates

In skarns, *ludwigite*-type minerals in northwest U.S.S.R. contain as much as 1.33 per cent tin (Nekrasov *et al.*, 1965). Tin-bearing ludwigite-type minerals occur in Canada at locality 16(0) (Gower, 1952), and at the Read Magnetite deposit in Washington State, U.S.A. (Bennett, 1962).

Magnetite

Magnetite is widely recognized as a collector of tin in skarn deposits, as in Canada at localities 16(a), 16(t) (Table 1). In northeast U.S.S.R., up to 0.45 per cent tin has been reported (Nekrasov *et al.*, 1965).

Niobate-Tantalates

Columbite-tantalite minerals are efficient collectors of tin, apparently in amounts up to that reported for ixiolite (see above). In Canada, much of the tin at locality 24 may be contained in the lattices of these minerals. Other tantalates and rare-earth minerals that may contain appreciable amounts of tin are yttrotantalite, samarskite, euxenite-Blomstrandite and ilmenorutile.

Wolframite

Wolframite commonly contains significant amounts of tin. A niobian wolframite from a pegmatite in Mozambique has been reported to contain 1.52 per cent tin (Saari *et al.*, 1968). In Canada, wolframites from tin-bearing deposits at localities 16 (1) and 44 (Table 1) were found to contain several tenths of one per cent tin.

Sulphides

Tin is widely reported as a constituent of various sulphide minerals. Sphalerite, chalcopyrite, and galena are considered to be the main collectors, but pyrite, pyrrhotite, and other

sulphides have been reported to contain substantial amounts, locally more than associated sphalerite, chalcopyrite, or galena. Nichol (1958) and Colwell (1963) reported the tin content of various sulphide minerals in base metal deposits in the Cambrian Shield (see Chapter IV). Warren and Thompson (1944) reported analyses for tin in sphalerite and galena from a large number of deposits in the Canadian Cordillera, and Sinclair (1964) gave data on the tin content of galena from deposits in the Kootenay Arc. Burnham (1959) reported on the tin content of sphalerite and chalcopyrite from numerous deposits in western United States and Mexico. A. W. Rose (1967) presented similar data for parts of New Mexico and Utah.

Boulangerite, jamesonite, tetrahedrite, and other complex sulphosalt minerals are also collectors of tin. A sample of tetrahedrite from the Cassiar District (loc. 16) was found to contain 1.58 per cent Sn by chemical analysis, but its purity is questionable.

The amounts of tin that can actually be contained within the lattices of the minerals are not known. Reported contents of several tenths of one per cent are common, but the total absence of included tin materials has apparently not been proved. Hawley and Nichol (1961) identified cassiterite in excessively tin-rich samples of pyrite and chalcopyrite. The writer has found stannite in a number of lead-zinc ores that contained less than 0.1 per cent tin. However, Boyle and Jambor (1963) found no tin minerals in sphalerite containing 0.08 per cent tin. Chalcopyrite, apparently free of stannite, at the Geco mine (loc. 35) was found to contain 0.1 per cent tin, whereas the coexisting sphalerite contained only 0.05 per cent (Banerjee, 1972). Fleischer (1955) suggested that 1000 parts per million (0.1 per cent) is the maximum amount of tin that can be contained in the lattices of sphalerite and chalcopyrite.

The manner of substitution is likewise unknown. Stannite, chalcopyrite, and sphalerite are very similar, based on the face-centred cubic ZnS structure, so that extensive solid solution between them is possible (Vokes, 1963). Tin has about the same covalent radius as zinc and copper, and the ionic radius of Sn^{+4} is close to that of Zn^{+2} and Cu^{+2} . Boyle and Jambor (1963) suggested that tetravalent tin might substitute for zinc in sphalerite to some extent in spite of the charge difference. Alternatively, Sn^{+2} might substitute for Zn^{+2} , Cu^{+2} , or Fe^{+2} at fairly high temperature in spite of its greater ionic radius. In sphalerite, stannife inclusions commonly show exsolution relationships, indicating decreasing solubility of tin with decreasing temperature.

Little information on the partition of tin among the sulphide minerals has been found. Fleischer (1955) found that pyrrhotite with appreciable tin content came mostly from deposits that contain no chalcopyrite. Warren and Thompson (1944) concluded that the tin content of sphalerite is usually greater than that of galena in the same deposits. Goldschmidt (1954) quoted an opinion that at higher temperatures, tin enters preferentially into galena, and at lower temperatures, into sphalerite.

The tin content of sulphide minerals appears to be generally higher in regions having tin deposits than in those without. Goldschmidt (1954) cited comparative figures for Norway and Czechoslovakia. Lead-zinc ores in the Cordilleran tin belt commonly have anomalous tin contents. In western U.S.A. and Mexico, Burnham (1959) outlined three subparallel tin-rich belts on the basis of the tin content of chalcopyrite and sphalerite.

Detection and Identification of Tin and Its Minerals

Mineral Identification and Tests

Cassiterite, especially if fine grained, may be difficult to recognize in hand specimens or in heavy mineral concentrates by its physical properties. A simple and effective means of identification is to place the mineral in contact with zinc and hydrochloric acid (a 1:1 solution of the concentrated acid is satisfactory). Within a few minutes, the surface becomes coated with a dull grey film of metallic tin, due to reduction of the oxide by atomic hydrogen. The film brightens when rubbed with cloth or soft paper. Zinc filings are most convenient for hand specimens or polished sections. Fine material in concentrates may be treated fairly well in a zinc tray. The tin film may be redissolved by nitric acid. The test is not infallible, as some naturally occurring cassiterite will not react.

In thin sections, cassiterite can be identified fairly definitely by its optical properties. In polished sections, it is negative to all reagents, hard and anisotropic, and may show resin-coloured internal reflections.

The tin sulphosalt minerals are all rather soft, dark grey to black, usually massive and difficult to distinguish from several common sulphide minerals and from each other. They are readily fusible and amenable to blowpipe tests but are not positively identifiable by such methods. Several, notably stannite, are fairly easily distinguished from ordinarily associated sulphide minerals by their optical properties in polished sections (see descriptions under "Mineralogy". Microchemical tests are useful but not conclusive.

Detection and Analytical Methods for Tin

Chemical

Chemical methods of analysis for tin in general, although standard for mine and mill products, are difficult, and are the subject of extensive literature.

A method of analysis for tin in low concentrations, as commonly used for soil and stream sediments, is the gallein colorimetric method. It is based on the reaction of tin with gallein (4, 5 dehydroxy-fluorescein), using ammonium iodide to volatilize the tin. The method has been described by Stanton and MacDonald (1961) and others. A modified procedure has been described by A.Y. Smith (1967).

Instrumental

Spectrographic methods are generally applicable and effective for the detection and approximate analysis of tin up to economic concentrations in most materials. Ordinary semiquantitative methods used by the Geological Survey of Canada are sensitive to about 0.01 per cent tin, and a quantitative method for volatile elements will detect concentrations down to less than one part per million. The accuracy of the methods is adversely affected by a number of interfering elements.

X-ray fluorescence methods are effective for the detection of tin in concentrations down to several parts per million by improved methods. They are less sensitive to interfering elements than are spectrographic methods, and are especially useful for sulphide and other ores high in iron and other heavy metals. They are also non-destructive.

A portable X-ray fluorescence analyzer has been developed (Bowie et al., 1965; Bowie, 1968). The original commercial instrument was manufactured by Hilger and Watts, Ltd., St. Pancras Way, Camden Road, London NW1, England. A more advanced version is known as the Ekco Mineral Analyzer.

The principle differs from that of conventional X-ray fluorescence apparatus in that a radioactive isotope provides the X-ray power source, and a pair of balanced absorption filters is used to measure the secondary fluorescent radiation characteristic of the element sought.

The instrument, which weighs about seventeen pounds, makes possible the detection and approximate analysis of tin on site or in prepared samples. The limit of detection on prepared samples is said to be 0.03 per cent tin, and the accuracy comparable to that of conventional analysis (Bowie *et al.*, 1968). For the direct measurement of tin in situ, the sensitivity and accuracy is limited by surface irregularities and inhomogeneity of distribution. The writer has found the instrument effective for detecting tin in local concentrations approaching economic levels in underground workings.

Chapter III

GENERAL GEOLOGY OF TIN DEPOSITS

Canadian tin occurrences are, with few exceptions, economically unimportant, but they are fairly numerous and varied in type and they provide some illustration of the geological features of tin deposits in general. They are shown on Map 1352A, and the details of their characteristics and geological environment are given in Chapter IV and Table 1.

In the present chapter an attempt is made to review the main geological features of tin deposits in general, and to place the various types of Canadian occurrence in the context of world deposits. For recent comprehensive descriptions of world deposits and geological characteristics the reader is referred to "Materials Survey—Tin" published by the United States Department of Commerce, 1953, and to summary descriptions in "Tin resources of the world," (Sainsbury, 1969).

Geological Environment of Tin Deposits

As a basis for consideration of the geological environment of tin deposits, two features of such deposits are outstanding:

1. Their irregularity in world distribution.

2. Their close association with igneous rocks of granitic composition.

These features are partly interdependent, as the large areas of the earth's surface devoid of igneous rocks are also devoid of tin deposits. However, there are large portions of the earth's crust that have abundant granitic rocks, but in which tin occurrences are insignificant or absent.

Distribution and Age

The major stanniferous regions of the world and their main geological characteristics have been described most recently by C. L. Sainsbury (1969). They are illustrated and identified in Figure 1 and the accompanying list. The irregular distribution of the tin-rich regions is at once apparent. They occur mainly in more or less linear groups that are restricted to certain parts of the earth's surface. These linear groups or belts can to some extent be correlated with major orogenic and tectonic features of continental development, but it is generally conceded that they reflect an erratic original distribution of tin in the earth's crust. Thus they conform to the concept of metallogenic provinces.

Many of the most important tin districts lie in an intermittent but well-defined chain near the western margin of the Pacific Ocean. This chain extends from Tasmania and eastern Australia through Indonesia, the Thai-Malay peninsula, Burma, China, and the U.S.S.R. to





ė	Erzgebirge, German Democratic	Mount Tallenburg-Albury-Eldorado
	Republic (East Germany) and Czechoslovakia	belt Barrier Bange
4	France 7.	Southwest Western Australia
	A EDICA	Northwest Western Australia
-	El Karitarea Morocco	Northwest Tasmania
- 01	Igla, Nuweibeh Abu, and Dabbab el	Northeast Tasmania
	Mueilha areas, United Arab Republic	ASIA
	(Egypt) 1-	14 Siberia IISSB
ŝ	Djilouet area, Algeria	1 Altai Mountains
4	Tamanrasset area, Algeria	2 Narvn Kazakstan area
ς.	Bir Oumgreine area, Mauritania	3. Kalba, East Kazakstan
ര്	Iforas area, Mali	4 Transhaikal (Zahavkal've)
۲.	Air district, Niger	
œ	Tawalafa area, Sierra Leone	E Vone Adrohe area
ъ.	Jos Plateau, Nigeria	5. Fana-Auyona area
Ģ	Maniema area, tin belt, Democratic	0. Ege-Miaya-Deputatskiy region
	Republic of the Congo	7. USI -Unicriug, parugyonag area
Ħ	Rwanda, Burundi, Uganda, and	0. Volume area
	Tanganyika (Tanzania)	
12.	Manono-Kitololo mines, Katanga,	10. Galimyy area
	Democratic Republic of the Congo	11. Nrasnoarmeysnoye area
13.	South-West Africa	12. Iul tin area
4	Southern Rhodesia and Nyasaland	13. Khingansk area
15.	Rooiberg-Leeuwport area, Republic	14. Lituazin-Knrustal nyy area
	of South Africa	15. Honshu Island, Japan
16.	Warmbad area. Republic of South	16. Kwangsi-Kwangtung-Hunan
	Africa	Provinces, China
		 Kochiu area, China
	ALISTRALIA	 Coastal zone, China
Ŧ		19. Hainan Island, China
- ^		20. Malay Peninsula
iω 4.	Stanthorpe-Ballandean district New England district	
fo	the Great Lakes is expected to herome an important .	stodioos of his modulet Tie Lee 1074

Black Hills area, South Dakota
 Franklin Mountains, Texas
 Black Range district, New Mexico
 Climax Mine, Colorado
 Gorman area, California
 Santa Eulalia district, Chihuahua
 Southern Appalachian belt
 New Brunswick area

Sullivan mine, British Columbia

5. Kootenay district including

British Columbia

3. McQuesten-Mayo area, Yukon 4. Cassiar district, Yukon and

Seward Peninsula, Alaska
 Manley Hot Springs, Alaska

NORTH AMERICA*

Rio Grande do Norte-Paraíba, Brazil
 Northeast Ceará, Brazil

SOUTH AMERICA

Eastern Minas Gerais, Brazil
 Rondônia-Tapajos, Brazil

6. Tin belt, Bolivia

Central Ceará, Brazil

Ipameri, Goiás, Brazil
 Encruzilhalda, Brazil
 Amapá area, Brazil

2. Portugal and Spain 1. Cornwall, England

EUROPE

important producer of by-product lin by 1974 5 *The Kidd Creek-mine (not shown) north east of the G

the Chukoida peninsula. The North American extension of this "circum-Pacific belt" (Smirnov, 1946) is much weaker, but it can be traced through Alaska, western Canada, and conterminous U.S.A. into Mexico (Sainsbury, *et al.*, 1971). The Andean belt of Bolivia and northern Argentina, although a disconnected entity, is related to the same pattern of orogenic development, and is regarded as the southern extremity of the belt.

Most of the other important tin districts are found in western Europe, Africa, and eastern South America, with some minor ones in eastern North America. An impressive number lie fairly close to the Atlantic Ocean, although some in Africa are more remote. They can be grouped into belts of considerable lengths (Schuiling, 1968), but these belts are of different ages and generally without co-linear relationship to each other. The tin belts of eastern South America and of western Africa are remarkably similar in type and geological environment, and are widely believed to belong to a single metallogenic province, which was disrupted by continental drift.

Most tin deposits fall into certain distinct age groups, which can be described as metallogenic epochs. Those of the circum-Pacific belt are mainly late Mesozoic, although they range from Devonian in Tasmania to Tertiary in parts of Bolivia, southern North America, and Japan. The Mesozoic group contains most of the main producing districts of the world, including those of southeast Asia, Indonesia, most of the U.S.S.R., and part of Bolivia.

The late Paleozoic Hercynian epoch is also of major importance. To this age group belong the desposits of western Europe, including Cornwall, the Iberian peninsula, and the Erzgebirge district. Some deposits, in Queensland, Australia, and in the Transbaikal district in Siberia, are also said to be of Hercynian age.

Deposits of Caledonian (late Devonian) age are generally of only minor importance (except in Tasmania). This group includes the Appalachian tin belt of North America. In Canada the deposits are related to late or post-orogenic phases of Devonian granites and the most significant deposit (Mount Pleasant) is emplaced in rocks believed to be Mississippian in age.

The Precambrian group includes all the deposits in the Precambrian Shield areas of the world, including the many important pegmatitic and other deposits of Africa and eastern South America. Their ages are widely variable, in many places uncertain, and some are probably somewhat younger than Precambrian. The important deposits associated with the "younger granites" of Nigeria and the western part of Brazil, in particular, are believed to be of early Paleozoic age. In North America the tin occurrences of the Precambrian Shield are virtually restricted to the oldest (Archean) structural provinces. However, a few late Precambrian deposits are found along the eastern fringe of the Cordilleran tin belt, notably in South Dakota (Black Hills) and Texas (Franklin Mountain). The stanniferous base-metal sulphide deposit of the Sullivan mine in the Canadian Cordillera (loc. 22) is also apparently of late Precambrian age.

Convergence and superimposition of tin belts of various ages, as in Brazil-Bolivia, eastern Australia, and possibly Seward Peninsula, may be a factor leading to major tin concentrations in certain areas.

Relationship to Granitic Rocks

The general and close association with igneous rocks, intrusive or extrusive, of granitic composition is the dominant geological feature of tin deposits. A genetic connection is inferred from the distribution of tin in igneous rocks, and its geochemical nature. It is generally

assumed that tin is concentrated in late crystallates and residual fluids during crystallization of granitic intrusions (see "Physical-Chemical Processes" below).

As fluids tend to migrate to zones of lowest pressure, the apical portions and upward protuberances of domical intrusions would, in the absence of disturbing factors, be favourable for the accumulation of tin-bearing fluids. Thus in Cornwall and many other tin fields (Hosking, 1965), tin-bearing greisen lodes are concentrated in cusps or cupolas on granitic ridges. For the same reason, areas of small intrusions, such as dykes and stocks which represent the uppermost parts of batholiths, are more favourable than areas in which the batholiths themselves have been deeply eroded.

It is clear, however, that only certain granitic masses in many tin belts have significant tin deposits associated with them, as in Malaya (W. R. Jones, 1925). Such granites are commonly discordant and highly variable in texture, with fine-grained, porphyritic, and pegmatitic phases and related dykes. They are regarded as truly "magmatic" granites. They are generally acid potassic granites, moderately rich in silica, and may have an abnormally high content of fluorine and (or) boron, in the case of tourmaliniferous granite. The relationship between tin deposits and composition of associated granite is discussed under "Physical– Chemical Processes" below.

It has been found that granites with associated tin deposits generally contain more tin than those without associated deposits. Barsukov (1957) reported 16 to 30 grams per ton tin in unaltered parts of such granites, compared with 3 to 5 grams per ton in "barren" granites. He holds that tin in greisen-type deposits is mainly derived from the biotite of the granite, released by reaction with solutions rich in fluorine, hydroxyl, and sodium ions (see "Physical– Chemical Processes" below).

In Canada some unaltered late-stage biotite granites in tin-bearing districts such as the Cassiar (loc. 16) contain as much as 15 parts per million tin, but in general only muscovitebearing granites in particular districts have an unusually high tin content (see Table 7). Some are greisenized and contain accessory fluorite and topaz, but where their over-all tin content is much higher than in surrounding biotite granite (as in New Ross, loc. 48) their enrichment could not have been caused simply by the alteration processes. Muscovite-bearing granite bodies are found in the Precambrian, Appalachian (Devonian), and Cordilleran (Cretaceous) tin-bearing regions of Canada. They commonly have associated porphyritic, aplitic, miaroly-tic, and pegmatitic phases and appear to represent the youngest phases of intrusion in each district. Rhyolitic extrusive and hypabyssal rocks with associated tin-deposits, such as Mount Pleasant (loc. 46), are also clearly younger than the common granitic rocks of these regions.

A similar relationship of tin deposits to leucocratic, muscovite-bearing granite in Malaya was noted by W. R. Jones (1925). The relationship of tin deposits to the youngest phases of multiple intrusions is clearly apparent in many parts of the world (Hosking, 1968, p. 273). Outstanding examples of this are the Nigerian and Rondonia (Brazil) tin fields where tin deposits are in large part related to ring-dyke structures (Jacobson *et al.*, 1958; Sayão Lobato 1967; Kloosterman 1967).

However, tin deposits of the subvolcanic and fumarole types, including some Canadian tin-bearing massive sulphide deposits, appear to be volcanogenic, and some are apparently unrelated to granitic rocks. The host rocks and associated hypabyssal or epizonal intrusions are generally of rhyolitic or dacitic composition, and they contain more tin than basic and intermediate rocks extruded earlier in the volcanic cycles (see under "Host Rocks" below). Thus they mark a geochemical culmination analogous to that in the compositionally similar intrusive rocks. On the other hand, some modern tin-bearing fumarole deposits are associated with andesite or even basalt, and their contained tin may have been derived directly from sources in the mantle.

Host Rocks and Metamorphic Environment

Most of the world's tin deposits are emplaced in quartzose and argillaceous sedimentary rocks or in granitoid or rhyolitic rocks that have invaded them (Ferguson and Bateman, 1912, Table 2). A few-notably pipe deposits in Thailand, Malaya, and China, and some lodes, as in Tasmania and the Lost River area, Alaska-are in dominantly calcareous rocks. In Canada the Cordilleran and Appalachian tin belts are underlain mainly by arenaceous and argillaceous rocks. In the tin-bearing Precambrian pegmatite districts also, the host rocks are wholly or partly of related sedimentary types (see Table 1). The world wide association with this class (type) of rock suggests that granitic rocks in tin-bearing areas and their contained tin may have originated at least in part by assimilation of tin-bearing sialic rocks in the course of granitization processes. The possible relationship of tin deposits in some areas to original sedimentary concentrations has been discussed by Garnett (1967), Stoll (1965), and others. Ljundgren (1962) suggested that the richness of the Bolivian tin belt is largely a result of the concentration of tin in the Paleozoic sediments derived from the tin-rich western part of the Brazilian Precambrian Shield. A sedimentary origin for some concordant magnetite skarns in Malaya that contain appreciable quantities of tin has been suggested by one geologist, according to Bean (1967). In Canada at Linklater Lake (loc. 34) tin-bearing granopegmatite stringers are apparently confined to a band of iron-formation. Stratabound iron ores of Grängesberg, Sweden average 105 ppm tin, much of it as cassiterite, and essentially stratabound ironformations and massive sulphide ores in many places contain abnormal amounts of tin (see under "Types, Massive Sulphide Deposits" below).

In this connection the possible remobilization of tin in fossil placer concentration is relevant. Jaskolski (1963) considered the stanniferous schists of Isergebirge, Poland, to have originated in this way. The widespread and close association of cassiterite and wolframite may be partly because both minerals are heavy and resistant to weathering and are commonly concentrated together in placer deposits. Such deposits might have been assimilated or remobilized in a subsequent cycle of granitization, the tin and tungsten thereafter being redeposited together because of their similar geochemical behaviour (see Chapter II).

In this connection the view, as expressed by Kittl (1957) and others, that tin and other metals that are concentrated with the anionic "mineralizers" during granitization are *excluded* from the resulting granite, may have some validity. It is difficult to reconcile with the commonly observed concentration of tin deposits within the upper parts of granitic bodies, as in Cornwall and numerous other places. However, an impervious capping like the Cornish "killas" might confine early-formed fluids to the upper contacts of cupolas of large granitic bodies. On solidification of the cupolas, the fluids would penetrate into any available fractures and deposit their metals during cooling and reaction with the host rocks.

The dominant concentration of major tin deposits in relatively young orogenic belts (Hercynian, Mesozoic, and Tertiary) is commonly attributed to opportunities for repeated reconcentration during several erosional, orogenic, and intrusive cycles. However, substantial concentrations of tin are found in some Archean massive sulphide deposits of Canada for which only a single volcanic-intrusive cycle can be recognized. These deposits are associated with rhyolitic extrusive and hypabyssal rocks in "greenstone" belts, which consist mainly of basic and intermediate volcanic rocks, although some of them are emplaced in intercalated sediments. They are of supposed volcanic origin. From the data in Table 6 it appears that intermediate and sialic volcanic rocks of the Canadian Shield contain about as much tin as their intrusive counterparts in the earth's crust, and probably about as much as sedimentary rocks do. They would therefore appear to be equally potent as a source of the tin in the deposits, whatever the mechanism by which it may have been concentrated. It is parti-

cularly interesting that the South Bay mine (loc. 32(a)), the strongest known concentration of tin in Canadian massive sulphide deposits, is in the Birch–Uchi belt, which has the highest level of tin of all the greenstone belts analyzed (Table 6). Assuming a content of 0.25 per cent tin and 14 per cent zinc in the orebody, the ratio of concentration in the orebody to concentration in associated volcanic rocks (average) is about the same for tin as for zinc. The second highest in tin is the Timmins–Noranda greenstone belt, where also tin is appreciably concentrated in a number of massive base-metal sulphide deposits, including the Kidd Creek mine where preparations for recovering tin are under way. Near both the South Bay and the Kidd Creek deposits, rhyolitic rocks sampled by the writer were found to contain up to 8 ppm tin. This suggests a progressive increase in tin concentration toward the orebodies.

It would appear from scanty references that regional metamorphism is not a characteristic feature of the host rocks in tin-rich parts of the Paleozoic and later folded zones that contain the bulk of the world's tin deposits. Moussu (1962) referred to these as "zones plissés non ou peu metamorphiques." In Canadian post-Precambrian regions, tin occurrences are predominantly in rocks of relatively low metamorphic grade, especially the veins with tinsulphide minerals and without cassiterite. In the Cordilleran Region they are notably rare in the areas of regionally metamorphosed complexes. In the Precambrian tin-bearing pegmatite districts the grade of metamorphism is somewhat higher than in the Appalachian and Cordilleran regions where the deposits are mainly of pneumatolytic or hydrothermal types. This evidently reflects the greater depth of emplacement of pegmatites, as well as a deeper level of erosion. In rare cases, tin-bearing massive sulphide deposits in the Shield are strongly metamorphosed, but this appears to be a local phenomenon. It is noteworthy that the Precambrian tin occurrences are practically all in the Archean Slave and Superior Provinces and are virtually absent from the younger Churchill and Grenville Provinces which are characterized by relatively high grade metamorphism. Lithium-bearing pegmatites are likewise extremely unusual in the latter provinces, whereas berylliferous pegmatites are present and fairly common in the Grenville Province. Tin and lithium are more volatile elements than beryllium, as evidenced by the different techniques required in spectrographic analysis, and this may have a bearing on their relative distribution. A possible explanation of the selective distribution of tin and lithium deposits among the structural provinces of the Shield may be found under "Precambrian Shield," Chapter IV.

Tectonic Environment

Most of the tin deposits of the world are in distinctly linear zones within major orogenic belts that are intensely folded and faulted, and dominated by intrusive (or more rarely extrusive) rocks of granitic composition. Many others, mainly pegmatite deposits, are in Precambrian cratonic Shield areas whose development involved similar tectonic processes.

The tin-bearing linear zones are generally marked by granitic intrusions that have distinctive characteristics and a relatively high tin content. These may be related to particular stages of geosynclinal development, subsequent deformation, or deep subcrustal fractures, many of global dimensions.

The relationship of mineral deposits to intrusion in the development of a geosyncline as a mobile belt was discussed by Bilibin (1955). He suggested that tin deposits are only likely to be associated with ultra-acid potassic granites, alaskites, aplites, and pegmatites of the middle stages, and with granites and their hypabyssal and volcanic equivalents of the late stage. The theory has been applied to the Appalachian Region of Canada by McCartney and Potter (1962). There tin deposits are associated with late stages of Devonian granitic intrusions, and the most significant deposit (Mount Pleasant) represents a final, post-Devonian extrusive

event. In the Canadian Cordilleran Region tin deposits are mainly confined to a miogeosynclinal, largely anticlinorial belt that forms the eastern boundary of the major Cordilleran eugeosyncline. The associated granitoid intrusions are generally somewhat younger (late Cretaceous) and more acid (siliceous and potassic) than those of the western part of the eugeosyncline. Copper deposits, mainly associated with basic volcanic rocks, characterize the western eugeosynclinal part of the Cordilleran belt in Canada, as in South America (Peru and Chile). According to Smirnov (1946), a similar relationship exists in Siberia, where copper deposits characterize the Pacific coastal zone, whereas most of the tin deposits lie farther inland. Tertiary rhyolitic effusives and hypabyssal rocks with associated tin deposits, mainly in southwestern United States, Mexico, and Bolivia, represent the latest stages of granitic development in the Cordilleran–Andean belt. Wood tin probably derived from rhyolitic rocks, in placer deposits in Yukon Territory, may also belong to this age-group.

The apparent preference of tin deposits for the miogeosynclinal (shelf) environment is widely recognized. In Malaya the tin-rich granites of the Main Range are in a western miogeosynclinal belt, bordered on the east by a eugeosyncline. Solomon et al. (1972) stated that in the Tasman Metallogenic Province of eastern Australia, potassic granites tend to be concentrated near the foreland areas of successive Paleozoic continental margins. However, in the Pacific Ocean ore belt of eastern Asia some tin deposits, mainly polymetallic "cassiteritesulphide" deposits, are related to Mesozoic, Tertiary, and younger volcanic effusions and intrusions, apparently in a eugeosynclinal environment. Onikhimovskiy (1972), with reference to the Amur region of the maritime belt, stated that quartz-cassiterite and pegmatite deposits are associated with granitoid intrusions in platforms and anticlinoria, in areas of thick crust marked by negative gravity anomalies. Cassiterite-sulphide deposits on the other hand are mostly associated with downwarps and synclinoria in areas of thin crust (presumably the belts of positive gravity anomalies mentioned in this context). The cassiterite-sulphide deposits are dominantly subvolcanic types, associated with Mesozoic and Tertiary volcanic and hypabyssal rocks, dominantly andesitic or dacitic. Recent volcanoes in Kamchatka and Japan that deposit appreciable amounts of tin in fumarolic incrustations (see under "Classification, Fumarolic Deposits") are also dominantly andesitic. These fumarolic deposits, and by analogy, the cassiterite-sulphide deposits farther west in the Maritime province are considered to be derived more or less directly from mantle material associated with oceanic crust in a zone of active subduction. The pegmatitic and "cassiterite-quartz" deposits of the interior belts on the other hand are considered to have resulted from the loss of mafic and heavy metal components during upward passage of metal-bearing magma through the thick layers of continental crust overlying deeper parts of the subduction zone. Active young island-arc and fringing young metallogenic belts with subvolcanic tin deposits comparable to the Asiatic ones appear to be lacking in western North America, at least between Alaska and Mexico. The three subparallel belts of anomalous tin concentration in sulphide deposits outlined by Burnham (1959) may include older and weaker counterparts. However, tin mineral occurrences within his westernmost belt in California are mostly pegmatite or cassiteritequartz types associated with Cretaceous granite, while those in Nevada are fumarole-type deposits in Tertiary rhyolite (Killeen and Newman, 1965). The distribution of tin in western United States is clearly too complex to be explained by a simple subduction model such as that of Sillitoe (1972), although his model is compatible with the general eastward succession: iron, copper, lead-zinc, molybdenum, tin, in North and South America.

The geoanticlinal environment was distinguished from the geosynclinal by Abdulayev (1964), with reference to tin deposits, and Moussu (1962) mentioned tin deposits in "anticlinals" in Cornwall and France in connection with concordant intrusive granites. In Bolivia, intrusions with associated tin deposits follow anticlinal zones parallel with the axis of the Andes

(Ahlfeld, 1936). In the Canadian Cordillera the main tin-bearing districts have anticlinal structures. The anticlinal environment evidently favours the emplacement of granitic intrusions and the development of open fracture systems.

Pronounced changes in direction or "bulges" in tin-bearing fold belts appear to be especially favourable for deposits. An outstanding example is the Bolivian tin belt, which is deflected around the westward bulge of the Brazilian Precambrian Shield (Ahlfeld, 1967). In the Kootenay District of the Canadian Cordillera (loc. 22) the trend of fold structures is deflected around the eastward bulge of the Nelson batholith. Noble (1970) called attention to the importance of bulge structures in metallogenesis in the western United States. One predictable effect of this type of deformation on folded strata is the development of a profusion of longitudinal or tangential faults, analogous to the longitudinal-shear failure of a wooden beam.

Faults are conspicuous features of the important tin-producing regions of the world, and have been important factors at every scale and stage of structural development. According to currently prevalent theories the fundamental tectonic factors leading to the formation of tin and most other epigenetic metallic deposits are the major subduction zones and the major rift structures of the world. One of the best-documented examples of the subduction-zone environment is the circum-Pacific belt in northeast Asia, and the outstanding example of the rift environment is the East African Rift Zone, where tin deposits are related to granitic rocks of the Bushveldt Complex (Hunter and Lenthall, 1971).

According to Itsikson et al. (1960), the gross structure of the Pacific Ocean Ore Zone in northeast Asia is determined by a first-order fracture zone, inferred from seismic and earthquake data, that follows the boundaries of the Pacific Ocean depression, and is marked by deep-water trenches. The zone dips toward the continent at angles of 35 to 60 degrees, is traceable to a depth of 700 km, and is interpreted as a subduction zone along which the continental blocks move over the oceanic platform. The chains of Recent and Tertiary volcanoes to which the inner Pacific Ocean metallogenic belt (Kamchatka, Japan, etc.) is related, are about 200 km west of the deep-water trenches and correspond to the 100 km depth contour on the subduction zone. They presumably mark the shallowest of the second-order transregional and lesser-rank fractures that develop at various depths above the subduction zones. and are linked with the folding stage of evolution of the belts. Such fractures are thought to provide conduits for magmas of various types with characteristic metallic associates corresponding with their varying depths of formation near the subduction zones. Such transregional fractures on the outer (continental) side of the Pacific belt are commonly marked by belts and chains of granitic intrusions that determine the occurrence of separate metallogenic provinces (Itsikson et al., 1960). In this outer zone belts and chains of granitic intrusions controlled by deep fractures, with associated tin deposits mainly of the quartz-cassiterite type, extend 2500 km from the Yana to Chukotka Peninsula and onward into Alaska (Matveyenko and Shatalov, 1963).

In the subvolcanic tin province of southern Bolivia the arrangement of volcanic necks shows a connection with faults that parallel the axis of the Andes (Ahlfeld, 1936). In the Kootenay District of the Canadian Cordillera (loc. 22) the emplacement of some Cretaceous granitic bodies has evidently been guided by major east-northeasterly trending transverse faults. One or more of these may date from Precambrian times, since one such fault appears to have been involved in the emplacement of Precambrian granite to which the tin-bearing Sullivan deposit may be related. In southern New Brunswick the line of granitic satellites and rhyolitic volcanic bodies (including the Mount Pleasant deposit, loc. 46) clearly marks a zone of deep structural weakness and probably of fault movement. The tin concentrations appear to be localized where this zone is intersected by transverse faults.

The single-stage subduction-zone hypothesis postulated by Sillitoe (1972), Onikhimovskiy (1972), and others and outlined above is obviously incapable of explaining the complexity of multiple metallogenic belts. The outer Asian Pacific tin belt is generally older (Mesozoic and older) than the inner oceanic belt. It would seem to be related to an earlier subduction zone with its cycle of island arc, geosynclinal evolution, and eventual stabilization and welding to the continental nucleus.

Post-intrusive faults or movements on pre-existing faults may give rise to pegmatites or lode-tin deposits, depending on depth and stage of differentiation of parent intrusions, by tapping deeply buried still-liquid late differentiates or concentrations of residual fluids. In Seward Peninsula, Alaska, the tin lodes, although generally related to tin-rich granite, are more closely related to a narrow zone of normal faults that were formed after consolidation of the exposed granite (Sainsbury and Hamilton, 1968). In parts of the Erzgebirge district the relationship of tin lodes to granite contacts is structural rather than genetic, the mineralization being derived from deeper parts of the crust (Stemprok, 1967).

In some places fracture systems have probably determined the locations of the granitic cusps or cupolae in which the tin deposits are mainly emplaced (Hosking, 1968, p. 296).

In Bolivia the greatest breadth and intensity of mineralization is in a zone of major transverse faults (the Arica Elbow Line) where the tin belt turns from north to northwest (Ahlfeld, 1936, 1967). The great longitudinal and depth extension of fault systems in major tin districts is well illustrated in the Malayan peninsula and Indonesia. In Malaya and Thailand wrench faults of large displacement cut and offset granitic intrusions. They form part of a complex pattern of faults to which tin mineralization is related (Burton, 1965). The great southeast Asian tin belt with which these structures are associated also extends far into Burma and into Indonesia.

Another major tectonic development bearing on world distribution of tin deposits is continental drift. The outstanding example is the widely presumed separation of South America and Africa, in which the tin belts and geological characteristics of Brazil and of western Africa are remarkably similar.

Classification of Tin Deposits

The classification of tin deposits is a complex problem, and has not been greatly emphasized in the literature. Among recent published classifications are brief summaries by Sainsbury (1969) and Boyle (1969). Hosking (1965) presented an interesting graphic illustration of types of tin deposits (Fig. 2). Existing classifications are based on various criteria, including form, geological environment, mineralogy, and inferred temperature and mode of deposition. However, they are dominantly genetic in viewpoint, the main emphasis being on temperature and depth of formation as inferred from the geological environment. Among primary deposits, the distinction most easily and commonly made is between pegmatites and various lode and replacement deposits of pneumatolytic and/or hydrothermal origin. Placer deposits, economically the most important of all, are treated as a separate group.

Table 11 is a compromise attempt to distinguish the more significant Canadian types and relate them as nearly as possible to a composite of existing schemes for world deposits. It is not a complete or authoritative list but is intended to give some indication of the variety of known types in terms of environment, petrology, mineral association, and conditions of formation. The foreign examples listed are those best known to the writer but are not necessarily the most important or best representatives of the types. The following explanatory notes are intended to clarify and supplement the information given in the table.





TA	BLE 11	Types	of tin deposits				
No.	Туре		Form	Typical host rock	Essential or gangue minerals	Metasomatic associated minerals	
1.	magmatic ? disseminations	3	disseminated	granite			
2.	pegmatites		dykes	metasedimentary, metavolcanic, granitoid	feldspar, quartz, muscovite	tourmaline, topaz, fluorite rare	
	(albitite)				albite, quartz, muscovite		
3.	skarn contact metam	orphic	irregular incl. pipes	calcareous-dolomitic	Ca-Mg-Fe aluminosilicates magnetite	fluorite, axinite, danburite, ± tourmaline	
4.	PNEUMATOLYTI HYDROTHERMAL quartz-feldspa greisen	C- r-	veins, lodes	generally granite	quartz K-feldspar (secondary)	adularia, albite, ± fluorite, topaz, ± Li micas	
	quartz-greisen		veins, lodes, pipes	quartzose and argillaceous schist, granitic	quartz	muscovite, Li mica, topaz, fluorite, ± tourmaline	
	quartz-tourmal (hydrothermal	line)	veins, lodes veins, lodes	argillite, quartzite argillite, quartzite	quartz quartz	tourmaline, chlorite	
			veins, lodes veins, lodes	argillite, quartzite argillite, quartzite	calcite rhodonite		
5.	subvolcanic		lodes, pipes	rhyolitic, volcanic, granitic, hypabyssal		fluorite, topaz, chlorite	
6.	fumarole		vein and segregation	rhyolitic, volcanic, and hypabyssal		fluorite, chalcedony, kaolin, hematite	
7.	. massive sulphide		concordant	argillite, quartzite rhyolitic, volcanic, and sedimentary	quartz, Fe Zn Pb sulphides Fe Zn Pb Cu sulphides	tourmaline	
8.	metamorphose fossil placer (?	d)	quartz lenses	argillaceous and limy schist	(chlorite-garnet zone)	chlorite	
9.	placer deposits	3	eluvial residual alluvial beach and marine				

	Associated metals and metallic			
Tin minerals	minerals	Canadian examples	Foreign examples	References
cassiterite	Ta-Nb, Zr, etc.		Zaiiplaats, South Africa Nigeria	Hunter and Lenthall, 1971 Hosking, 1965
cassiterite	Li, Be, Ta-Nb, etc. W, Mo, etc., rare	Yellowknife (24) Winnipeg R. (30) Linklater L. (34)	Africa, Brazil, etc. (numerous) Carolinas, U.S.A. Plack Hills, S. Dakota	Pratt and Sterrett, 1904 Roberts and Rapp, 1965
cassiterite wodginite		Red Sucker L. (28) Winnipeg R. (30)	Diack mills, S. Dakota	
cassiterite malayaite hulsite-paigeite stannif, ludwigite	W (scheelite± wolframite) Be(helvite, chrysoberyl) Mo, various sulphides	Cassiar (16 a,o,t)	Lost River, Alaska; Devonshire; Malaya; etc. Brooks Mt., Alaska; Stevens Co., Washington;	Sainsbury, 1964 Sharkawi and Dearman, 1966 Bennett, 1962
stannif. Fe-Al silicates		Cassiar (16u)	U.S.S.R. Czechoslovakia; Thailand, Devon	Nekrasova <i>et al.</i> , 1965 Dadák and Novák, 1965 Hosking, 1965
cassiterite			Erzgebirge, U.S.S.R. Cornwall (South Crofty)	Stemprok, 1964, 1967 Cronshaw, 1921
cassiterite stannite	W (wolframite) Mo, Be (beryl), local, Li micas	Yukon Tungsten (161) Atlin (15) Burnt Hill (44)	Most numerous and important lode types	
cassiterite stannite canfieldite stannite	arsenopyrite, Cu Zn etc. sulphides minor Zn-Pb-Cu-Ag sulphides major Pb,Zn,Sb sulphides	New Ross (48) Mt. Pleasant (46) (in part) Dublin Gulch(4j) Sullivan(22k) Snowflake(22a); numerous minor in Cordillera Coal River(14)		
franckeite ?	V, Zn, Co, Cu	Tsitsutl Mt. (18)		
cassiterite stannite other tin sulphosalts	various sulphides and sulphosalts, notably silver	Mt. Pleasant(46)	Bolivian tin-silver belt U.S.S.R. Japan	Ahlfeld (1967) Matveyenko and Shatalov, 1963 Miyahisa, 1961
cassiterite {notably wood tin}		Possible origin wood tin in Yukon placers(3, etc.)	Bolivia Mexico, Southwest U.S.A. U.S.S.R.	Ahlfeld, 1967 Sainsbury, 1969 Knopf, 1916 Matveyenko and Shatalov, 1963
cassiterite cassiterite stannite		Sullivan (22k) Bathurst area (45) Kidd Creek (36) South Bay (32a) Geco (35) Lac Dufault (37)	Bleikvassli, Norway Boliden, Sweden	Vokes, 1963 Hübner, 1972
cassiterite	Fe sulphides, Co, Ti		lsergebirge, Poland	Jaskolski, 1963
cassiterite	numerous heavy and resistant minerals of rocks and of primary tin deposits	North Cordillera (3) (4a,i,j) (15) (insignificant)	Congo, Nigeria, Brazil, etc. widespread Malaya, Indonesia, Thailand Cornwall, etc.	

1. Magmatic Disseminations

This term was used by Hosking (1965, p. 268) with reference to widespread disseminations of cassiterite in granite in the Jos-Bukuru and Odigi fields of northern Nigeria. The term implies that the cassiterite crystallized entirely as a primary accessory mineral from the granite in which it is found. No first-hand description has been found by the writer. A possible primary origin seems to be implied but is not stated. However, W. R. Jones (1925) suggested that some disseminations in granite are primary. Some cassiterite in the Bobbejaankoop granite of the Zaiiplaats area, South Africa, has been considered primary (Hunter and Lenthall, 1971).

The "disseminated deposits," as referred to by Sainsbury (1969), are in altered granite, commonly associated with fluorite, topaz, and tourmaline. These are probably not of primary origin, as the tin may have been introduced. Such deposits are not important direct sources of tin but have contributed substantially to placer deposits in some areas.

2. Pegmatites

Pegmatites are important sources of tin in the Precambrian Shield terrains in the Congo, South-West Africa (Karibib), Rhodesia (Kamativi) and some other parts of Africa, and in Brazil. Cassiterite is generally recovered as a co-product or byproduct along with tantalum and columbium minerals, lithium minerals, beryl, and occasionally wolframite. Many productive pegmatites are in areas of deep tropical weathering, as in Minas Gerais, Brazil, and can be mined cheaply because they are completely decomposed. Elsewhere, selected parts of large undecomposed pegmatites are rich enough for economic exploitation. Pegmatites have supplied or contributed to tin placer deposits in many Precambrian Shield areas.

In Paraíba and Rio Grande do Norte in northeastern Brazil, cassiterite is concentrated mainly in muscovite-quartz selvages in contact with the quartz-mica schist wall-rocks. This mode of occurrence is analogous to that of greisen deposits. At the Joazireinho pegmatite, cassiterite occurs in albitized feldspar close to the wall-rocks.

Albitization is a characteristic feature of tin-rich pegmatites in many areas, including South-West Africa, Rhodesia, and some Canadian occurrences, and the albite-type pegmatites are shown in the table as a subgroup. In Canada tin concentrations at Red Sucker Lake (loc. 28) and in the Winnipeg River District (loc. 30) are in albitized parts of pegmatites, generally in greisen-like muscovitic contact zones. In these, the tin has probably been redistributed by autometasomatic albitization processes. At the Chemalloy Minerals Limited mine wodginite (a tin tantalate) is concentrated in an albitite unit probably of similar origin. In the tin-bearing pegmatites in the Yellowknife-Beaulieu District (loc. 24), cleavelandite a platy form of albite, presumably secondary—is prominent and may be the dominant feldspathic constituent.

3. Skarns

Contact metamorphic or skarn deposits are not clearly distinguishable genetically from high-temperature pneumatolytic-hydrothermal deposits. However, as they are emplaced in limestone or dolomitic rocks, they are rather rare and have unusual and complex mineral assemblages. Only a few have been of much economic importance.

Tin or tin-bearing minerals in addition to cassiterite include tin-sphene (malayaite), borates (hulsite-paigeite and tin-bearing ludwigite), and tin-bearing aluminosilicates (andradite garnet, epidote, and ferroactinolite). Magnetite may contain appreciable amounts of tin (Bean, 1967). Fluorite is generally abundant, and boron minerals commonly so. The characteristic boron minerals are axinite and danburite, but tourmaline may also be present. Magnetite and/or metallic sulphides may be abundant or scarce. Scheelite is the 'characteristic tungsten mineral but wolframite may be important. The presence of tin, fluorine, and boron minerals in skarns may be largely related to imposition of quartz-feldspar metasomatism and / or greisenization on the typical skarn assemblage (Zharikov, 1970). Thus skarns may grade into pneumatolytic-hydrothermal deposits.

Prominent representatives of this class are pipe deposits in limestone in Malaya, Thailand, China, and South-West Africa (Duong, 1969). Other skarn deposits with various, generally irregular forms are found in Cornwall (Sharkawi and Dearman, 1966), Czechoslovakia (Dadak and Novak, 1965), the U.S.S.R. (Nekrasov *et al*; 1965, and elsewhere. In Malaya, a tin-bearing magnetite skarn may have been originally a sedimentary deposit (Bean, 1967).

In North America some deposits in the Lost River area, Alaska, have been referred to this class (Sainsbury, 1964). Perhaps more typical are skarns in the nearby Brooks Mountain area, which contain hulsite and paigeite. A tin-bearing magnetite skarn in Washington State was described by Bennett (1962). In Canada, skarn-type tin occurrences in the Cassiar District (loc. 16) include a notable occurrence of stanniferous andradite, epidote, and ferroactino-lite.

4. Pneumatolytic-Hydrothermal (and Hydrothermal)

The pneumatolytic-hydrothermal group, as generally described, embraces the great bulk of the world's vein and related types of tin deposits, except the Bolivian subvolcanic group. It is the main source of tin production, from both lode and derived placer deposits.

These "pneumatolytic-hydrothermal" deposits are too varied to be profitably described as a single group. They embrace a wide range of deposits, with differing characteristics, apparently mainly the result of different temperatures and conditions of formation. They may have formed partly through pneumatolytic, partly through hydrothermal processes (Stemprok and Vanecek, 1965). Actually, uncertainty about the distinction between the processes is implied by the term "pneumatolytic–hydrothermal."

In Table 11 an attempt is made to subdivide the group according to special characteristics and in the general supposed order of decreasing temperature of deposition.

Feldspathic veins and lodes are shown as a separate subgroup because of their controversial origin. They are generally thought to reflect a fairly high temperature of deposition, although the feldspar (notably adularia) is probably secondary and has replaced both quartz and greisen minerals (Stemprok, 1967).

Quartz-greisen veins with muscovite, locally lithia micas, and usually topaz and more or less fluorite, are the most important representatives of the class. Tourmaline may be present or absent. Muscovite is typically concentrated along the walls of the quartz veins and these selvages commonly contain most of the cassiterite. Wolframite is a very common associated mineral and several Canadian representatives are essentially wolframite deposits. Beryl is occasionally prominent. Of associated sulphide minerals, arsenopyrite is most characteristic; others include chalcopyrite, sphalerite, molybdenite, and stannite.

Tourmaline is generally scarce in, or absent from Canadian quartz-greisen deposits, and Canadian deposits that are conspicuously associated with tourmaline and lack typical greisen minerals are shown in the table as a separate subgroup. A good example of this group is the important Sullivan deposit, although it is classified primarily as a massive sulphide deposit.

With the appearance of stannite and increasing abundance of sulphide minerals, quartzcassiterite griesen deposits grade into stannite-sulphide deposits. Lateral and vertical zoning relationships have been noted in many places, with cassiterite-greisen deposits closer to

associated granites than are the stannite-sulphide deposits. Where both types occur together, as at Mount Pleasant (loc. 46), the deposits are commonly described as "telescoped." In the table, Canadian quartz-sulphide deposits with stannite and without cassiterite, fluorine-bearing, or boron minerals, are listed separately. They are regarded as low-temperature hydrothermal deposits. Those sulphide-tin occurrences with carbonate minerals rather than quartz as gangue (Coal River and Tsitsutl Mountain) would seem to be clearly of lowest temperature hydrothermal origin.

5. Subvolcanic Deposits

The term refers principally to the tin-silver lode deposits in Tertiary rhyolitic volcanic and hypabyssal rocks in southern Bolivia, which have generally been considered a distinct class. They are also referred to as "epithermal and xenothermal deposits" (Hosking, 1965, p. 262). Most characteristic are veins and impregnations in lavas and breccias. They contain cassiterite (commonly acicular) and various tin, base-metal, and silver sulphides and sulphosalts, their complexity being attributed to telescoping as a result of near-surface deposition. The Mount Pleasant deposit (loc. 46) resembles these in some ways, although the volcanic host rocks are of mid-Paleozoic age. Some deposits in Tertiary volcanics in Japan have been compared with the Bolivian subvolcanic type (Miyahisa, 1961) and some "subvolcanic" deposits with wood tin in various parts of the U.S.S.R. and elsewhere may be of related origin.

Tin-bearing massive sulphide deposits in "greenstone" belts in the Canadian Shield and Appalachian Region have features in common with this type. They are genetically related to rhyolitic phases of basic-intermediate-acid volcanic cycles. Most of them, notably the Kidd Creek (loc. 36) and South Bay (loc. 32a) deposits have appreciable silver as well as tin, though their contents of both are much lower than the Bolivian deposits.

6. Fumarole Deposits

This term was applied by Sainsbury (1969), following Ahlfeld (1958), to a peculiar type of small deposit in Tertiary rhyolitic lavas. They are described as fracture fillings containing cassiterite associated with specular hematite, chalcedony, cristobalite, tridymite, etc. The wall-rocks are generally kaolinized. Many such deposits contain wood tin (Knopf, 1916; Newhouse and Buerger, 1928; Ahlfeld, 1967). They are found in various parts of southwestern U.S.A., in Mexico, and in Bolivia and Argentina. In southern Bolivia they are distinguished from the subvolcanic-type deposits in the same region (Ahlfeld, 1967, p. 300).

The writer believes that wood tin in Yukon gold placer deposits (loc. 3, etc.) may have formed by fumarolic action connected with associated rhyolitic volcanic or hypabyssal rocks. The mineral constituents are thought to have been deposited in the colloidal state from aqueous solutions below 360°C (Knopf, 1916). W. M. Little (1960) referred to these deposits as the "Mexican volcanic class." He thought they might be truly pneumatolytic deposits, formed under fumarolic conditions.

It is clear that some presently or recently active volcanoes have transported tin and that it, together with other constituents, was in the gaseous state at the time of deposition in the "sublimates." Before the sudden release of pressure on issuing from the vent, the emanations may have been superheated aqueous liquids, but gases other than H_2O , including CO_2 , NH_3 , H_2S , SO_2 , CH_4 , HCl, and Hf were apparently predominant in many volcanic emanations (White and Waring, 1963). Some data on recorded tin occurrences in volcanic sublimates and on associated gases follow:

Locality	Reference	Sn	F	Cl	в	S	CO ₂	Other Metals
Showa Shinzan, Hokkaido Japan	Onikhimovskiy, 1972	0.18 max						
Showa Shinzan, Hokkaido Japan	White and Waring 1963, p. 24	0.03	238	728	22			Zn, As, Ag
Showa Shinzan, Hokkaido Japan	White and Waring 1963, p. 25	0.04– –0.18	14.9	1.9				
Showa Shinzan, Hokkaido Japan	White and Waring 1963, p. 23		195	772	21			
White Island, New Zealand	White and Waring 1963, p. 22	-0.5	290	3400		0.5		Pb, Cu, Zn
Etna, Sicily (Fissure fumarole, 1863) (basalt)	White and Waring 1963, p. 21					19	81	
Etna, Sicily (Fissure fumarole, 1863) (basalt)	Corsini, 1967	cassiterite	5					
Valley of Ten Thousand Smokes (Katmai and near, Alaska)	White and Waring 1963, p. 17		11–17	22–87		61 H ₂	8	
Valley of Ten Thousand Smokes (fumarole No. 1)	Lovering, 1957	0.02						Pb, Zn, Cu
Kamchatka, U.S.S.R. Golovin (andesite dome) and Mendeleyev volcanoes Kunishir Island	Onikhimovskiy, 1972 5	0.18						

The composition and temperature of gases seems to be a function of time since evolution started, and of distance from the volcanic throat. Fumaroles of explosive craters are higher in sulphur than those on effusive vents, which are higher in HCl and HF. Some volcanic gases, as at Showa Shinzan and Katmai, are notably rich in fluorine. HF is generally less abundant than HCl, apparently, but fluorine analyses are scarce. There is a suggested increase in HF:HCl ratio with increased silica content in lavas. At Showa Shinzan the ratio is nearly constant in gases above 300°C but is much lower in cooler gases (White and Waring, 1963). Gas temperatures above 700°C have been recorded at Showa Shinzan. Boron has not been determined directly in gases, but fumarolic condensates indicate boric-hydrochloric acid ratios up to 1:20 (White and Waring, 1963). Steam from hot springs at Larderello, Italy, and several New Zealand localities are especially rich in boron. Hot brines from deep boreholes in the Salton Sea area, California, are very rich in boron, and also in lithium and potassium.

It appears that different gases are in equilibrium with different rock types. H_2 is a maximum in gases associated with basaltic lavas; total sulphur and especially SO_2 with silicic lavas (White and Waring, 1963). In northwestern Nevada, agpaitic effusives are enriched in tin (Kovalenko and Finko, 1971). It is noteworthy that fumarolic products relatively rich in tin at Kamchatka, Showa Shinzan, and White Island are associated with andesite or andesite–dacite (Onikhimovskiy, 1971, 1972). This is taken to indicate that the tin is derived from the mantle. Mount Etna is a basaltic volcano.

Tin minerals have not been reported in volcanic sublimates except at Etna, where cassiterite was reported among the fumarolic constituents (Corsini, 1967). At fumarole No. 1 in the Valley of Ten Thousand Smokes, tin, lead, and zinc were most abundant in the innermost zone of incrustation, associated with opaline material, hematite, and magnetite (Lovering, 1957). Most lead was in the form of PbSO₄ and most zinc as a soluble salt. The associa-

tion of tin with opal and hematite is similar to that of typical "Fumarolic" deposits in Tertiary lavas. Tin may have been deposited in the form of colloidal SnO_2 , capable of segregating into macroscopic accumulations before solidification and thus producing wood tin.

7. Massive Sulphide Deposits (see Table 13)

These deposits are grouped as a separate class mainly because of the special status of the Sullivan mine as the only long-established Canadian tin producer. Recovery of tin from the Kidd Creek orebody (loc. 36), expected to begin by the end of 1973, will make it the largest North American tin producer. Other massive sulphide deposits in Canada, notably the South Bay deposit (loc. 32a), and elsewhere contain significant amounts of tin as cassiterite and (or) stannite, and also dispersed in the base-metal sulphides. Tin is not, to the writer's knowledge, recovered from other massive sulphide deposits, but with the advent of new discoveries and improved recovery techniques it seems likely that such deposits will become increasingly important as sources of tin in the future.

The "Massive Sulphide" deposits discussed here are essentially stratiform stratabound bodies that consist of banded or mixed sulphides mixed with, and locally interbanded with, variable but generally subordinate amounts of detrital gangue mineral grains. Their mode of formation is controversial, but they are now commonly supposed to have been deposited at the surface or sea floor under pressures not much higher than atmospheric. Many are underlain by or grade stratigraphically downward into zones of lower grade pyritic or pyrrhotite-bearing "disseminated" or "vein" ore that is obviously not "stratabound." These zones are commonly marked by extensive alteration, fracturing, brecciation, etc. Where apparently absent, they may have been detached during subsequent movement. Such zones are taken to represent the channelways through which ore-forming materials reached the surface. In this concept, the origin of the ore materials is not essentially different from that of hypothermal and other classes of "hydrothermal" deposits.

The class may be subdivided into volcanic-stratabound and sedimentary-stratabound. Deposits of the volcanic subclass are almost everywhere associated with rhyolitic or other alkali-siliceous rocks interbedded with more basic volcanic rocks, and thought to mark the end stage of basic-intermediate-acid volcanic cycles. The rhyolitic rocks are commonly fragmental, but massive lavas and supposedly hypabyssal intrusive phases are present in some places. However many, including Kidd Creek and South Bay are near margins of sedimentary depositional basins, and the sedimentary-stratabound deposits like Manitouwadge (but not Sullivan) are commonly in sedimentary depositional basins surrounded by volcanic rocks. Again excluding Sullivan, iron-formation is commonly represented in sedimentary-stratabound assemblages, notably at Manitouwadge. Grängesberg is an iron oxide deposit exclusively. At Boliden and Broken Hill some sulphide bodies grade laterally into iron-formation. Iron ore deposits much richer in tin occur in Malaya (S. Singh, pers. com.). Iron-formation is fairly common also in the volcanic-sedimentary belts that contain the rhyolite-associated massive sulphide bodies, but is mostly associated with the mafic volcanic facies. "Sulphide iron-formation," i.e., massive pyritic deposits with negligible base metal content and commonly accompanied by bands of chert, graphitic horizons, etc., are generally more closely related to economic base-metal massive sulphide deposits. They may be deep-water stratigraphical equivalents of the oxide iron-formations. According to one theory, pre-existing pyritic iron-formation provided the source of sulphur to precipitate the base metals in some deposits.

Massive sulphide bodies are more or less, often highly, deformed. In some cases major deformation, metamorphism, and igneous intrusion have followed deposition of the sulphides,

but pre-existing structural situations are inferred as the fundamental controls in providing channelways for the ore-bearing fluids as well as the associated extrusive and intrusive rocks themselves.

Deposits of the volcanic association are generally less metamorphosed (though more or less affected by metasomatism and hydrothermal alteration) than those of the sedimentary association, and some are almost undeformed. In these deposits the ore metals are commonly thought to be genetically related to the volcanic process. The anomalously high tin content in the rhyolitic host rocks of some of them, notably South Bay (loc. 32a) and Kidd Creek (loc. 36), suggests that this applies also to tin. Indeed the unusually high tin content of the South Bay deposit can be correlated with a relatively high over-all tin content in the volcanic rocks of the belt in which it lies (see Table 6). These deposits therefore appear to be most closely related to the subvolcanic type of tin deposit. The silver content of several is notably high, for Archean massive sulphide deposits, although it is low in comparison with the Bolivian tin-silver ores.

Many tin-bearing deposits of the sedimentary association are in assemblages that include volcanic rocks and are probably also closely related in space and time to volcanic activity. However, some other differences are apparent, at least in the deposits listed here (Table 13). The sedimentary deposits are generally characterized by strong metamorphism and deformation of both host rocks and ores, and well-developed recrystallization and replacement phenomena. Most but not all are close to granitic intrusions and associated with pegmatite bodies. Cordierite, usually associated with gahnite, is a common metamorphic mineral in the gneisses bordering the orebodies. These minerals are also prominent near some volcanic types (e.g., the cordierite-bearing rock "dalmatianite" in northwestern Quebec). At Manitouwadge cordierite and gahnite are abundantly and closely associated with cassiterite in tinrich mineralized "quartz-biotite hornfels," especially near granite and pegmatite contacts. The abundant cordierite and other ferromagnesian minerals indicate that the original sedimentary beds were rich in magnesium as well as aluminum, probably as montmorillonite. Montmorillonite, having the highest adsorptive capacity of all the clays (Krauskopf, 1955), might have taken up enough zinc from the sea water at the time of deposition to account for the gabnite as well as enough tin to account for the cassiterite in the metamorphosed rocks.

Further concentration within the thermal aureole might have resulted from outward diffusion of tin and other elements from pre-existing bedded rocks during granitization and pegmatization. In such deposits this may have been the dominant source of tin in the deposits.

Moreover, some deposits in dominantly sedimentary assemblages have associated tourmaline, others fluorite; and apatite (generally considered to be derived from sedimentary phosphates) is characteristically fluorine-bearing. In the Bathurst area (loc. 45) several deposits contain cassiterite, and are suggestively close to granitic masses, some of which have beryl, molybdenite, and tungsten minerals associated with them. These features suggest a genetic affinity with the pneumatolytic-hydrothermal type of deposit. The Sullivan deposit (loc. 22k) shows marked concentration of tin in certain zones, which have distinct characteristics of pneumatolytic-hydrothermal deposits associated with tourmaline. It is noteworthy that the nearest exposed granitic bodies are the only known Precambrian ones in the region, and as such are broadly contemporaneous with the ore. Furthermore, prominent pegmatitic phases contain abundant tourmaline, locally beryl, and are anomalously high in tin.

8. Metamorphosed Fossil Placer(?)

The "schistes stannifères" of the Isergebirge district in Poland occupy a stratigraphic zone several metres thick in a series of ancient crystalline chloritic schists intruded by Hercynian granite. The zone extends intermittently for some 14 kilometres. It consists of chlorite-garnet schists believed to have resulted from metamorphism of originally argillaceous and limy sedimentary rocks.

Within the zone cassiterite occurs principally in small quartz veins cutting the schist. It is accompanied by sulphides, apparently mainly of iron, and secondary iron-rich chlorite believed to have resulted from hydrothermal alteration of garnet and biotite. Cobalt and titanium minerals are also present.

Because of this complex association, and the confinement of the zone to a specific stratigraphic horizon, it is concluded that the mineralization could not have been introduced by normal hydrothermal processes. The deposits are believed to represent an ancient placer, enriched in iron and other heavy elements.

It is suggested that the sulphur and part of the iron could have come from pyritiferous sediments. Migration and reconstitution of the constituents is attributed to regional meta-morphism dating from the Hercynian (or Caledonian) orogeny.

The deposits may exemplify an important factor in the genesis of many tin deposits (see under "Host rocks and metamorphic environment"). Garnett (1967) suggested the possible sedimentary origin of some flat-lying, conformable tin deposits in South Africa and Indonesia. Bean (1967) described some concordant magnetite-sulphide deposits in Malaya that contain appreciable amounts of tin. Hosking (1965) mentioned ancient placers with a little cassiterite (Banket, South Africa, and conglomerates of Zambia), none of which contain economic concentrations of tin¹.

9. Placer Deposits

Placer deposits account for about 75 per cent of the world's tin production, of which a major part comes from the Thai–Malay peninsula and Indonesia. Among other important areas of placer production are Nigeria, the Congo, and Brazil (especially the Rondonia tin field). Tin placer deposits are natural gravity concentrations of cassiterite from eroded primary deposits and locally contain important amounts of other heavy minerals such as wolframite and columbium-tantalum minerals. They are further concentrated and recovered by essentially similar mechanical–hydraulic operations. Deposits containing as little as 0.25 pound of cassiterite per cubic yard are worked economically by dredging methods in Malaya.

Tin placer deposits are intricately classified according to various environmental criteria (see Fig. 2). Residual placers, enriched in cassiterite and other heavy resistant minerals commonly grade downward, in areas of deep tropical weathering, into decomposed primary bodies, as in Minas Gerais, Brazil. These are mined essentially as placer deposits. Eluvial deposits generally grade downslope into alluvial deposits and these, if close to a coastline may grade downstream into beach, estuarine, and marine placers.

The relationship of beach and marine placers to present shorelines is complicated by changes in sea level during the Pleistocene epoch. Some nearshore deposits formed during glacial advances are now marine placers, whereas some formed during interglacial periods are now in raised beaches.

No placer deposits have been worked for their tin content in Canada, but minor amounts of cassiterite have been recovered from some gold placer deposits in the northern Cordilleran Region, notably at Clear Creek (loc. 4(a)), Haggart Creek (4(i)) and Atlin (15).

¹A minor paleoplacer tin concentration occurs in Canada in Churchill Province (Chapter IV).

Physical-Chemical Processes in Formation of Tin Deposits

Genetic Relationship to Granite

A genetic relationship between tin deposits and granitic rocks is inferred from the geochemical nature of tin and from its distribution in igneous rocks (see Chapter II). According to the general theory, tin is largely excluded from the early-formed feldspars, quartz, and ferromagnesian minerals of crystallizing igneous rocks, but enters into the lattices of late ferromagnesian minerals, notably biotite, of the granitic stage. Any tin not so fixed will remain in late crystallates and/or residual "volatile" fluids, together with the typical anionforming elements and complexes such as fluorine, hydroxyl, carboxyl (CO_3^{-2}) boron, phosphorus, and sulphur. Depending on the concentration and composition of such fluids, temperature—pressure conditions, and development of fractures, it will be either precipitated in situ or transported and deposited in pegmatites, skarns, or pneumatolytic or hydrothermal lode deposits.

Pegmatites, tin-bearing porphyry dykes, etc., presumably formed in fractures that tapped late crystallates, still fluid because of the fluxing action of contained volatile components. In the case of non-pegmatitic vein and lode deposits, fractures presumably tapped remaining residual fluids free of rock-forming minerals.

Much of the tin that is fixed in the lattices of rock-forming minerals may also be remobilized and reconcentrated by the same volatile fluids during postmagmatic metasomatic processes. Barsukov (1957) suggested that most of the tin in pneumatolytic-hydrothermal deposits was released from biotite by fluorine metasomatism and transported as a complex of the form Na₂Sn (OH,F)₆.

The foregoing is essentially a magmatist view of the relation of tin deposits to granitic rocks. In an alternative view, expressed by Kittl (1957) and others, tin and other metals are concentrated with the volatile anionic components during granitization and largely *excluded* from the resulting granite. It seems at least theoretically possible that ore-bearing fluids identical with so-called "residual" fluids from granitic magmas might form in this way. Granitization or related metasomatic processes may have been important in the concentration and mobilization of tin from sedimentary or other source rocks, as discussed under "Host rocks and metamorphic environment."

The actual relationship of tin to granite probably lies somewhere between these extremes, depending mainly on the relative partition of tin between silicate and aqueous phases of granitic magma. Owing to the common association of tin with fluorine-bearing minerals, the effect of fluorine and its relationship to chlorine seems especially important. As most metallic chlorides are readily soluble and more or less volatile, and chlorides are among the most abundant components of fluid inclusions in the minerals of base metal sulphide deposits, discussion of the origin of these deposits has centred around the role of chlorine in hydro-thermal systems. On the other hand, the very common association of tin with fluorine-bearing minerals suggests a dominant role for fluorine in the concentration of tin from associated granitic bodies.

The ability of fluorine to lower the melting temperature of siliceous melts is well known. Wyllie and Tuttle (1961) found that at 2750 bars pressure the temperature of beginning of melting of granite in the presence of 4.3 weight per cent HF solution is 605° C, 65° C lower than in the presence of H₂O alone. Although much has been written on physical-chemical controls in the concentration of tin, most of it appears to be speculative. In comparison with abundant data on the physical-chemical parameters of the major base metals in hydrothermal solution, firm data on the behaviour of tin appear to be scarce. For example, Holland

(1972) showed from experimental evidence that partition of some divalent metals, notably Mn and Zn, into the aqueous phase coexisting with a silicate melt increases with the chloride content. This is generally believed to be the case also with the other common base metals. Holland speculated that tin would likewise be strongly partitioned toward the chloride-rich aqueous phase, and suggested that "highly saline hydrothermal solutions are excellent scavengers of tin from granitic melts." He conceded, however, that the frequent association of fluorite and topaz with tin and tungsten suggests that fluorine may be an important component of solutions from which these were deposited. Smith (1947) assumed that some salts which have "homopolar properties, for example fluorides which can form fluorosilicate and fluoroaluminate groups" would be concentrated together with chlorine in the aqueous phase coexisting with a silicate liquid. However, in later experimental work he found that fluorine is more strongly partitioned toward the melt than to a coexisting aqueous phase (Smith, 1948). Burnham (1967) showed that fluorine, unlike chlorine, is strongly partitioned toward the silicate melt rather than a coexisting aqueous phase. He reported that in a melt of representative material from the Harding pegmatite, which contains 0.64 per cent F, the weight per cent of F in the melt was three times as high as in the aqueous phase. In a melt of material from the Spruce Pine pegmatite (which contains negligible F) and chloride solution, the proportion of chlorine in the aqueous phase was at least five times as high as in the melt. Burnham (1967) also conceded that a sufficiently high fluorine content (as was probably present in some fluorite-rich granites) would promote mutual solubility of silicate melt and aqueous phases.

Some geochemical data suggest that tin is relatively enriched in granitic rock during granitization. In the absence of firm data to the contrary it may be suspected that in the presence of sufficient fluorine at high temperature, tin is bound largely in un-ionized "homopolar" fluoride complexes, and is concentrated together with fluorine in the silicate melt until close to the end of the crystallization process. This might explain the relatively close association of tin in pneumatolytic-hydrothermal deposits with granitic bodies, in contrast with the more tenuous association of the common base metals. If the tin is derived in large part by anatexis of pre-existing rocks, it should therefore be much more soluble in magmas formed where fluorine is abundant, whereas the divalent metals might be partitioned predominantly into a coexisting chloride-rich aqueous phase. The latter would be largely immiscible with the silicate melt from the start, and would be readily transported to sites of deposition comparatively remote from the granitic intrusions. At the same time any base metal-chloride components incorporated into the granitic melt, whether of primary (juvenile) or secondary (anatectic) origin would be largely separated, together with the bulk of dissolved water, during the main crystallization stage.

If the separation process involved "resurgent boiling" resulting from decreasing external pressure during ascent of the magma (Burnham, 1967), tin bound in a fluoride complex would tend to remain in the silicate melt, because of the comparatively low volatility of tin and other fluorides (Krauskopf, 1964). However, as temperatures above 705°C (the boiling point of SnF₄ at atmospheric pressure) have been recorded in some volcanic gases in which fluorine is comparatively abundant, and tin is appreciably concentrated in associated fumarolic encrustations, it appears likely that tin was transported as a volatile fluoride or fluoride complex in some fumarolic deposits (see under "Classification"). If, however, the ratio of chloride to fluoride were very high, tin might be quantitatively volatilized as a chloride during resurgent boiling, as it is "the only common metal for which a chloride of higher valence seems to be a possible vehicle for high-temperature transportation" (Krauskopf, 1964). This appears to be the most plausible mechanism for the formation of those "fumarolic" deposits in which fluorine minerals are commonly lacking. Iron oxides are intimately associated with

cassiterite in these deposits, and the volatile chloride $FeCl_3$ is stable only in the presence of high chloride concentration (Krauskopf, 1964). Under hydrothermal conditions, in the absence of fluorine, tin would undoubtedly be concentrated in an immiscible chloride-rich aqueous phase together with the base metals. This was probably the case in tin-bearing base metal sulphide deposits.

The tin capacity of granitoid rocks depends in part on the amount of tin that can be dispersed in the ferromagnesian minerals. This is determined by the amount and composition of these minerals, which in turn depend on the composition of, and the temperature-pressure conditions in the magmas from which they crystallized. In general it seems to be the common belief that the tin capacity of biotite increases with increase in the iron-magnesium ratio, the "iron index" (Fe/Fe + Mg) of Levashev et al. (1971). Durasova (1967) found that the tin content of biotite increases with increase in the ratio of Fe^{+3} to $(Fe^{+2} + Mg^{+2})$. At the same time the ratio of O^{-2} to $(F^- + OH^-)$ increased, thus compensating for the increased positive charge involved in substitution of Sn^{+4} for Fe⁺³. Therefore an abundance of fluorine in the granitic melt should act to impede the isomorphous substitution of tin in biotite, and therefore promote the retention of tin in the fluid fractions, hence leading to higher primary concentrations. Simultaneous or successive crystallization of two ferromagnesian silicates greatly complicates the picture. Levashev (1971) found that in granitoids of the East Iul'tinsk area, the ratio of tin content in biotite to its content in amphibole varies considerably. For the same iron index, the highest tin concentrations are found in the amphiboles with the highest alumina and fluorine contents. In the biotites the correlation between tin and fluorine was found to be inverse. This might explain the higher tin content in amphiboles than in biotites in granitoid rocks of the Dzhida area (see Table 8). In alkalic rocks, tin is largely dispersed in ferromagnesian minerals, notably alkaline amphiboles (see Chapter II).

The presence of lithium, an element commonly associated with tin in pegmatites and pneumatolytic-hydrothermal deposits, can increase the dispersion of tin in ferromagnesian minerals, especially in the presence of fluorine. The most commonly visualized form of coupled substitution of lithium is $(Li^+ + F^- = Mg^{+2} + O^{-2})$. However, an equally plausible form should be $(2Li^{+1} + Sn^{+4} + 6F^{-1} = 3Fe^{+3} + 60^{-2})$. The tendency of lithium to lower the melting point and increase the fluidity of silicic melts is well known from its application in the ceramic industry.

Potassium, in view of the common association of tin with potassium-rich granite, would appear to have an influence on the possible concentration and behaviour of tin in alkalialuminosilicate melts. Actually, there is not complete agreement that granites with associated tin deposits are especially potassium-rich. The ratio of $K_2O + Na_2O$ to MgO + CaO in granites of Australia with associated tin deposits is 15, but the same ratios for Bolivian and Cornish granites is 1.5 and 3.7 respectively (Hunter and Lenthall, 1971). The relation of tin deposits to potassium is evidently complex, the main connection being that both tend to be concentrated in the late stages of granitoid intrusion. It may be more directly related to the dispersion of tin in micas. Levashev et al. (1971) found that the content of tin in biotites of the same alkalinity group, the ratio of Mg+Fe to Al being constant, increases with increase in total alkalinity and decreases with increase in the activity of potassium in the melt. Thus, by restricting the dispersion of tin in biotite, an abundance of potassium may promote the concentration of tin in residual fluids and the formation of primary tin deposits. Barsukov and Kuril'chikova (1966) found experimentally that complexing of tin as an alkali hydroxofluorostannate is favoured by the presence of potassium in the solutions, although the presence of sodium also makes formation of the complex easy.

Other alkali cations of significance in the relation of granite to derived tin deposits are rubidium and barium. The Rb content is generally higher, and the K:Rb ratio lower, in granites with associated tin deposits than in unmineralized granite (Tauson and Kozlov, 1972; Stavrov, 1971). The theoretical explanation is that Rb is bound up with volatile components, particularly fluorine, and concentrates in residual melts. Its concentration relative to potassium is therefore an index to the extent of differentiation of the magma. Similarly, the Ba:Rb ratio is lower in mineralized than in unmineralized granites because barium enters largely into the early feldspars of granitoids (Tauson and Kozlov, 1972). In the Canadian Cordillera, the Rb content (and the K content) increase rapidly and the K:Rb ratio decreases eastward from the Coast Range (i.e. toward the tin belt) (Culbert, 1972).

Anionic components, other than fluorine and chlorine, of importance to tin in granite magmas are boron and phosphorus, because of their relative abundance and, especially in the case of boron, close relationship to many tin deposits. Boron, like fluorine, is concentrated in silicate melts coexisting with aqueous fluids at high temperatures (Smith, 1963). According to Lyakhovich (1965) "Boron apparently does not participate directly in the transport of tin. ... Possibly accumulation of cassiterite in tourmaliniferous granite is a result of capture of most of the iron by tourmaline . . . preventing formation of mica, the principal concentrator of tin, and favouring precipitation of cassiterite." However, prevention of formation of biotite or other ferromagnesian minerals could not account for the observed higher content of tin in many tourmaline-bearing granites. Boron is a main constituent of hulsite, paigeite, and tin-bearing members of the ludwigite-group minerals, and of some alkali fluoroborate minerals of the avogadrite-ferrucite group $(K,Cs)BF_4$ -NaBF₄. Tin is very commonly and intimately related to tourmaline in high temperature deposits, and tourmaline may contain several hundred ppm tin as well as appreciable amounts of fluorine (see under "Mineralogy," Chapter II). The possible existence of fluoroborate complexes of tin in granitic magmas should be considered.

Phosphorus, like boron and fluorine, is mainly concentrated in the silicate phase of crystallizing magma, and occurs chiefly in apatite. Apatite may contain possibly several hundred ppm tin (see under "Mineralogy," Chapter II), and commonly contains as much as 3.5 weight per cent fluorine (Smith, 1963). A tin-rich apatite in which Sn_9Ca substitutes for Ca_{10} has been synthesized (McConnell and Foreman, 1966). Stannous fluoride is advertised as the active ingredient in some dentrifices, which suggests that tin may enter the apatite of tooth enamel together with fluorine. Possibly the connection between tin and phosphorus in magmatic fluids is also more than incidental.

The chemical relationship of tin to sulphur is known only at comparatively low temperature (the hydrothermal stage), and is discussed in the following section and in Chapter II. However, some tin sulphides melt at temperatures as low as $640^{\circ}C$ (Scherbina, 1972). Although the existence of soluble tin thiosulphide complexes at temperatures below $300^{\circ}C$ is well established, tin has strongly lithophile (oxyphile) tendencies at high temperature and is probably not bound to sulphur in the magmatic environment.

The role of carbon dioxide in magmatic fluids must be considered because of its abundance in some volcanic gases and fluid inclusions. According to Smith (1963), CO₂ is generally abundant in fluid inclusions in high temperature quartz vein deposits with cassiterite, wolframite, scheelite, tourmaline, and topaz. It is so also in fluid inclusions in pegmatite deposits. Chlorides (mainly NaCl), on the other hand, are characteristically dominant constituents in mesothermal sulphide deposits. Brotzen (1959) considered CO₂ — (the most common component, next to H₂O of liquid inclusions in zoned pegmatites) — to be a predominant influence, with particular reference to segregation of quartz from feldspar and formation of quartz cores. The process is illustrated by the following general formula: SiO₃ $^{-2}$ + CO² = SiO₂ (silica gel) + CO₃ $^{-2}$. Progress of the reaction is favoured by the presence of potassium which, having a highly soluble carbonate, becomes mobile. Wyllie and Tuttle (1961) found that CO_2 raises the melting temperature of a granite-water system. According to Burnham (1967), the presence of CO_2 in the aqueous fluid in equilibrium with granite at 650°C and 6.0 kb has the effect of lowering the solubility of silica, alumina, and the alkalis, in that order, in the aqueous fluid.

According to Barsukov and Kuril'chikova (1966), the solubility of tin hydroxide in the presence of KHCO₃ and K_2CO_3 is very low, especially above 300°C, although it increases slightly at lower temperatures. Carbonate complexes are therefore not feasible as vehicles for the extraction or transport of tin from granite magma¹. On the contrary they would tend to reduce the solubility of tin, together with silica, alumina, and the alkalis in the aqueous phase and concentrate it in the residual silicate melt. Thus its effect on the partitioning of tin is similar to that assumed for fluorine.

The primary effect of silica in magmas is to exclude tin, which, as a complex-forming element, is unable to compete with silica for available oxygen (see Chapter II). Tin-bearing granites are commonly said to be highly siliceous but are not consistently so (Hosking, 1965; Rattigan, 1963). Probably granites with associate tin deposits are generally fairly rich in silica because they represent the late stages of igneous differentiation and approach the eutectic composition of alkali–silica–alumina melts. Silica in the form of orthosilicic acid solution can dissolve as much as 10–12 grams per litre tin as hydroxide at 25°C; this is probably due to the formation of compatible silica and tin hydroxide colloidal suspensions under the same conditions (Barsukov and Kuril'chikova, 1966). This suggests a possible mechanism for the association of colloform cassiterite with cryptocrystalline silica in fumarolic deposits. However, the solubility of tin hydroxide in the presence of silica was found to decrease sharply at 300°C. Tin silicate minerals are rare, and the possibility of tin-silicate complexes at magmatic temperatures is remote.

Transport and Deposition of Tin

The composition of fluids with which tin is concentrated and by which it is transported to sites of deposition is inferred mainly from the composition of certain minerals with which it is commonly found. These are minerals that contain anionic elements and radicals with which tin can combine to form volatile or soluble compounds. Precipitation from such compounds is supposed to have been effected by changes in physical-chemical conditions, such as falling temperature and pressure, acidity-alkalinity conditions, and reactions with country rocks. The ionic agencies most commonly considered to have been involved in the transportation of tin are hydroxyl (OH⁻⁻), fluorine (F⁻⁻), boron (B⁻⁻3), and sulphur (S⁻⁻2). Another ion seriously considered because of its abundance in natural (marine) waters is chlorine (Cl⁻). Theoretically possible modes of transport have been studied by experimental work, such as that of F. G. Smith (1947) and Barsukov (1957). Only the most plausible modes of transport are briefly reviewed here; further details regarding these and other possible modes may be found in the preceding section.

A chemical factor of major importance in the case of tin is its amphoteric nature. Depending on acidity-alkalinity conditions tin can act either as a metal or non-metal to form salts or ionic complexes. F. G. Smith (1947) has demonstrated that sodium stannate is soluble in alkaline solution up to at least 450°C, its solubility decreasing with decreasing alkalinity.

Another significant property of tin is the volatility of its halogen compounds at comparatively low temperatures. This has given rise to arguments whether tin was transported mainly in the gaseous state (pneumatolytic) or as a liquid (hydrothermal). The question has been discussed from various standpoints by F. G. Smith (1947), W. M. Little (1960), Krauskopf

¹Onikhimovskiy (1971) reported tin complexes with CO₃ but not HCO₃ ions at 300°C.

(1964), Stemprok and Vanacek (1965) and many others. As the boiling point of SnCl₄ at atmospheric pressure is only 114°C, transport as the volatile chloride would seem possible. Krauskopf (1964, Fig. 5) found that at 627°C, the partial pressure of SnCl₄ in equilibrium with cassiterite and tin sulphide is constant over the cassiterite field, whereas $SnCl_2$ decreases toward high oxidation states; SnCl₂ is the dominant gas except at high pressures of both O and HCl. At 827°C in the presence of high S and O, tin as SnCl₄ is restricted to very high HCl values. SnCl₂ is volatile at lower HCl concentration but less so than FeCl₂ and much less than the chlorides of copper, zinc, and lead. Thus tin, together with iron, would be condensed first from an ore fluid with high HCl initially, followed by Pb and Cu with traces of Zn and Ag. At 827°C with low S and O, the volatility of tin as SnCl² is greatly increased and that of Cu and Ag is decreased; with neutralization Cu and Fe would condense first, followed by Pb, Zn, and Sn. At 627°C with low S and high O, SnCl₂ is less volatile than Zn, Cu or Pb, but with high S and low O it is more volatile. At 427 C with high S and O, only Sn and a little Zn remain in the gas phase, and only at high HCl pressure; with low S and high O, Zn is somewhat more volatile at intermediate HCl ranges and Cu and Sn are appreciably volatile at high HCl pressure. Krauskopf concluded that "..., Fe₂Cl₆, CuCl₂, AuCl₃ and the higher chlorides of Mo, W, and U are well known volatile compounds but they are so unstable with respect to decomposition and hydrolysis that they could not be effective except at pressures of HCl or Cl_2 unattainable in ore fluids. Tin is the only common metal for which a chloride of higher valence seems to be a possible vehicle for high temperature transportation."

The boiling point of SnF_4 (705°C at atmospheric pressure), on the other hand, is well above the temperature range in which tin is believed to have been deposited in typical greisen lodes with abundant fluorine minerals. Fumaroles are the most obvious products of pneumatolytic transport, and temperatures above 705°C have been recorded in some volcanic gases (see under classification). However, it seems to be generally conceded that pneumatolysis may have played a part also in the development of tin-bearing pegmatites, skarns, and some greisen veins, although most lode deposits are considered to be dominantly hydrothermal in origin. According to Oelsner (1966), cassiterite in pegmatites is generally in compact short columns with little prismatic development or twinning; in pneumatolytic deposits twinning and complex forms are common but the prism is suppressed, whereas in hydrothermal deposits long, thin prisms and acute pyramids are common. On the whole, however, criteria for distinguishing the mineral products of the two processes are unreliable, and uncertainty about the state of the tin-bearing fluids is indicated by the commonly used term "pneumatolytic-hydrothermal".

Because fluorine-bearing minerals such as fluorite, topaz, and fluorine-rich muscovitic or lithia micas are so commonly associated with tin minerals, fluorine has long been considered the most important agent of transportation. Daubrée, in a classical experiment in 1849, synthesized cassiterite by the action of steam on stannic fluoride. This illustrates the fact that SnF_4 is unstable in the presence of hot water. Because the conditions of transportation are believed to be alkaline and hydrous, Barsukov (1957) argued that tin is most likely to be carried as a hydroxyfluorostannate of the form $(Na,K)_2Sn$ $(OH,F)_6$. With dilution and decreasing alkalinity, this compound is hydrolyzed. Tin is precipitated as SnO_2 , while resulting hydrofluoric acid reacts with the feldspars, etc. of the country rocks to form fluorite, topaz, and muscovite. If temperature and pressure decrease suddenly, cassiterite may be precipitated from solution in colloidal form. Probably for this reason, colloform cassiterite (wood tin) is common only in subvolcanic and fumarole deposits, which were deposited at shallow depth.

The role of chlorine in the transportation of ore-metals including tin in the gas state under various physical chemical conditions, has been discussed by Krauskopf (1964) (see above). An important role in the hydrothermal transportation of tin and other metals had been inferred from its presence in fluid inclusions, etc. The role of chlorine is not as perceptible as that of fluorine because it forms few minerals. Its metallic salts, for example $CaCl_2$, are mostly quite soluble and probably escape from the system. The precipitation agent of tin from chloride solutions, whether as cassiterite or sulphide mineral, is probably the sulphide ion (see below). In Bolivian ores, according to Turneaure (1971, p. 223), the ore fluid, as indicated by fluid inclusions, was a brine rich in NaCl. The salt content reached 46 per cent during the early quartz-cassiterite stage, but dropped to 10 per cent or less during the sulphide stage, while temperature decreased from 530 to 70°C. Transport as a chloride seems particularly appropriate for tin in presumably syngenetic volcanogenic massive sulphide deposits; it may be relevant also in the hypothetical concentration of tin in the bordering rocks of some metasedimentary-stratabound massive sulphides by granitization.

Because of the very common association of boron minerals (tourmaline, axinite, ludwigite, etc.), with tin deposits, boron has long been suggested as an agent in the transportation of tin. Emmons (1940) mentioned H_3 BO₃ as one of the "mineralizers." The association is especially marked in pegmatites, skarns, and other pneumatolytic-hydrothermal deposits from which fluorine minerals are absent. However, no specific tin-boron compound seems to have been suggested as a possible form in which tin can be transported. Lyakhovich (1965) reported a high degree of correlation between tin and boron in granitoid rocks in a tin-bearing district. He concluded that boron apparently does not participate directly in the transport of tin, but admitted that an antipathetic relationship between fluorine and boron minerals in tin deposits makes the hypothetical transport of tin as a fluoride complex unsatisfactory in such cases. Tin forms some borate minerals; some fluoroborates (not including any of tin) have been found as daughter minerals in fluid inclusions; and tourmaline may contain appreciable amounts of fluorine (as well as tin), thus masking its presence in the tourmalinized rock. It seems possible that tin might be associated with fluoroborate ions in solutions containing both boron and fluorine. In some Canadian deposits, such as the Sullivan mine (loc. 22k) and Dublin Gulch (loc. 4j), a genetic connection between cassiterite and tourmaline seems almost indubitable¹.

The occurrence of tin as compound sulphide minerals in sulphide ores, especially where no fluorine or boron minerals are present, has led to much discussion of possible mechanisms for the transport of tin in sulphide complexes. F. G. Smith (1947) postulated the following equilibrium: $Sn^{+4} + 8OH^{-1} = SnO_2 + 2H_2O + 4OH^{-1} = SnO_4^{-4} + 4H_2O$

(acid solutions) (alkali solutions)

In high concentration of sulphide ion the corresponding equilibrium is:

 $8Sn^{+4} + 8HS^{-1} = SnS_2 + 2H_2S + 4HS^{-1} = SnS_4 + 4H_2S$

(acid solutions) (alkaline solutions)

i.e., stannic sulphide is soluble in strongly acid and strongly alkaline but not in nearly neutral solutions. However, in aqueous solutions containing the sulphide ion, the solid phase in equilibrium with neutral or weakly alkaline solutions is the oxide rather than the sulphide. That is, if a dilute solution of sodium thiostannate is boiled, tin oxide is precipitated. F. G. Smith (1947) found on the basis of experimental work that in the presence of Na_2S or H_2S in a sodium stannate solution heated to 450° C, cassiterite precipitated instead of tin sulphide, although crystals of pyrrhotite were co-precipitated in some runs. He concluded that (1947, p. 260) in aqueous solutions containing the sulphide ion tin is held partly as the stannate ion and partly as the thiostannate ion, according to the following equilibrium:

$$Sn S^{-4} + 4OH^{-} = Sn O_4^{-4} + 4HS^{-}$$

¹Tourmalinized footwall conglomerate containing 100 ppm tin from the Sullivan mine contains 0.11 per cent fluorine, more than 10 times the amount needed to transport this tin as sodium fluorostannate.

He reasoned (p. 263) that "since the solubility of stannic sulphide is much greater than that of stannic oxide in aqueous alkaline solutions, tin will tend to precipitate late in the sequence as thiostannate minerals, whereas cassiterite will precipitate early in the sequence." Nekrasov (1971) found that a number of tin sulphides ranging from SnS to SnS₂ could be synthesized under hydrothermal conditions with increasing sulphur-ion concentration, at any pH and temperature from 200°C to 500°C. However, at about 500°C even solutions high in S⁻² tend to precipitate SnO₂, especially in alkaline solution. Thus acid solutions and reducing conditions favour the formation of tin sulphides. In acid solutions at 200°C to 300°C under reducing conditions, sulphides may precipitate even with S⁻² concentrations as low as 0.01-0.5 moles per litre.

It seems relevant in this connection that cassiterite is the characteristic tin mineral in strongly metamorphosed and other high-temperature sulphide ores, commonly associated with pyrrhotite where the latter is present. Tin sulphide minerals are more common in lowtemperature deposits, or associated with copper, zinc, and lead deposited late in the paragenetic sequence in high-temperature deposits.

It may also be worth recalling that tin, together with Pb, Cu, As, etc. (but not Zn, Fe, or Mn—i.e., the Group II of systematic chemical analysis) is precipitated quantitatively as sulphides with H₂S in 0.3*N* HCl. It is redissolved with Group IIB as a polysulphide, Na₂SnS₃ by Na₂S_x solution, from which it is reprecipitated by adding HCl till just acid. Arsenic, if present, accompanies tin through these stages; this suggests one possible factor in the very common association of tin minerals with arsenopyrite.

Metasomatic Processes

The metasomatic processes chiefly involved in the formation of tin deposits are greisenization and albitization, which are of primary importance in pneumatolytic-hydrothermal deposits. They are most characteristic of the granitic host-rock environment, in which they are complementary, but greisenization was effective also in siliceous-aluminous sedimentary rocks.

Definitions of greisenization are variable and generally vague. Some writers include tourmalinization and silicification as integral parts of the process. The chemistry of the process is correspondingly indefinite, involving many physical-chemical and environmental factors. Ferguson and Bateman (1912) attempted to investigate the greisenization process by comparing the chemical composition of greisenized granites with that of the unaltered rocks.

As considered here, greisenization involves chiefly the formation of muscovite and topaz, and is attributed to the action of fluorine and hydroxyl-bearing residual fluids on potassium feldspar and biotite (in granitic rocks) or other aluminosilicate minerals (in greisen-veined sedimentary rocks). Fluorite is also generally prominent, and implies the availability of calcium from plagioclase, etc. or from calcareous wall-rocks. Lithium, if present in the fluid complexes, tends to become fixed in lithia micas (Turner, 1949). Fixation of fluorine and hydroxyl in the new minerals entails the breakdown of tin fluorine complexes perhaps of the Sn(OH,F)₆⁻² (Barsukov, 1957), and precipitation of tin as cassiterite. The reactions involved may be formulated, rather speculatively, as follows:

1.
$$[K_2O \cdot Al_2O_3 \cdot 6SiO_2] + 2Al_2O_3 + 4(F,OH) \rightarrow [4(F,OH) \cdot K_2O \cdot 3Al_2O_3 \cdot 6SiO_2]$$

K = feldspar Muscovite

2. $[4(OH,F) \cdot K_2O \cdot 6(Mg,Fe)O \cdot Al_2O_3 \cdot 6SiO_2] + 2Al_2O_3 + F \rightarrow [4(F,OH) \cdot K_2O \cdot 3Al_2O_3 \cdot 6SiO_2]$ Biotite + 6(Mg,Fe)O

Muscovite
- 3. $2[KAlSi_3O_8] + 2(F,OH) \rightarrow [(F,OH)_2Al_2SiO_4] + K_2O + 5SiO_2$ K-feldspar Topaz
- 4. $3[2H_2O \cdot Al_2O_3 \cdot 2SiO_2] + K_2O + 2(F,OH) \rightarrow [2(F,OH) \cdot K_2O \cdot 3Al_2O_3 \cdot 6SiO_2] + 6H_2O$ Kaolin Muscovite
- 5. $[H_4Al_2Si_2O_8] + 2F \rightarrow [F_2Al_2SiO_4] + SiO_2 + 2H_2O$ Kaolin Topaz
- 6. $[K_2O \cdot Al_2O_3 \cdot 6SiO_2] + Na_2O \rightarrow [Na_2O \cdot Al_2O_3 \cdot 6SiO_2] + K_2O$ K-feldspar Albite
- 7. $[CaO \cdot Al_2O_3 \cdot Si_2O_8] + 2HF \rightarrow [CaF_2] + Al_2O_3 + 2SiO_2$ Plagioclase Fluorite (anorthite component) 8. $[CaO \cdot Al_2O_3 + 2HF \rightarrow [CaF_2] + Al_2O_3 + 2SiO_2$
- 8. $[CaCO_3] + 2HF \rightarrow [CaF_2] + CO_2 + H_2O$ Calcite Fluorite

From (1) and (2) it is clear that conversion of K-feldspar or biotite into muscovite requires a relative increase in alumina. Some may be provided by the breakdown of calcic plagioclase, as in (7), but in most cases some must be introduced. Ferguson and Bateman (1912) noted that an increase in aluminum is a common result of greisenization. The introduced aluminum may be in the form of an aluminofluoride complex.

Muscovite can be formed from kaolin according to (4) by fluorine metasomatism without addition of Al. This may account for the large development of muscovite on the borders of quartz-greisen veins in contact with argillaceous wall-rocks. The potassium necessary to effect this conversion might be provided by the conversion of K-feldspar into topaz, as in (3), or by the albitization of K-feldspar, as in (6)¹. The combination of (6) and (4) may explain the strong development of muscovite at the contact of albitized pegmatites with aluminous wall-rocks. The transformation of K-feldspar into topaz, as in (3) releases a large amount of silica, as would also the rather dubious change of kaolin into topaz (5), and leads to the common development of quartz-topaz greisen assemblages. Chlorite, also a common mineral in greisen veins, is evidently one of the decomposition products of biotite.

In greisen-veined granite, according to Barsukov (1957) greisenization decreases with depth, giving way to a strongly albitized zone in which feldspars are converted to albite. Potassium released from K-feldspar in the process goes mainly to form the muscovite of the greisen zone but, under certain conditions, may give rise to new feldspar, both in the greisen and in quartz veins.

Stemprok (1967) considered the postmagmatic metasomatism of granitic intrusions in the Erzgebirge district to have taken place in a series of stages. An early potassium metasomatism was followed by albitization and in turn by greisenization accompanied by deposition of cassiterite. In some places a second stage of potassium metasomatism and albitization followed greisenization and resulted in the deposition of new feldspars in veins and greisens. Such feldspathic veins have sometimes been described as pegmatites. Those of the South Crofty mine, Cornwall, probably originated in this way (Stemprok, pers. com. 1967). Subsequent stages involved "hydrothermal" deposition of sulphides, and final alteration of primary silicates to kaolin, sericite, chlorite, hematite, etc.

Kaolinization is especially characteristic of tin deposits that contain an abundance of fluorine-bearing minerals, and is considered to be the ultimate result of fluorine metasomatism in aluminosilicate rocks. Kaolin and other clay minerals replaced topaz and other greisen minerals and any residual feldspar. Turner (1949) cites other authors to the effect that "kaolin originates from SiO₂ or Al₂O₃ gels in neutral solutions free of alkali metals or in acid solutions containing alkali metals, at temperatures below 400°C." Sainsbury (1964) suggested

¹Kaolin itself commonly holds an appreciable amount of adsorbed potassium.

that in the Lost River area much kaolin formed by reaction between topaz, quartz, water, and the limestone country rock. Kaolinization is a prominent feature in Cornwall and Devon, also in the Erzgebirge and many other tin districts. At the Mount Pleasant deposit (loc. 46) the richest tin shoots are closely related to kaolin masses in topaz–greisen rock.

Boron metasomatism is also very common in tin-bearing districts, but not exclusively so, and it is doubtful whether boron is directly involved in the transportation of tin. In granitic or siliceous-aluminous sedimentary rocks tourmaline replaces the aluminosilicate minerals. In calcareous rocks the common mineral formed is axinite. Tourmaline is a characteristic mineral of many pegmatitic and pneumatolitic-hydrothermal tin deposits and environments, but is absent or scarce in others. In Nigeria and Rondonia (Brazil), for example, most important tin deposits are associated with "younger granites" which, unlike the older granites, contain topaz but very little tourmaline. In Canada, tourmaline is rare in most typical quartzgreisen deposits but is abundantly associated with tin deposits at Dublin Gulch (loc. 4(j)) and the Sullivan mine (loc. 22(k)). In the (Precambrian) Yellowknife District (loc. 24), tourmaline is rather scarce in the rare-element-bearing pegmatites but is common in older goldquartz veins.

Association with Other Metals, and Metal Zoning

The metals most commonly associated with tin differ according to type of deposit and are listed in Table 11. In pegmatite and pneumatolytic-hydrothermal deposits tin is usually in the form of cassiterite and is associated chiefly with other "lithophile" metals assumed to be concentrated in the residual fluids of crystallizing granite (Table 9).

In pegmatitic deposits the most common associated metals are lithium, beryllium, and tantalum and these may be the main products of mining. Some pegmatites, as in South-West Africa also contain important amounts of wolframite.

In pneumatolytic-hydrothermal deposits the most consistent and important associated metal is tungsten, usually in the form of wolframite. Cassiterite and wolframite occur together in quartz-greisen deposits in most producing areas of the world but zonal separations, both internal and regional, have been noted in many places. In some deposits where they occur together wolframite is considered to have formed before cassiterite, in others after. At Mount Pleasant (loc. 46) tin-rich zones grade downward into tungsten-molybdenum zones. In the southeast Asian belt, wolframite predominates in Burma, but tin increases southward and predominates in Malaya. Scheelite is comparatively uncommon except in skarn tin deposits.

Lithia micas are prominent in some areas, notably the Erzgebirge district. Beryllium minerals are occasionally prominent, as in the Lost River area, Alaska, and at the Burnt Hill mine (loc. 44). Molybdenite is fairly common in wolframite-cassiterite deposits where sulphide minerals are relatively abundant, and bismuth may be economically important. Of associated sulphide minerals arsenopyrite is the most widespread and characteristic.

With increasing abundance of sulphide minerals, pneumatolytic-hydrothermal deposits grade into hydrothermal ones. Cassiterite, if present, is most closely related to pyrrhotite and arsenopyrite, whereas stannite is mainly associated with zinc and copper sulphides, and stannite and chalcopyrite commonly occur together in exsolution patterns in sphalerite. Silver and tin are concentrated together in some districts, as in southern Bolivia and Mexico. In tin-bearing Pb-Zn-Ag deposits of the Canadian Cordillera both can be correlated with the presence of minor copper. Canfieldite occurs in some galena ores rich in both silver and tin. The tin-bearing massive sulphide deposits of the Canadian Precambrian Shield are also relatively rich in silver. A spatial relationship between tin and gold deposits has been noted in various parts of the world and may have some metallogenetic significance. In the northern part of the Canadian Cordillera most of the known detrital cassiterite occurrences are in gold placer deposits. This is at least partly because gold, not tin, was the metal sought by prospectors, and the presence of cassiterite was only recognized in the course of placer operation. However, in the Precambrian Yellowknife-Beaulieu District (loc. 24) the rare-element pegmatite belt borders on an important gold-belt. At the nearby Philmore–Yellowknife property (loc. 25), gold, tungsten and tin occur together. The important tin-bearing massive sulphide deposit at Kidd Creek (loc. 36) is close to the important Timmins gold deposits, which also contain significant amounts of scheelite. The South Bay tin-bearing massive sulphide deposit (loc. 32a) is near the Uchi Lake gold deposits, and the Lac Dufault deposit (loc. 37) is near the main Quebec gold belt.

Zoning relationships between tin and base metals have been noted in many tin districts. A well-known example is Cornwall, where tin and tungsten are concentrated in and near granite contacts, and are succeeded upward and outward in turn by copper, zinc, lead, and antimony minerals (Dewey, 1948).

Chapter IV

DESCRIPTION OF CANADIAN TIN DISTRICTS AND OCCURRENCES

This chapter contains summary descriptions of entire tin-bearing regions, and of districts which contain relatively compact groups of occurrences. Where necessary, these are followed by notes on individual occurrences. The latter are identified by numbers and letters in parentheses, corresponding to the locality numbers on Map 1352A and in Table 1. The notes on individual occurrences are in addition to the readily classifiable facts recorded in the table which are not in general repeated here.

Decision as to what constitutes an occurrence is of necessity arbitrary. On the one hand, some very small and low-grade occurrences have been included, since they document the existence of metallogenically favourable belts. Some, though considered dubious, are included because to omit them might suggest that they had been overlooked. On the other hand some, for example, lithium-bearing pegmatites containing 100 parts per million or more Sn have been omitted since only a few lithium-bearing pegmatites have been analyzed for tin, and the inclusion of those that have might be misleading. This illustrates the fact that a strictly geochemical (concentration) approach to a decision would fail because of inadequate sampling and analytical coverages.

Cordilleran Region

The Cordilleran Region, specifically the Western Cordilleran subregion, contains the largest number of tin occurrences of any geological province, and the only currently producing mine. It forms part of the circum-Pacific tin belt that extends through Alaska into Asia on the one hand, and through the United States into Mexico on the other (Sainsbury, Mulligan, and Smith, 1971).

Throughout the North American Cordillera the deposits are mostly associated with Mesozoic (mostly Upper Cretaceous in Canada) and Tertiary granitic intrusions, which characterize this part of the continent. In Canada, most of the known tin occurrences lie within a narrow, fairly consistent petrological, structural, and metallogenic belt that extends along the northeast fringe of the Western Cordilleran subregion, and is herein referred to as the "tin belt" (see Map 1352A). This fringe zone, and (*sensu stricto*) "tin belt," is underlain by chiefly Proterozoic and lower Paleozoic miogeosynclinal sedimentary rocks, more or less metamorphosed but otherwise generally equivalent to the less severely deformed rocks that underlie the adjacent part of the Eastern Cordilleran subregion. In this respect they contrast with Late Paleozoic and Mesozoic volcanic-sedimentary rocks farther west.

The northeastern boundary of this zone is most simply defined as the practical eastern limit of intrusive and metamorphic rocks. South of about latitude 60° this boundary follows the approximate course of the Rocky Mountain Trench, a major complex physical and structural break. North of latitude 60° the boundary, as above defined, veers abruptly northeastward to encompass the areas of granitic and metamorphic rocks that lie northeast of the Tintina Trench. This trench, a complex regional zone of faults, is similar to and follows the same general trend as the Rocky Mountain Trench but is neither co-linear nor quite parallel with it. The abrupt dislocation of the boundary near latitude 60° may be largely a result of right-hand strike-slip movement along the Tintina Trench, which Roddick (1967) postulated to be of the order of 240 miles. An offset of this magnitude would help to rationalize the hypothetical extension of the main tin belt southeastward from the McQuesten-Mayo District (loc. 4) to the Coal River occurrence (loc. 14), and its abrupt termination there. The possibility of such an extension is supported by evidence of anomalous tin concentration in the Mount Armstrong area (loc. 12) and at Sheldon Mountain (loc. 13). Some scheelitebearing skarns in the section, including the Canada Tungsten mine, are also slightly enriched in tin, and cassiterite has been found as microscopic inclusions in scheelite.

Within the main tin belt, the two largest groups of tin occurrences are on the fringes of the main granitic batholiths—the Cassiar–Omineca in the north-central part and the Nelson in the south. These are areas of extraordinarily severe deformation, for example, the "Kootenay Arc" structure in the south and the general disruption (*see below*) in the Cassiar District. In the McQuesten–Mayo District also there appears to be a relatively severe flexure centred in the area of Galena and Keno Hills. These districts have over-all anticlinorial structures and a profusion of longitudinal or "tangential" and cross-faults.

The Cassiar District (loc. 16) seems to be an area of breakup and divergence of the main tin belt. In addition to a hypothetical westward extension to the Atlin District and the assumed main eastward diversion to Coal River, a part of the belt may extend northwestward to Little Salmon Lake (loc. 11). This minor trend is indicated by anomalous tin concentrations in some granitoid bodies and skarns in the Teslin area and in a tourmaliniferous pegmatite and a molybdenite deposit in the Quiet Lake area.

In western Yukon southwest of the Tintina Trench, the occurrences are in areas characterized by hypabyssal and extrusive granitic and rhyolitic rocks of more or less definite Tertiary age. In addition to the Klondike placer district (loc. 3), several of these areas have been reported to contain wood tin. Three dubiously substantiated occurrences lie close to the Shakwack Trench—a major fault zone that passes through Kluane Lake and is co-extensive with the Denali fault zone of Alaska. These Tertiary hypabyssal deposits may be quasi-contemporaneous with post-magmatic activity connected with mineralization in the main tin belt.

Some of the other tin concentrations west of the main tin belt may be related to bridgelike extensions of the eastern granitic bodies, toward the Coast Range Intrusions—the Atlin District and the Tsitsutl Mountain and Hazelton areas, for example. The Atlin area lies near the nose of a body of late or post-orogenic alkali granite that is possibly related to similar granite phases in the Atsutla Range of the Cassiar District. Similarly, in the "Skeena Arch" in central British Columbia, the Omineca batholith appears to break up into a zone of disconnected intrusions extending westward. Some of these are rhyolitic types of possibly early Tertiary age. Some samples from the general area between Tsitsutl Mountain and Hazelton showed appreciable tin (F. Joubin, pers. com.). They are mostly from "rhyolite" stocks containing pyrite or pyrrhotite, and unlike the greisen type, resemble some tin deposits of Mexico and Bolivia.

Between the Cassiar District and the Fort Grahame-Finlay River area the tin belt passes through an area that is (1970) incompletely mapped and has probably not been extensively prospected. Southeastward from that area, the main tin belt is assumed to follow the main southeasterly structural and lithological trend of the Cordillera, although no tin occur-

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rences are known until the relatively tin-rich district of the Kootenay Arc is reached. This interval in general is characterized by metamorphic complexes with pegmatites, occasionally sparingly berylliferous, but with no major granitic batholiths. It lies opposite the Churchill structural province of the Precambrian Shield, in which tin occurrences are virtually un-known, and it seems possible that the nature of the Precambrian basement rocks has something to do with the lack of tin occurrences in this section. In this connection it may be significant that the relatively tin-rich northern part of the belt lies opposite the tin-bearing Slave Province of the Shield, and is much closer to it than the southern part of the belt is to the remainder of the exposed Shield. Furthermore, the tin-bearing Kootenay District in the extreme south lies opposite the Superior Province, where also tin occurrences are relatively abundant. Burwash and Krupicka (1970) distinguished the basement rocks east of the southern Cordillera (the "Assiniboia" block) from those of the "Athabasca" central zone and the "Liard" north block, on the basis of composition and metamorphism.

Some northeasterly trending major faults in Kootenay District may date from Precambrian time, since one of them seems to have been involved in the emplacement of Precambrian granite to which the Precambrian ore of the Sullivan mine may be related (see below). These northeasterly trending faults may reflect a northeasterly gain in the Precambrian basement, which may also be reflected in the northeasterly strike of old fold axes in metamorphic complexes like the Shuswap Terrane (Jones, 1959).

An outstanding exception to the general environment of Cordilleran tin deposits is that of the Blow River occurrence (loc. 1). The granitic rocks in this northwestern part of Yukon Territory are of Devonian age. As they apparently do not extend southward, they can not properly be considered as part of the Cordilleran belt. Another exceptional case is that of the Sullivan mine (loc. 22(k)). Both the lead-isotope ratios of the ores, and the K-Ar ratio of the nearest granitic body, a berylliferous pegmatitic complex somewhat enriched in tin, indicate a late Precambrian age.

Types of occurrences in the region include placer and alluvial concentrations, cassiteritebearing lodes with minor or no sulphides, and heavy sulphide deposits with minor cassiterite and(or) stannite. The eastern "fringe belt" of the Western Cordillera, which contains the tin belt, largely coincides with a lead-zinc-silver metallogenic province, whereas copper deposits characterize the eugeosynclinal part of the region farther west. The largest number of tin occurrences are in important lead-zinc-silver-producing areas, and many are actually minor tin concentrations in deposits of this type. This group includes the Sullivan mine, the only current Canadian producer of tin.

The preponderance of occurrences in the eastern miogeosynclinal zone of the Western Cordillera as emphasized in the preceding discussion, is the main evidence for its designation as a tin metallogenic province. It is also significant that sphalerites in which Warren and Thompson (1944) found the highest tin content are nearly all from this eastern belt. Other supporting evidence may be the fact that the main molybdenum producers Red Mountain, Boss Mountain, and Endako, which lie west of the tin belt, contain very little tin (4,3, and 7 ppm respectively by spectrographic analysis of mill-feed composites supplied to the writer). These are dominantly lithophile deposits in which a fairly strong tin concentration might be expected.

However, the presence of appreciable tin concentrations west of the belt is also significant. Strong traces of tin are present in ores of the CanAm copper-molybdenum property (lat. 49°10′, long. 121°02′), and cassiterite occurs in Tertiary conglomerate in Kings County, northwestern Washington State. It is quite possible that undiscovered valuable tin deposits may be associated with late leucocratic phases of granitic intrusions west of the "tin belt," for example, the Coast Range Intrusions.

(1) Blow River

According to H. S. Bostock (1951), three samples reported to be from the Blow-Porcupine River divide appeared to be heavy placer concentrates. One sample assayed 6.39 oz. gold and 66.8 per cent tungsten, and contained a crystal of cassiterite. The locality is one of several tungsten and molybdenum occurrences shown on Geol. Surv. Can. Map 10-1963. Others are farther northwest in the British Mountains and Old Crow Range. These are all associated with Devonian granitic plutons. Devonian conglomerates overlying corresponding granitic bodies in nearby parts of Alaska are known to contain cassiterite (Reed, 1968). Occurrence of tin in primary deposits associated with granite, and alluvial concentrations in the areas mentioned, are a reasonable probability.

(2) Sixty Mile River

The Sixty Mile River area is listed as a tin locality, although the reported finding of wood tin (W. Matzloff, pers. com.) in boxes at the old dredge near Glacier Creek is unconfirmed. The writer did not definitely identify any in concentrate from an amalgam barrel at Glacier Creek, but the sample contained 0.033 per cent tin by spectrographic analysis. This compares with 0.036 per cent in a sample from Wade Creek, about 24 miles west in Alaska, where the presence of both crystalline and wood tin has been documented (Mertie, 1936). Both localities are in the Birch Creek Schist and both contain a little cinnabar. The Sixty Mile area is at the edge of a Tertiary porphyry body, and the presence of cinnabar is itself suggestive of the sort of fumarolic action by which wood tin might have been formed (see Klondike District, loc. 3).

(3) Klondike District

The Klondike District is the most northwesterly substantial group of tin occurrences in the Cordilleran tin belt in Canada. Corresponding Alaskan occurrences form a belt through the Forty Mile, Eagle, and Circle districts.

The Klondike District (Fig. 3) extends from 2 to 35 miles southeast of Dawson and lies just southwest of the Tintina Trench (see Map 1352A, and general description, "Cordilleran Region"). All the tin is in the form of cassiterite of the colloform type known as wood tin. None has been recovered except for specimen or ornamental use. The occurrences are all minor concentrations in gold placer deposits, which have yielded more than 11 million ounces of gold.

The area was not covered by a continental ice sheet during the Pleistocene period. This permitted deep weathering, undisturbed accumulation, and preservation of gravel deposits from the Tertiary period. Of the various types of gravel deposits, the oldest and most note-worthy is the White Channel gravel, whose remnants form terraces or benches up to 300 feet above present valley bottoms. The benches are up to 150 feet thick and are conspicuously light coloured, consisting chiefly of quartz and leached schist fragments. Pay streaks near the base of the White Channel gravel form the material of most of the presently worked placer deposits, although the valley bottoms contained the fabulously rich early discoveries.

The area is underlain chiefly by quartz-mica-chlorite schist and micaceous quartzite (Yukon Group) of dubious age (Precambrian ?), cut by foliated granite, some ultramafic intrusions, and by sheared quartz-feldspar porphyry dykes. The Yukon Group has been subdivided into a Nasina "Series" and a Klondike Schist. The Nasina "Series" underlies the areas where most of the cassiterite has been found, most notably the ridge between Hunker



Creek and Klondike River. This ridge, especially between Germaine Creek and Last Chance Creek, is also the area in which leucoquartz-feldspar porphyry dykes outcrop most abundantly and in which Gleeson's (1970) eluvial samples contained the highest concentrations of tin (see Fig. 3). No quartz-feldspar porphyry dykes were seen, however, near the tin-rich parts of Dominion and Sulphur Creeks where Ray (1962) found fragments of wood tin, up to a maximum of 25 per cent in some non-magnetic heavy mineral fractions of concentrates. Cassiterite was found also in much of Bonanza Creek, although porphyry dykes are scarce or absent. A sample of black sand taken by the writer from a placer on upper Eldorado Creek was found to contain 0.05 per cent tin by spectrographic analysis, although no cassiterite was identified by microscopic study.

The granite of the Mount Burnham area is mostly gneissic, with pegmatitic phases and dykes which commonly contain tourmaline. It is a plausible source of tin but no concentrations have been found associated with it, although a sample of tourmaliniferous pegmatite was found to contain 12 ppm tin.

The typical quartz feldspar porphyry has a rhyolitic texture, with phenocrysts of glassy to smoky quartz, orthoclase, and sodic plagioclase up to $\frac{1}{8}$ inch long, and occasional muscovite and biotite flakes. The groundmass is a fine-grained mixture of these minerals, with accessory zircon, and locally significant amounts of colourless to purple fluorite, fine greenish tourmaline, and colourless topaz. Topaz and fluorite were found in relative abundance in eluvial samples from the main rhyolite porphyry area between Hunker Creek and Germaine Creek (Fig. 3, Table 12, and Gleeson, 1970, Tables 5 and 3), where the highest concentrations of cassiterite were also found. In the lower workings on Germaine Creek, where cassiterite is most abundant and coarse, the rhyolite porphyry bedrock is highly altered to clayey material. No topaz or fluorite, and only black tourmaline, was found in the samples from Dominion Creek, where rhyolite dykes are apparently absent.

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TABLE 12	Tin, fluorite, topaz, and tourmaline; percentage in bromoform sink fraction of eluvial samples, tin-area I (Fig. 3), Klondike District					
Location	Tin	Fluorite	Topaz	Tourmaline		
1	0.1	1	3+			
2			1 —			
3	N.F.	1 —	1 - 3			
4	0.3	5+		3+		
5	0.05	1 - 5	1 -			
6	0.15		3 +	1		
7			1 —			
8	0.5		1.0			
9			1 - 3			
10		1+		1-		

The cassiterite of the district occurs as smooth, polished, partly rounded pebbles of light brownish over-all colour, and up to an inch or more across. They are banded in lighter and darker shades, and the bands are commonly concentric within individual pebbles (Pl. IVA). In thin section, bands of relatively clear cassiterite up to 5 mm wide alternate with darker bands of unidentifiable dark material containing some flourite. This material probably consists largely of iron oxides, which make up 3 to 7 per cent of the pebbles. The over-all tin content of the wood-tin pebbles is about 70 per cent. Thin sections show radial, check-like cracks. The cassiterite may be, in part at least, finely crystalline. Some specimens show small orbicular-banded areas that interfere with each other as though developed from agglomerates of discrete grains.

The origin of the Klondike cassiterite occurrences is especially interesting. The district is the only well-confirmed locality in Canada where wood tin is found, although it has been reported in other occurrences in Yukon southwest of the Tintina Trench. The cassiterite in the McQuesten-Mayo District northeast of the Tintina Trench and elsewhere in Canada is of the crystalline variety. This consideration suggests a distinctly different mode of origin. GEOLOGY OF CANADIAN TIN OCCURRENCES

Crystalline cassiterite is characteristic of pegmatite and quartz-greisen vein types, whereas wood tin is characteristic of deposits in rhyolitic lavas, as in Nevada and Mexico. These lavas are of Tertiary (postorogenic) age, as are also hypabyssal granites and rhyolites in other areas in southwestern Yukon where wood tin has been reported. This suggests a genetic connection with the rhyolite porphyry dykes in the Klondike District, although their age is not definitely known. No cassiterite has been found in place in them, and samples taken by the writer contained only about 7 ppm tin, but highly kaolinized porphyry from the Germaine Creek placer was found to contain up to 100 ppm. It seems most likely that moderately high temperature fumarolic or hydrothermal fluids carrying tin-halide complexes deposited cassiterite as colloform rounded aggregates in vugs and vesicles in the rhyolite porphyry intrusions or derived lavas above the present level of erosion. The present distribution probably reflects a Tertiary drainage pattern.

TABLE 13

Selected features of some tin-bearing essentially stratabound massive sulphide deposits

			Metamorphism/Metasomatism minerals						
Deposit (locality map, Table Age ¹	1) Main metals Fe Sulphides	Host rocks (ppm Sn)	Grade	Garn ² Sill ³ Anth ⁴	Cords	Gahn ^s	Ap ⁷	Tourm ^s	Fluor®
Kidd Creek (36) PC	Zn,Cu,Pb,Ag(Sn) pyr.	rhy (8)	L						tr.
South Bay (32) PC	Zn,Cu,Ag pyr.	rhy (8)	L						
Lac Dufault (37) PC	Zn,Cu,+Ag pyr,pyrrh,mag	rhy	L-M?		x	X (near)			
Matagami (37) PC	Zn,Cu,+Ag,Au pyr,pyrrh	rhy	L-M?		×		-		
Brunswick (45) Ord/Dev ?	Zn,Pb,Cu pyr,mag,pyrrh	rhy,sed. Fe-form.	L						
Manitouwadge (35) PC	Zn,Cu,Pb,Ag pyr,pyrrh	sed (+volc?) Fe-form.	Н	x	x	х	minor		tr.
Sullivan (22K) Proter./Meso.	Zn,Pb+Ag(Sn) pyrrh+pyrite	sed. +conglom.	L-M local	X local	tr.			X (footwall)	X local
Boliden (Sweden) PC	As(Cu,Zn,Pb),Au pyr,pyrrh,asop.	sed+volc +conglom-Fe-form	L-H variable	X (local)	X (local)		X (fluor)	X (veins)	
Grängesberg (Sweden) PC?	Fe(mag+hem) (no sulphide)	rhy					X (fluor)		х
Bleikvassli (Norway) O-S/Dev	Zn,Pb,Cu pyr,pyrrh	sed	Н	х		x		local	
Broken Hill (Austral.) PC	Zn,Pb, Cu pyrrh	sed Fe-form	н	х		x	X (fiuor)	х	х

¹PC = Precambrian, Ord = Ordovician, O-S = Ordovician or Silurian, Dev = Devonian

Proter = Proterozoic, Meso = Mesozoic; Age following / is age of granite and/or metamorphism. ²Garnet ³Sillimanite ⁴Anthophyllite, etc. ⁵Cordierite ⁴Gahnite ⁷Apatite ⁸Tourmaline ⁹Fluorite

(4) McQuesten-Mayo Distict (Fig. 4)

This district although only about 40 miles at the nearest point from the Klondike District and trending directly toward it, is on the opposite (northeast) side of the Tintina Trench, and is quite different in character. The stratified rocks are relatively gently deformed argillite, quartzite, limestone, and greenstone, and related schists, of generally lower meta-morphic grade. The cassiterite is exclusively crystalline, and commonly is spatially related to small granitic intrusions of Mesozoic (probably late Cretaceous) age. Almost the only feature the two districts have in common is that in this district also most of the known concentrations are in placer gold deposits. The placer concentrations of this district generally also contain abundant scheelite and /or wolframite. The district contains several lode (vein) occurrences of cassiterite, and some of the silver–lead–zinc veins locally contain several hundred parts per million tin. Stream sediments and (probably) eluvial soils in many places contain anomalous amounts of tin (Gleeson, 1967, and Fig. 4).

Granitoid intrus. (ppm Sn)	Pegma (ppm Sn)	Tin mineral	Sn Conc. %	Other lithophile elements	Remarks — References
3 mi (5 km) (8)		cassit	0.12	W(tr.)	
1-2 mi (3 km) (7.5)		cassit	0.37	W(tr.)	
1 mi (1.6 km)		stannite			
6 mi (10 km) ?		-	0.05?		
3 mi (5 km) (12)		cassit stannite	0.05-0.1	Be,Mo	in associated Gr.
near (4)	abund (8)	cassit	0.1?	Mo(tr.)	Sn to 1%+ in border rocks
12 mi (19 km) (22)		cassit	0.05-0.1	Be	in assoc. tourmaline Gr
near?	x	stannite	0.006	W,Mo	Hübner, Grip
near (5)	abund (15)	cassit	0.01+ (to 0.2 non-mag)	W,Mo,Be	Bjorkstedt (Fe ore, apatite produced)
10 km	x	cassit +stannite	0.03		Vokes (1960, 1963)
near	abund	cassit	tr?	W	refs to tin in orebody vague but Be,Sn,Li deposits near (Mn abund as rhodonite, etc.)

Geology

The bedded rocks mentioned above are of Proterozoic(?) to Cretaceous(?) age (Bostock, 1947, 1964). The most important unit economically is the Keno Hill Quartzite (see Fig. 4). This is the most competent unit. It contains numerous sill-like greenstone bodies.

Bostock's maps (1947, 1964) show the upper limits of late glacial advance. Some of the larger creek valleys in McQuesten area are floored by brown and rusty gravels believed to be partly of Pliocene age. Some closely resemble the White Channel gravels of the Klondike District. The gold placers associated with old gravels probably contain the most abundant tin concentrations.

The areal structure has been discussed by Bostock (1947), Kindle (1962), R. H. Green (1957), Aho (1964), and others. In general (see Fig. 4) the main feature is considered to be an east-trending anticline, bifurcating or swinging southeastward across Mayo Lake and complicated by domal structures and by major longitudinal faults. Transverse and oblique secondary faults are probably of major importance to mineralization. The sulphide deposits of Keno and Galena Hills are conspicuously related to northeasterly and southeasterly trending fractures.

Granitic rocks form a few large, and numerous smaller rounded or irregular bodies suggestive of "cupolas," and numerous dykes. Tin concentrations are commonly in spatial relationship with the smaller stock-like bodies. Samples of granite from Dublin Gulch, Highet Creek, and Lynx Creek bodies were found to contain only a few parts per million tin. These are certainly not "tin-granites" in the accepted sense. However, samples of altered rusty granite from two sheared zones in the large granitic body west of Roop Lakes were found to contain about 0.04 per cent tin, although samples of the unaltered granite contained less than 5 ppm. It therefore seems possible that intersection of faults with granitic bodies might provide channelways for tin concentration.

Tourmaliniferous pegmatites are reported near scheelite occurrences on the southeast border of the Roop Lakes batholith (H. W. Little, 1959). This part of the contact zone should therefore be especially favourable for tin concentrations. Pegmatite has also been reported to occur around the head of Ledge Creek (Bostock, 1947).

The granitic bodies are believed to be all of Mesozoic (Cretaceous) age. However, it is possible that the tin concentrations resulted from late or post-magmatic activity, actually of Tertiary age, and therefore quasicontemporaneous with tin mineralization in the Klondike District, according to its assumed mode of origin. This might explain the apparent continuity of the tin belt across Tintina Trench, on which the lateral movement might have taken place mainly in pre-Tertiary time. Bostock (1947, 1964) described quartz-porphyry and granite-porphyry dykes which resemble Tertiary lavas in the valley of Minto Creek (see his maps 890A and 1143A). These are most conspicuous in the general area of the Keno Hill Quartzite (see Fig. 4, *in pocket*). They might correspond to the rhyolitic porphyry dykes in the Klondike District, and be another manifestation of late, post-orogenic igneous activity. The main Cordilleran tin-tungsten belt is believed (Bostock, 1951, and others) to extend southeastward from this district to the Mount Sheldon and Coal River occurrences (see general description, "Cordilleran Region"). At Mount Armstrong (loc. 12) the writer found up to 0.1 per cent tin in heavy mineral concentrates from streams draining the granitic stock.

(4a) Clear Creek

At the gold placer operation on Clear Creek, Aho (1949,1964) reported finding 25 per cent cassiterite in nonmagnetic heavy mineral concentrates from the dredge and from bed-rock. Bostock (1951) reported that 100 pounds per day of tin concentrate was recovered

from one short section of the creek in 1942–1943, but it appears that the tin-rich section was soon passed. In 1964 the writer found a few small pebbles of cassiterite in a roughly panned concentrate from a recent sluice-tailings area. The finer material contained fairly abundant cassiterite crystals and a sample was found to contain more than 1 per cent tin by spectroscopic analysis. In that area oxidized rusty gravel overlies sericitic quartzite and schist bedrock and is covered by black muck. The bedrock surface slopes gently to the present stream course.

(4b) Arizona Creek

According to Bostock (1942), Cecil Pohl, who worked two seasons on Arizona Creek, reported much tinstone in the sluice boxes there and also down Drapeau and Kobe creeks, but none in Drapeau above Atizona Creek. D. Morgan (pers. com., 1964) reported large chunks of cassiterite found by prospectors in the area. Aho (1949) reported gold, tin, and tungsten in placers formed by reconcentration from an old channel. A heavy mineral concentrate of a sample reported to be from the area was found to contain abundant cassiterite in clear, glassy, reddish-pink grains.

(4i) Haggart Creek

Much cassiterite has been found in the heavy concentrates from the extensive goldplacer operations on Haggart Creek, which are mainly below Dublin Gulch. Aho (1949) reported 20 per cent cassiterite, 20 per cent scheelite, and 10 per cent hematite in a heavy mineral concentrate from Barker's workings, just below Dublin Gulch. Bostock (1951) reported that a shipment of 800 pounds of heavy sands from Barker's workings to the Mines Branch assayed 30.8 per cent tin and 14.24 per cent WO₃. This was screened material from which the magnetite had been extracted. Production of black sands at the time was about 600 pounds per day. Ferberite is fairly abundant in some of the heavy mineral concentrates.

(4j) Dublin Gulch

Cassiterite-rich pebbles are abundant in gold placer concentrates in the gulch for about one mile above its mouth, and cassiterite occurs in tourmaliniferous quartz veins on the hill north of that section.

The bedded rocks are quartzites and quartz-mica schists. An elliptical body of granodiorite underlies the upper part of the hill south of the gulch and one or more small plugs outcrop in the creek bottom. Scheelite-bearing quartz veins border the northeast fringe of the main granodiorite stock. Scorodite-stained arsenopyrite-quartz veins are common on the north fringe of the stock, and carry low gold values (MacLean, 1914). Neither the granodiorite, the scheelite veins, nor the arsenopyrite veins carry more than 1 or 2 parts per million tin and evidently are not the source of the tin.

The presence of cassiterite as pebbles and small crystals in sluice boxes was noted in 1940. In 1962 the creek bottom was being worked about $\frac{3}{4}$ mile above the mouth. Rusty cemented gravel overlain by a thick layer of till was exposed locally in recent cuts. The pebbles, exceptionally as large as $2\frac{1}{2}$ pounds, are somewhat rounded and water worn. They consist of angular fragments of quartz, quartzite, and schist, embedded in tourmaline, cassiterite, chlorite, and limonite. They are rough textured and have the appearance of brown sugar. Thin sections of pebbles examined by the writer contained 80 to 90 per cent cassiterite, with irregular patches and stringers filled with grains of quartz, fine granite, and fine tourmaline needles (Plate IVB). The cassiterite grains are mostly less than 0.5 mm in diameter. Some masses appear to consist of nearly euhedral recrystallized grains with incipient zoning and twinning. They are light reddish, though stained by iron oxides. According to Thompson (1945, p. 143), tin is a minor constituent of gold from these placers.

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The lode tin deposit, near the top of the ridge north of the placer workings, was discovered in 1943 (Bostock, 1951). Samples from a vertical vein 30 inches wide contained 1.54 and 0.84 per cent tin and samples of veinlets along strike, less than 1 per cent tin. According to Thompson (1945, p. 146), the vein material consisted of cassiterite in grains up to 1 mm across, with quartz, tourmaline, chlorite, pyrite, and limonite. Fine acicular green and brown tourmaline is abundant in the vein material and in the soil near the veins.

In 1962 the writer found poorly exposed white and banded quartzite on the slope northeast of the hill. Toward the deposit this gives way to more schistose green and black rocks, which become brecciated near the tin locality. The area had been bulldozed the previous year and neither vein structure nor bedrock was visible in the bulldozer trenches. A few brecciatedlooking fragments containing white vein quartz were crushed and panned. The concentrate contained fairly abundant cassiterite, and a spectrographic analysis yielded 1.1 per cent tin. Cassiterite was found in a thin section that consisted mainly of dark quartz-tourmaline rock with much limonite and a few stained pyrite cubes. This is cut by streaks of fine- and coarse-grained quartz. Several grains of cassiterite up to 0.3 mm across were identified along the contact of one of these veinlets with the quartz-tourmaline rock. This material is much lighter and poorer in tin than the pebbles in the placer concentrate, but it is clear that the latter were derived from veins of this type in the vicinity.

(4m) Keno and Galena Hills

The geology of the economically important silver–lead–zinc deposits has been discussed by Bostock (1947), McTaggart (1950), Kindle (1962), and others. The deposits are chiefly in massive quartzites where these rocks have been sharply flexed, and occupy northeasterly or southeasterly trending fault fractures. The ore is rich in silver and consists mainly of galena, sphalerite and tetrahedrite–tennantite minerals, with some pyrite, arsenopyrite, chalcopyrite, and ruby silver. The gangue is manganiferous siderite and quartz. The tin content of the sphalerite, by spectroscopic analysis, in per cent, was reported by Warren and Thompson (1944) as follows: Hope, 0.05–0.1; Elsa and Lucky Queen, 0.01–0.05; Lake Group and Keno, tr–0.01. That of galena was reported as 0.01–0.05 per cent. Boyle and Jambor (1963, p. 485) reported 0.08 and 0.03 per cent tin respectively in sphalerite from the Onek and Calumet mines and 0.02 per cent from the Lucky Queen, by chemical analysis. They found no stannite or cassiterite in polished sections, and concluded that the tin is probably in the lattice sites of the sphalerite. Of various sulphide samples collected by the writer, only that from the Onek was found to contain tin (0.03 per cent reported) by the semiquantitative spectrographic method used. The limit of detection is probably greater than 0.01 per cent.

(12) Mount Armstrong

Heavy mineral concentrates of samples panned by the writer from two of the streams draining the granitic stock at Mount Armstrong were found to contain 0.07 and 0.1 per cent tin by spectroscopic analysis. Both contain more than 1 per cent tungsten. These streams drain the deepest pass through the massif. Concentrates from other streams were reported to contain 100 ppm tin or less, as were those from streams draining a stock at Emerald Lake, 68 miles northeast of Mount Armstrong. One of the latter contained more than 1 per cent tungsten, and tungsten mineralization occurs in bordering skarns. Samples of granite from both stocks were found to contain only 3 to 5 ppm tin, but a tourmaliniferous phase from Mount Armstrong contained 66 ppm. The stocks are two of many that lie in the hypothetical extension of the tin belt southeastward from Mayo Lake.

(14) Coal River

A poorly defined calcareous vein up to 18 inches thick in black argillite is exposed for about 40 feet by shallow trenches in the river bank. It is sparsely mineralized with pyrite, sphalerite, and galena, and contains appreciable amounts of geocronite and franckeite, a lead-tin-antimony sulphide. A little stannite was seen in polished sections, bordering franckeite and as inclusions in sphalerite. A sample of mineralized vein material taken by the writer was found to contain more than 1 per cent tin by spectroscopic analysis.

(15) Atlin District

The Atlin District (Fig. 5) lies near the western extremity of a granitic body mapped as alaskite and quartz monzonite (Aitken, 1959). The body cuts Pennsylvanian and Permian sedimentary and volcanic rocks of the Cache Creek Group, and ultramafic intrusions. It is also in contact with undifferentiated granitoid rocks on the west. Tin is a minor component of tungsten and molybdenum occurrences that lie in a roughly linear zone across the heads of Boulder and Ruby creeks. This zone includes the Black Diamond mine where cassiterite is a minor component of quartz-wolframite veins. Cassiterite occurs also in appreciable amount in the heavy concentrates of gold placer deposits on Boulder, Ruby, Birch, and Pine creeks.

The granitic rocks of upper Boulder and Ruby creeks are highly variable in granularity and texture, and include aplite, and various quartz and feldspar porphyries as well as coarsely porphyritic granite. Various phases cut one another and are commonly altered and stained, and laced with quartz veins. The feldspar is commonly altered to sericite or kaolin. Reddish iron and black (manganese?) staining is widespread. Purple fluorite is locally abundant. Such granitic material contains up to 41 parts per million tin, and may be considered as "tin-granite," although the average over the whole area is probably much less.

Around the saddle between Boulder and Birch creeks and on the slope below the Black Diamond mine the strike of shear zones and quartz veins appears to be generally northeasterly. H. W. Little (1959, p. 39, 40) states that the strikes of two of the main zones at the Black Diamond mine are N40° E and N45° E. This is about the trend of the main tungsten-molybdenum zone across the upper part of Boulder and Ruby creeks.

At the Black Diamond mine (H. W. Little, 1959; British Columbia Annual Report, 1950), wolframite occurs as fine and coarse crystals in quartz veins characterized by comb structure. A bulk sample of 1797 pounds of wolframite ore contained 15.2 per cent WO_3 and 0.18 per cent tin (British Columbia Annual Report, 1943).

Samples of quartz-veined, sheared and altered granite taken by the writer from the pass between Boulder Creek and Birch Creek were found to contain up to 0.05 per cent tin, and samples from molybdenite showings on Ruby Creek up to 0.03 per cent. A sample from a fluorite-sulphide-scheelite skarn west of Boulder Creek contained 0.03 per cent tin.

Bulk samples of placer concentrates from upper Boulder Creek shipped in 1949 averaged 9.73 per cent tin and 48.5 per cent WO_3 (British Columbia Annual Report, 1950). Black sands and heavy mineral concentrates taken by the writer from Boulder, Ruby, and Pine creeks were found to contain from 1 to 2 per cent tin by spectroscopic analysis.

In 1968 and 1969 molybdenite showings in the upper Ruby Creek area were being diamond drilled by Adanac, Ltd., and Johns-Manville, Ltd. A report in Northern Miner, July 23, 1970, stated that bulk sampling had begun from a drift then 1400 feet long, and further work was planned by Kerr-Addison, Ltd.



(16) Cassiar District

This district (Fig. 6), embracing the northern part of the Cassiar batholith and its satellites, contains a remarkable number and variety of mineral occurrences. In addition to tin these include many beryllium, tungsten, and molybdenum occurrences, many small deposits of lead-zinc-silver, and a few of other metals (Mulligan, 1969).

In this district the Cassiar batholith, the granitic core of the Cassiar Mountains, breaks up into a number of segments following diverse structural trends. One chain of intrusions extends west to Atlin Lake (loc. 15), almost connecting with the Coast Range intrusions. The main Cordilleran structural trend is reflected in an intermittent train of elongated granitic intrusions extending northwestward beyond Little Salmon Lake (loc. 11). Also at this latitude, the northeast boundary of the Western Cordilleran region veers abruptly northeastward from its generally northwesterly course along the Rocky Mountain Trench, to encompass the masses of granite and metamorphic rocks northeast of Watson Lake and the Tintina Trench. A fault marking this trench, and another subparallel one in the (projected) 'Rocky Mountain Trench,' are shown passing across the northeast corner of Wolf Lake (105B) map-sheet.

The geology has been described by Watson and Mathews (1944), Gabrielse (1963, 1969), Poole (1956), and Poole *et al.* (1960). In Figure 6, the formations have been combined into a few arbitrary age groups to illustrate the geological environment of mineral deposits.

The Proterozoic to Mississippian rocks east of Cassiar batholith, and in fault-slices west of the batholith, comprise typically unmetamorphosed argillite, quartzite, phyllite, limestone, and dolomite with volcanic greenstone abundant in a Devono–Mississippian sequence that occupies the centre of the McDame synclinorium.

West of the batholith, a broad synform encloses Mississippian? and Pennsylvanian limestones and overlying or intercalated argillite, quartzite, chert, grit, and conglomerate that overlies the Devono-Mississippian metamorphic complex at the west boundary. This complex of micaceous schist, gneiss, quartzite, and crystalline limestone, with abundant metamorphosed volcanic greenstone, occupies an anticlinal structure that plunges southeastward and may pass beneath the Mississippian-Pennsylvanian rocks previously mentioned.

The metamorphic rocks in the south-central area, are micaceous schist, quartzite, and crystalline limestone, called the Oblique Creek Formation by Watson and Mathews. They lack the prominent greenstone components of the Devono-Mississippian metamorphic complex, and may be younger.

The Permian and Mesozoic rocks of the southwest corner are unmetamorphosed argillite, greywacke, chert, limestone, and andesitic volcanic rocks, part of a central eugeosynclinal trough of Yukon and northern British Columbia.

The granitoid rocks, of Jurassic(?) to early Tertiary(?) age, vary from granodiorite to granite, with biotite-quartz-monzonite predominant, and some dioritic border zones and satellites. Muscovitic granite and alaskite phases, and aplite and pegmatite dykes are prominent in some parts of the Cassiar batholith, (G^1) especially in a foliated, cataclastic zone along the southwest fault contact. Miarolytic and aplite phases are locally prominent, especially in unit G³ and in the southwest corner (G⁴). The Seagull batholith (G⁵) is especially rich in miarolytic cavities, and is distinctive. Fluorite is a common accessory, and tourmaline-quartz concentrations are characteristic. Topaz has been found as large crystals in some miarolytic cavities. The Seagull is younger than the Cassiar batholith and was probably emplaced at shallower depth. Tourmaline, axinite, and vesuvianite-bearing skarns are common in a metamorphic aureole.

The main structural elements are shown in Figure 6. The Cassiar batholith occupies a generally anticlinal zone, but the east contact lies at a slight angle to the regional trend of bordering rocks. The most conspicuous fault zone is that along the southwest border of the



LEGEND

G	Granitic intrusions	Pcc Proterozoic-Lower Cambrian
Mz	Mesozoic	
Per	Pennsylvanian? & Permian	Fault
MP	Mississippian & Pennsylvanian	Pegmatiticv
mMP	Mississippian & Pennsylvanian (Metamorphosed)	Quartz greisen veins+
DM	Devono-Mississippian	Skarnsx
mDM	Devono-Mississippian (metamorphosed)	Lead-zinc-silver sulphide
OSD	Ordovician-Devonian	Placerso

FIGURE 6. Geology and tin concentration of the Cassiar District, British Columbia, tin 0.05—0.5 per cent in symbolized and lettered occurrences (explained in text); ppm in granite shown by numbers.

Cassiar batholith, but numerous other faults have affected the distribution of the bedded rocks and the emplacement of mineral deposits.

The main tin-bearing deposits and occurrences of the Cassiar District are symbolized according to type in Figure 6, and identified by number and letter in Table 1. Tin is concentrated in tungsten, beryllium, and molybdenum occurrences as well as independently, but most enrichments are in lead-zinc sulphide deposits. There are at least three distinct types of tin deposit. Cassiterite accompanies wolframite in the quartz-greisen veins of the Yukon Tungsten mine (loc. 16(l)) and occurs in small quartz-tourmaline veins bordering the Seagull batholith (loc. 16(p)). Tin is a minor but essential component of andradite garnet, epidote, and ferroactinolite in some silicate skarns at locality 16(u). It is also present in magnetite skarns at locs. 16(a) and (t) and in small amount in some tourmaline-axinite-vesuvianite skarns (loc. 16(g)). Most of the lead-zinc sulphide deposits contain several hundredths of one per cent tin; a few contain more than 0.1 per cent, and the Silvertip deposit (16(g)) has about 0.25 per cent. Stannite and ludwigite-type borate minerals have been identified in one (16(o)) and cassiterite in another (16(t)).

Heavy mineral concentrates (specific gravity greater than 3.3) of sediments from a number of streams contain from several hundredths to about 1.0 per cent tin. This is considered significant because in most of the streams panned, tin was not detectable. Only the richest are shown on the map. Others worthy of mention include Seagull Creek (Mile 733) with 0.1 to 0.15 per cent, a small stream near Mile 714 with 0.37 per cent, and a small stream east of Logjam Creek (Mile 750.5) with 0.2 per cent tin.

The granite bodies of the area are not tin-rich. Analyses range from less than 1 to 15 ppm tin. The Cassiar batholith (G^1 , Fig. 6) generally contains less than 5 ppm, but there is evidence of some enrichment in the western cataclastic, muscovitic border zone. The younger, more leucocratic Seagull batholith (G^5) appears to be significantly richer, as do the leucocratic phases of the granitic rocks in the southwest corner (G^4).

(16a) Low Grade Claim, Needlepoint Mountain

At the Low Grade Claim, a lenticular body of black, heavy, and strongly magnetic skarn about 300 feet long and up to 35 feet thick lies within a thin lens of impure crystalline limestone. It extends southeastward from the contact with Cassiar granite and a small tongue of granite lies above and parallel with it. The skarn is in part banded, consisting mainly of magnetite with minor amounts of chlorite, garnet, and small areas of fluorite and quartz. A beryllium mineral of the helvite-danalite group is sparsely disseminated through the skarn. The tin content of composite samples is 0.038 per cent by spectroscopic analysis. X-ray fluorescence work indicates that the concentration in the magnetic fraction, which amounts to 75 per cent of the total sample, is twice as high as in the nonmagnetic remainder.

(16g) Silvertip Property

At the *Silvertip* property (Holland, 1968), lead-zinc-silver sulphide mineralization is largely localized in faults and fractures in Devonian limestone along the crest of an anticline, and close beneath the contact with overlying slate and phyllite. It is just west of a major northerly striking fault. A composite sample of galena-rich sulphide ore, which is scattered abundantly down the surface of the hillside, and one from a lower zinc-rich zone were each found to contain 0.2 per cent tin by spectroscopic analysis. Chemical analysis indicated 0.25 per cent tin in both samples. Stannite and tetrahedrite were identified in polished sections.

GEOLOGY OF CANADIAN TIN OCCURRENCES

(161) Yukon Tungsten Property

At the Yukon Tungsten (Fiddler) property, about 6 miles by secondary road north of the Alaska Highway at Mile 701.6, quartz-greisen veins up to $2\frac{1}{2}$ feet thick cut contorted chloritic mica schist and limy phyllite on and near the top of a rounded dome. About 1952 an adit was driven from a point some 700 feet southeast of the surface showings for about 500 feet, and an inclined raise connected it to a pit near the main vein (Green, 1966). The adit was blocked by ice in 1965.

One or more veins up to $2\frac{1}{2}$ feet thick are exposed in trenches on top of the hill, and appear to strike northeasterly and dip about 30 degrees southeast. These veins are partly massive but elsewhere contain large subhedral quartz crystals interlocking in comb structure. In places they are banded, with thin streaks of yellowish to greenish mica at the hanging-wall. Wolframite, in bladed crystals several inches long, is commonly in the upper parts of the veins, and blue-green secondary copper minerals are mostly in the lower part. A little molybdenite and yellow molybdite are present, and purple fluorite is locally common.

Cassiterite is apparently scarce in these veins; it is more abundant in small veins on the south slope of the hill above the adit. These veins consist chiefly of quartz and bordering plumose pale greenish mica, with scattered pale green fluorite. Cassiterite is in small grains and fine dendritic intergrowths, mainly in quartz at or near its contact with micaceous bands (Pl. IIIA). The veins apparently do not extend to any great depth, as none were found in the lower part of the cirque wall to the east.

Composite samples of vein material were found to contain up to 0.2 per cent tin by spectroscopic analysis. A sample of apparently clean wolframite also indicated 0.2 per cent tin. The greenish mica is evidently unusually high in lithium, as a composite sample of vein material was found to contain 160 ppm Li.

A small mill was built at the end of the access road at the Alaska Highway but never operated (Green, 1966), and was destroyed by fire.

(160) BOM Property

At the *BOM property* a lower (No. 1) showing is exposed in trenches at the head of Swift River. The country rocks are carbonates, recrystallized and partly altered to silicates. Mineralization consists of sphalerite, galena, and pyrrhotite, with variable amounts of magnetite and much black manganese stain. Samples from two trenches each yielded 0.1 per cent tin by spectroscopic analysis.

The upper (No. 2) showings are just beyond a pass about $1\frac{1}{4}$ miles northwest of No. 1. Trenches expose pyroxenitic and garnetiferous skarn intercalated with hornfels and quartzite. A little black tourmaline was seen. Mineralization consists of sphalerite and galena, with much pyrrhotite and a little arsenopyrite and fine molybdenite. Spectroscopic analysis of three samples yielded 0.1, 0.1, and 0.3 per cent tin. Stannite and a stanniferous ludwigitetype borate mineral were identified in specimens from drill core (Gower, 1952).

(16t) Blue Light Claims

At the Blue Light claims the main tin concentrations are massive magnetite-pyrite veins or skarn bands up to 10 feet thick and several hundred feet long that lie in indefinite relationship with enclosing quartzitic hornfels. They consist chiefly of magnetite, pyrite, and quartz. The magnetite is in the form of small disseminated grains and prismatic aggregates, roughly aligned, and appears to replace pyrite. Two composite samples were found to contain 0.5 per cent tin by spectroscopic analysis, and one of a reddish hematitic-looking band, 0.15 per cent. No tin minerals were found. From X-ray fluorescence work on concentrates it appears that most of the tin is contained in the magnetite. Silicified muscovitic granite is exposed a short distance away and contains about 17 ppm tin.

Pegmatite dykes are abundant some distance away on the general strike-line of the veins and beryl is fairly common in some. A composite sample contained only 11 ppm tin. About $\frac{1}{2}$ mile above the veins a massive body of fluorite occurs in skarny rock close to a limestone bed, and apparently in a fault zone. The main showing at the property is a scheelite deposit. Scheelite-rich skarn occurs in bands interleaved with grey augen gneiss, all of which are cut by irregular pegmatite dykes. A composite sample of the skarn bands yielded 0.03 per cent tin by spectroscopic analysis.

(16u) Ash Mountain

Near Ash Mountain, tin-bearing aluminosilicate minerals occur in silicate skarn bands among metamorphosed sedimentary rocks near their contact with biotite granite of variegated texture (Mulligan and Jambor, 1968).

At the pass about $1\frac{34}{4}$ miles north of Ash Mountain, tin-bearing coarse garnetite occupies a small area surrounded by broken rock and drift, among which various kinds of pyroxene, garnet, and vesuvianite skarns outcrop. The garnetite appears brown in hand specimen with a rough faceted surface of interlocking garnet crystals and finer interstitial material. It consists mainly of deep green garnet crystals up to 1 inch across, with a minor amount of finer greenishbrown clinopyroxene and a little calcite, fluorite, and graphite. Samples of the garnetite were found by spectroscopic analysis to contain about 1.2 per cent tin. The garnet crystals are finely banded in concentric zones parallel to crystal outlines (Pl. V), the bands showing varying colour intensity and optical anisotropy. Scans across the zones with the electron probe showed that the darker green bands contain more tin and less iron than the lighter bands. The garnet is a calcium--iron andradite with about 2.5 per cent Al₂O₃. A cleaned sample was found to contain 0.9 per cent SnO₂ by chemical analysis. The pyroxene in the garnetite is in anhedral interstitial masses and in thin bands along the zone boundaries of the garnet crystals. An impure sample was found to contain 0.19 per cent tin by spectroscopic analysis.

Samples from a nearby boulder of dark greenish-brown pyroxenite were found to contain 0.78 per cent tin by spectroscopic analysis. It consists principally of pale greenish clinopyroxene like that in the garnetite but in part altered to dark greenish amphibole. The other minerals present are smoky-coloured epidote, minor garnet, and a little quartz, calcite, and sphene. Samples of the epidote were found to contain more than 1 per cent tin by spectroscopic analysis and 0.8 per cent by chemical analysis of cleaned material. It has an unusual structure and Fe³: Fe² ratio. The amphibole is a ferroactinolite, containing 2.7 per cent Al, less than 1 per cent Mg, and Mn, and up to 0.4 per cent tin. The garnet is andradite, but unlike that of the garnetite is unzoned, completely isotropic, and contains very little tin.

Various garnet, pyroxenite, and vesuvianite skarns in the pass, on nearby ridges, and in the cirque $4\frac{1}{2}$ miles north of Ash Mountain were found to contain several hundred parts per million tin. No comparable tin-rich garnetite was found, but samples of epidote and ferroactinolite from skarn 2 miles southeast of Ash Mountain were found by spectroscopic analysis to contain more than 1 per cent and 0.62 per cent tin, respectively. No ordinary tin minerals were found anywhere in the area and very little scheelite, magnetite, or sulphide minerals.

The granite in the pass is largely aplite, and that in the north cirque contains large miarolytic cavities and some pegmatitic phases. Composite samples from these areas were found to contain a maximum of only 5 ppm tin.

As andradite and epidote contain major iron as Fe^{+3} , and ferroactinolite may contain appreciable amounts of ferric iron, it is probable that tin occurs in the lattices of these minerals principally as Sn^{+4} substituting for Fe^{+3} .

(18) Tsitsutl Mountain, Fort St. James Area, B.C.

According to Armstrong (1949, p. 194), the locality is about 20 miles by pack-trail from Middle River, at about 5,500 feet elevation. A rhodonite vein 18 to 24 inches thick was uncovered in two places 24 feet apart. It cuts metasedimentary rocks of the Permian Cache Creek Group near their contact with a quartz porphyry stock of possible Tertiary age.

The vein is said to consist of about 70 per cent rhodonite, with 2 or 3 per cent arsenopyrite, and some calcite, garnet, and ilmenite. Two samples assayed 0.09 per cent and 0.2 to 0.3 per cent tin, respectively, together with manganese and "appreciable" amounts of zinc, cobalt, and vanadium, and very little copper. The cobalt and vanadium found were thought to be derived from ilmenite. No tin minerals were reported. No commercial amounts of the above metals were found by Cominco Ltd. in 1943.

(21) Crowfoot Mountain, Shuswap Lake Area, B.C.

In a press release (Northern Miner, Feb. 25, 1965, p. 18) tin was reported to occur with lead-zinc-silver mineralization in an area underlain by metasedimentary rocks (Shuswap Terrane) and intruded by diorite, granodiorite, and syenite dykes. The locality was not found by the writer. According to British Columbia Department of Mines Annual Report, 1964, it is reported to be at elevation 6,200 feet on the ridge joining Crowfoot Mountain and Mount Mobley. Samples sent to the Department contained quartz, sphalerite, minor pyrite and chalcopyrite, and small amounts of tin. No tin mineral was identified, but response to attempted concentration suggested that a considerable part of the tin occurs as cassiterite.

Samples, supposedly from this locality, were found to contain patches of stannite 1 cm in size in a groundmass of galena, sphalerite, minor chalcopyrite, and vuggy quartz (American Mineralogist, v. 38, 1953, p. 548).

(22) Kootenay District

This district extends from the International Boundary northward to the area northeast of Revelstoke (Fig. 7). It is probably the most important tin-bearing district in the Cordillera, and contains a variety of types of occurrences including the Sullivan mine, the only Canadian tin producer.

The geology of various parts of the district has been described by many writers, including Cairnes (1934, 1935), Rice (1947), Walker (1926; Walker, *et al.*, 1929), Gunning (1929), Reesor (1957, 1958), A. G. Jones (1959), Leech (1957, 1962), H. W. Little (1960), Fyles (1964, 1967; Fyles and Eastwood, 1962), and Wheeler (1963, 1964).

The bedded rocks, almost all sedimentary, are of Proterozoic and early Paleozoic age except in the Slocan district where the host rocks of the tin-bearing deposits are Triassic. They include the oldest Proterozoic rocks exposed in the Cordilleran Region, and the Proterozoic succession involves a major unconformity. In Figure 7 the formations have been combined into a small number of age-groups to illustrate the main geological features. The basic structural and stratigraphic control is an anticlinorium that plunges gently northward, bringing up successively younger formations at the nose and on the flanks. The district in part borders on the widespread regionally metamorphosed Shuswap Terrane, but within it the rocks are generally of low metamorphic grade.

Intrusive rocks, in addition to the Cretaceous Nelson batholith and its satellites, include some of Proterozoic age. The Purcell intrusions are great sill-like sheets of partly differentiated diorite-micropegmatite composition, which were apparently folded with the enclosing rocks in Precambrian time. Probably younger than these are a group of granitic stocks and tourmaliniferous beryl-bearing pegmatites 6 to 12 miles southwest of the Sullivan mine. Their age, as indicated by K-Ar isotope ratios, is 700 to 750 million years but Rb-Sr ratios yield a 1260 million year age (Ryan and Blenkinsop, 1971). A 1200 to 1400 million year age is indicated by lead isotope ratios on the ores of the Sullivan mine. The rocks of the Cretaceous Nelson batholith and its satellites (unit 6, Fig. 7) vary widely in composition but consist largely of granite. Some satellite bodies, like the White Creek batholith, are strongly differentiated. Pegmatites, locally containing beryl, are common in some places.

None of the granitoid rocks of the Nelson batholith or its satellites was found to contain more than 2 or 3 ppm tin, nor ordinary pegmatites more than 6 ppm (see Table 6). However, berylliferous pegmatite of the Precambrian Hellroaring Creek stock southwest of the Sullivan mine contains 22 ppm tin and berylliferous pegmatites northwest of the mine contain 20 ppm. One cassiterite-bearing pegmatite occurrence (loc. 22b) has been reported in the district.

The outstanding structural feature of the district is the Kootenay Arc. This term refers to a general change in direction of geological contacts and fold structures from northeasterly in the southern part to northwesterly in the northern part of the district. It reflects the great easterly bulge of the Nelson batholith, which culminates in the vicinity of Kootenay Lake. The general anticlinorial structure of the district was mentioned previously. The most important faults fall into two groups. One group of northeasterly to northwesterly trending faults are more or less parallel with the major structure. The other group consists of a number of major transverse faults, striking generally eastward. They may be of relatively ancient origin, dating originally from Proterozoic time. Some have apparently acted to control Cretaceous granitic intrusions. Intersections of these with longitudinal faults were probably exceptionally favourable localities for mineral deposits, including tin concentrations.

The Sullivan mine (22(k)) is at a complex junction of easterly and northerly trending faults. From there five occurrences lie along a line, in part marked by faults, that extends northwest more than 100 miles to the Snowflake-Regal Silver deposit (22(a)).

Most of the tin occurrences known in the district are minor concentrations in essentially lead-zinc sulphide deposits. Except at the Sullivan mine, almost all the tin appears to be in the form of stannite or in the lattices of lead or zinc sulphide minerals, and deposited under comparatively low temperature hydrothermal conditions. Again excepting the Sullivan mine, the vein-type deposits in general contain much more tin than the replacement type (Sinclair, 1964). Many are relatively rich in silver and contain some copper in the form of tetrahedrite-tennantite minerals. Outstanding examples are the Snowflake (22(a)) and Humbolt (22(h)) deposits. The latter was found to contain 1.3 per cent tin in a composite sample collected by the writer. Tin is especially common as a minor constituent of silver–lead–zinc veins in the Slocan (22(e)) and Ainsworth (22(f)) camps.

However, the non-sulphide quartz-vein type with cassiterite is represented at locality 22(j), and cassiterite-bearing pegmatite has been reported at locality 22(b).

Tin is moderately concentrated with tungsten at locality 22(a), 22(d), and 22(j), and composite samples from the Emerald mine were found to contain up to 0.016 per cent tin. However, the Akokli, a quartz-wolframite deposit east of Kootenay Lake, rather surprisingly appears to contain very little tin.

(22a) Snowflake–Regal Silver Property (see Fig. 8)

The property was first opened in 1922 and operated until 1930, about 12,000 feet of development being done on five levels. Some underground diamond drilling was done in 1942 by the Federal Government in an attempt to investigate the down-dip extension of the upper stannite shoot. The property was operated again from 1950 to 1953 (British Columbia





Department of Mines, Annual Reports), when small shipments of lead and scheelite concentrates were made. It was reopened in 1967 by Stannex Minerals Ltd., and a substantial amount of new underground exploration and development was done in 1968 and 1969.

The property is underlain by carbonaceous black slates and more quartzitic grey slates (Lardeau Group). They dip northeasterly at angles varying from 60 degrees in the upper levels to 35 degrees in the lower workings. The metamorphic grade of the rocks is low. No intrusions outcrop near the property. Quartz monzonite cuts the granite gneiss that marks the northeast boundary of the Shuswap complex. This boundary lies about 3 miles to the southwest. Beryl has been found in pegmatites that cut the granite gneiss a few miles south of the property (Gunning, 1929). Granitic rocks also outcrop within 7 miles south of the property. Cassiterite is associated with this granitic mass at locality 22(b), and pegmatite and greisen have been reported in that general area (Wheeler, 1963).

The mineralized bodies on the property are quartz sulphide veins. At least six subparallel veins cross the property within a total distance of about 1,600 feet across their strike. They strike northwesterly and dip 30 to 60 degrees northeastward, in general concordance with the country rocks (Fig. 8). The veins range generally from a few inches to 8 feet in width, and up to at least 1,000 feet in length. They are commonly banded, with ribbons of unreplaced slate and /or sulphides, and contain many lenses and fragments of slate. The veins commonly follow fault surfaces, marked by crush zones and slickensiding. Other faults, distinctly transverse, cut the veins and wall-rocks.

The veins consist chiefly of massive milky quartz with lenses of pyrite, galena, and sphalerite, minor amounts of stannite, chalcopyrite, tetrahedrite, and other silver-rich minerals, and scheelite. A little fluorite was found in dump material at No. 5 adit and a thin greenish micaceous selvage was noted on some lumps of vein quartz. A sample of this mica was found to contain 70 ppm tin and 0.03 per cent Li₂O. Pyrite is the most common sulphide mineral and is abundant in places in the slate wall-rock. Pyrrhotite is also common in the lower levels east of Clabon Creek. Galena and sphalerite are mainly in scattered pods throughout the veins.

Stannite occurs in scattered concentrations in the main sulphides throughout the workings but is found in abundance only in the uppermost level, which crosses the boundary between the original Snowflake and Regal Silver properties (Fig. 8). There lumps and patches up to a foot or more in diameter of relatively pure stannite¹ are found in the vein, associated chiefly with pyrite (Pl. IIIA) and locally sphalerite, chalcopyrite, and tetrahedrite. Most of the tin-rich ore is confined to a section of the drift a little over 100 feet long, and extends about 70 feet up a raise. This section averages about 1 per cent tin, and the tin-rich shoot was estimated to contain about 10,000 tons of ore averaging 1 per cent tin (McClelland, 1952). This section is also relatively rich in silver², which occurs partly in microscopic inclusions in stannite.

Scheelite occurs in very small amounts throughout the quartz veins (Stevenson, 1943), but the main concentration appears to be in a pyrite-chlorite-rich zone encompassing several levels in the lower workings (see Fig. 8). There irregular masses of scheelite several inches across are fairly common. A little wolframite and powellite have also been identified. Small concentrations of tin are scattered throughout the scheelite zone but there does not appear to be a significantly higher incidence of such concentrations in the scheelite zone than elsewhere.

Kesterite, the pure zinc analogue of stannite, occurs in exsolution pattern in the stannite (Harris and Owens, 1972).

²Tellurian canfieldite, Ag₈Sn(S,Te)₆ occurs as small inclusions in galena (Harris and Owens, 1971).

No cassiterite was found by the writer in samples from tin concentrations, mainly from the scheelite zone, indicated by a Portable X-ray Fluorescence Analyzer, but no samples taken contained as much as 1 per cent tin. As far as known, no cassiterite has been definitely identified at the property and there is no evidence of a downward gradation into cassiterite mineralization within the mine workings. However, some degree of vertical zoning is apparent in the relative distribution of stannite and scheelite, and the presence of a little fluorite and the lithium-bearing micaceous selvages mentioned earlier are suggestive of minor local greisenization. Greisen zones in the granite near the cassiterite occurrence at Locality 22(b), 18 miles southeast, have been reported (Wheeler, 1963). Related greisenized granite bodies may occur at depth in the intervening area, which should therefore be especially favourable for tin deposits.

(22e) Slocan Area

The area, which lies north of the Nelson granitic batholith west of Kootenay Lake, is underlain by thin-bedded and impure argillite, quartzite, and limestone. These rocks are of Triassic age, unlike the host rocks of the other tin occurrences in the district. They are generally unmetamorphosed, but are cut by numerous small stocks and dykes of granitic and basic composition. The salic dykes (Cairnes, 1934) are variable in texture, including pegmatite, aplite, and various porphyries.

The area is noted for the great number and richness of its silver-lead-zinc deposits, many of which contain freibergite and other silver-rich minerals. Most are veins but a few are replacement bodies in limestone. Sphalerite is the most common sulphide mineral and calcite or siderite the most common gangue, but quartz may predominate, especially in intrusive host rocks. Fluorite is locally present.

Tin has been detected in many deposits, apparently mostly in sphalerite, in amounts ranging up to 0.3 per cent. Hedley (1952) mentioned the Payne, Hartney, Lucky Jim, and Mammoth. The tin seems to be mostly in stannite, but some cassiterite may be present at the Lucky Jim. Warren and Thompson (1944) listed spectrographic analyses of some 30 sphalerites from the area, about half of which were reported to contain 0.1 per cent or more tin. These included the Jackson Basin property, with 0.3 per cent and the Whitewater, with 0.2 per cent. A sample of fine spilled material from the old Whitewater mill taken by the writer was found to contain 0.03 per cent tin by spectrographic analysis.

(22f) Ainsworth Area

The Ainsworth camp (Fyles, 1967), like the Slocan area, contains numerous silver-rich lead-zinc vein deposits. The bedded rocks are moderately metamorphosed schists, quartzite and limestone, of the late Paleozoic Milford Group. They are intruded by more or less concordant dykes and lenses of fine-grained, somewhat gneissic granite, and by some lamprophyre dykes. The orebodies are mostly fissure veins, with some minor replacements in limestone. Sulphides, in addition to galena and sphalerite, include pyrrhotite and arsenopyrite. Gangue minerals are quartz, calcite, and locally, abundant fluorite.

In samples collected by the writer the highest tin content was found in vein deposits at the Early Bird (0.031 per cent), Highland (0.027 per cent), and Lakeshore (0.043 per cent), by spectroscopic analysis. These contain appreciable fluorite, and arsenopyrite is prominent at the Highland and Early Bird. The lowest tin content was found in replacement deposits at the No. 1 and Silver Hoard, although the latter also contains abundant fluorite. It also has light-coloured sphalerite. Stannite and possibly cassiterite were found in polished sections from the Early Bird and Lakeshore. R. Thorpe (pers. com.) also found stannite in ore from the Highland, Little Donald, Silver Glance, and Ida C. claims and appreciable amounts

from the Tardiff. The Tardiff and Little Donald deposits are close to a large granitic lens about a mile south of Ainsworth.

(22h) Humbolt and Rose Pass

The Humbolt claim is on the Crawford Bay – Rose Pass trail, about 10 miles northeast of Crawford Bay, Kootenay Lake. A flat-lying quartz vein is exposed for about 60 feet southward from a creek to a caved adit and a further 120 feet to the end of a partly caved open cut. It cuts micaceous argillite of the Proterozoic Horsethief Creek Formation, and is about 4 feet thick near the creek, but thins to 2 feet beyond the adit.

The vein is well mineralized with sphalerite, galena, pyrite, chalcopyrite, minor stannite, and possibly tetrahedrite. The stannite is chiefly associated with sphalerite, which contains small blebs of stannite, galena, and chalcopyrite. A composite sample of well-mineralized vein material taken by the writer was found to contain more than 2 per cent tin by spectroscopic analysis and 1.3 per cent by chemical analysis. X-ray fluorescence analysis indicated appreciable silver as well as tin.

The Rose Pass prospect, about a mile farther east near the summit of the pass, was not found by the writer. According to Rice (1941), a quartz vein was exposed in two shallow open-cuts about 1,700 feet apart with a short adit between, but the intervening ground was covered. Mineralization was said to be similar to that at the Humbolt. A picked sample assayed 1.5 per cent tin and 9.1 ounces of silver per ton.

(22j) Skookumchuck Creek

The occurrences are on the crest and slopes of "Rusty Ridge," at the head of a north tributary of Skookumchuck Creek, and about a mile north of the composite White Creek granitoid batholith (Reesor, 1958). The area is underlain by quartzite, argillite, and minor conglomerate of the Proterozoic Aldridge Formation, intruded by dioritic Purcell Sills. Argillaceous rocks are locally tourmalinized, and tourmaline is common in quartz veins and pegmatites in the general area. Some pegmatites also contain beryl (Mulligan, 1968).

Scheelite and cassiterite have been found in some small quartz veins, and in float and soil samples, but no substantial concentrations have been reported. The locality is about 22 miles northwest of the Sullivan mine (22(k)), where cassiterite-bearing veins likewise occur in a tourmalinized conglomerate horizon in the Aldrige Formation.

(22k) Sullivan Mine

The Sullivan mine at Kimberley, B.C., has been the largest lead-zinc-silver producer in Canada since about 1923, and is one of the largest deposits of this type in the world. Tin as cassiterite concentrate or metal has been recovered as a minor by-product since about 1941. The Sullivan, a sedimentary-stratabound massive sulphide deposit, is the largest of three bodies of essentially similar ore in the immediate area. The others are the Stemwinder and the North Star, which are about 1 and 2 miles respectively south-southwest of the Sullivan¹. The Stemwinder, which is also known to contain tin, is however thought to be at a lower stratigraphic horizon than the Sullivan and is notably discordant (Freeze, 1966).

Host rocks, structure. The country rocks are quartzite, argillaceous quartzite, siltstone, argillite, and minor conglomerate of the Aldridge Formation, which is in the lower part of the Proterozoic Purcell System. The predominantly clastic sediments of the Lower Purcell Aldridge Formation, about 16,000 feet thick, and the overlying Creston Formation, show primary structures indicative of shallow-water deposition in a slowly subsiding basin. The

¹A composite sample of ore from the surface at the North Star was found to contain 300 ppm tin by X-ray fluorescence.



FIGURE 9A. Vertical east-west section, Sullivan mine, British Columbia (after C.O. Swanson and H. C. Gunning, 1944).



FIGURE 9B. Tin grade distribution plan, Suliivan mine, British Columbia (after A. C. Freeze, 1966).

Aldridge Formation is divided into lower, middle, and upper members, and the Sullivan orebody is near the transition between its lower and middle members. The Lower and Upper members are characteristically rusty-weathering, and contain fine disseminated pyrrhotite, or less commonly pyrite, iron silicates, or carbonates (Freeze, 1966). Lenses of intraformational conglomerate up to 3 miles long and 1,000 feet thick are common near the top of the lower Aldridge, and one major lens underlies most of the Sullivan ore zone. The Middle Aldridge member, however, appears to have been deposited in a relatively deep-water environment (Freeze, 1966).

The bedded rocks were folded on generally north-trending axes, mostly during Mesozoic orogeny, but some folding evidently took place in Precambrian time. The generally geanticlinal structure of the Purcell Mountains is dislocated by several major northeasterly to easterly trending faults which repeat the structure successively northward and between which the segments plunge 10 to 20 degrees northward. At least one of these, the Moyie Fault, is in or near the site of a structure that existed at least as early as Cambrian time (Leech and Wanless, 1962). Another, the St. Mary's Fault, cuts the Precambrian Hellroaring Creek Stock, and limits its metamorphic aureole but may also be originally a more ancient structure. The east-trending Kimberley Fault, which passes just north of the Sullivan orebody, has a large stratigraphic displacement (Freeze, 1966). Other major faults strike generally north to northwest, forming a complex network with the east-northeasterly striking faults.

Igneous rocks, metamorphism. The only volcanic rocks in the Purcell system are thin basaltic flows and tuffs about 21,000 feet stratigraphically above the Sullivan ore zone. Abundant dioritic sills and dykes up to several hundred feet thick, known as the Purcell or Moyie Intrusions, are interleaved with and cut the Purcell strata, especially the Aldridge Formation. They are predominantly quartz-diabase in composition and texture. Locally, thick sills show development of micropegmatite and granophyre at their upper margins. These rocks were considered to be a product of gravity differentiation by early workers, but Rice (1937) concluded that they represented greisenized sediments related to the intense metamorphism that affected argillaceous sediments for a distance of 100 feet or more from the contacts. Pyrite, pyrrhotite, and chalcopyrite occur as small specks and patches in the sills and are locally abundant enough to form small disseminated and vein deposits (Rice, 1941). The sills were folded together with the enclosing rocks. Some are thought to be related to and contemporaneous with the Purcell lavas and similar intrusions penetrate the orebody, but the maximum age of these intrusions is in doubt. A few lamprophyre dykes also cut the ore horizon.

The nearest granitic intrusion of appreciable size is a stock of Precambrian granodiorite and pegmatite on Hellroaring Creek, about 10 to 12 miles (16 to 19 km) southwest of the mine. This and the Matthew Creek body (see below) are the only known granitic rocks of Precambrian age in the Cordillera; all the others in the district, including the White Creek batholith, about 12 miles northwest of the mine, are Cretaceous. Pegmatitic phases of the Hellroaring Creek Stock contain muscovite, abundant tourmaline, and locally beryl. Composite samples taken by the writer from a berylliferous zone on Hellroaring Creek and a nearby small body on Lightning Creek were found to contain 22 ppm and 330 ppm tin, respectively, by spectroscopic analysis¹. The body cuts Aldridge strata and Purcell Sills and is believed to be intrusive into a pre-existing anticline (Leech, 1963). It terminates southward at the St. Mary's fault, a major tranverse feature.

Muscovite, granodiorite, and pegmatite similar to that on Hellroaring Creek also outcrop in a highly metamorphosed zone of tourmaline-bearing sillimanite-muscovite-quartz schist and biotite-garnet schist near Matthew Creek (Freeze, 1966; Leech, 1962). This area

¹A tin content of 164 ppm found by X-ray fluorescence in a heavy mineral concentrate from Hellroaring Creek above Lightning confirms this anomaly.

is between the Hellroaring Creek stock and the Sullivan mine, about 5 miles southwest of the mine.

Low grade regional metamorphism of the stratified rocks has resulted in development principally of sericite and chlorite from original clay minerals. Granitoid rocks at the contacts of some Purcell Sills have been interpreted as granitized sediments. Garnet and sillimanite have developed in the metamorphic zone near Matthew Creek. Garnet, actinolite, tremolite, scapolite, and cordierite occur as gangue minerals in the Sullivan orebody, and are abundant in some tin-bearing parts of the footwall zone (Freeze, 1966). The footwall sediments have been extensively tourmalinized in a zone that underlies most of the orebody and extends downward at least 1,500 feet beneath the western part of the orebody. This and other metasomatic phenomena closely related to the orebody are discussed more fully below.

The orebody. The orebody is at the crest and on the east limb of an anticlinal nose and dips about 30 degrees east, concordantly with the bedded rocks (Fig. 9A). It has been mined for about 6,000 feet along strike and 4,500 feet down dip. Minor folds on the limb, locally sharp, trend about north. A well-developed set of faults (Sullivan type), striking east of north, offsets the orebody progressively downward to the west. A large east-trending fault, the Kimberley Fault, crosses the workings toward the northern limit.

The footwall of the orebody consists of thin-bedded sediments with an extensive horizon of conglomerate (Fig. 9A and Pl. IB). The footwall conglomerate marks the lower limit of the ore zone in much of the mine. These rocks are extensively tournalinized. The hangingwall is typically massive quartzite, in large part albitized and chloritized. The ore horizon is mainly thin-bedded argillaceous siltstone, and the orebody pinches and swells, attaining a maximum thickness in excess of 200 feet. Much of the ore is well-banded, in layers ranging down to a fraction of an inch thick, and consists of alternate laminae of galena, marmatite (iron-rich sphalerite), and pyrrhotite. The laminae are commonly contorted and evidently reflect original sedimentary bedding. Pyrite, chalcopyrite, and arsenopyrite are occasionally present. Typical high temperature minerals, also present in small amounts, include garnet, magnetite, and cassiterite. A central oval-shaped zone about 800 feet long (the "iron core"), consists chiefly of pyrrhotite and locally, pyrite (Fig. 9B). The outer part of this zone is relatively rich in tin, and the ratio of lead to zinc is especially high around the outer edge (Pentland, 1943). Chalcopyrite, although very scarce in the orebody, has been observed in all areas where the grade of tin is high, and may have some value as an indicator (Pentland, 1943).

The existence of the tourmalinized footwall zone is especially relevant to the presence of cassiterite mineralization. The zone underlies much of the central part of the orebody, including the central iron zone. The tourmaline, which developed mainly at the expense of sericite, is largely in cryptocrystalline masses which form a matrix for the original sedimentary grains. Tourmalinization took place almost entirely prior to the development of sulphide mineralization, although it was preceded by an early minor development of pyrrhotite (Swanson and Gunning, 1944). A single sample of tourmalinized footwall conglomerate, collected by the writer in a part of the mine remote from the main tin concentrations, was found to contain 100 ppm tin and 1.5 per cent boron by spectographic analysis¹. The sample is from a slab that was collected to show the conglomeratic structure (Pl. IB), and contained very little pyrrhotite².

In some strongly deformed and fractured zones, tourmalinization extends up into the ore zone and even the hanging-wall rocks. However, albitization is the characteristic alteration in the hanging-wall zone. Chloritization is also a common feature, especially near the

¹The fluorine content (0.11 per cent) is more than 10 times the amount needed to transport this tin as sodium fluorostannate (see Chapter III, Transport and deposition of tin).

²Tin contents found by X-ray fluorescence of composites taken around and nearer the tin fracture zone (61 ppm) are: thin-bedded 61 ppm, massive 88 ppm, breccia zone 178 ppm, conglomeratic 252 ppm.

contact between the orebody and the albitized hanging-wall in the area around the central iron core (Freeze, 1966). Some of these pyrite-chlorite zones are higher than average in tin.

The entire orebody contains some cassiterite, but the main concentrations are near the outer part of the central pyrrhotite zone (Fig. 9B). They are associated with the pyrrhotite-rich zone that lies just above the footwall of the orebody, and the concentration tends to fall off toward the hanging-wall. Some pyrite zones near the central core also contain abnormal concentrations of cassiterite. However, the bulk of the pyrrhotite contains very little tin. Some small rich pockets are associated with folds, faults, and fractures (Pl. IA).

One such structure, the "tin zone" fracture, is one of the large crosscutting mineralized fractures in the mine (Freeze, 1966, p. 270 and Fig. 17-6). It lies below the southeast corner of the central pyrrhotite zone and is one of several shear-zones that penetrate the footwall of the normal orebody. This "tin-zone" shear is more than 200 feet long, up to 20 feet wide, and is mineralized for at least 300 feet below the footwall. In the footwall sediments it is narrow and essentially confined between well-defined walls. The intervening space is filled with crushed wall-rock fragments, considerably chloritized and mineralized with narrow veinlets of cassiterite-bearing pyrrhotite, sphalerite, and galena. On passing into the tourmalinized sediments, the zone widens and contains more large fragments and open cavities. A large irregular lens of pyrrhotite is quite rich in cassiterite. Smaller veinlets of cassiterite-bearing pyrrhotite and into the fractured wall-rocks. Pyrite, sphalerite, and galena are locally associated with the pyrrhotite. Sphalerite and galena enclose cassiterite and penetrate fractured cassiterite crystals. Some arsenopyrite, and scattered grains of scheelite, are present.

More than 90 per cent of the tin is in the form of cassiterite, with the remainder in unknown form in the sulphides. Most of the cassiterite is in rounded grains without crystal faces. According to Pentland (1943), it ranges in size from 85 microns to half a millimetre, but Banks (1941) noted that the maximum grain-size was about 75 microns.

The tin content of the ore as mined was estimated by Pentland (1943) at about 0.05 per cent, but it would average much less on the basis of published recent tonnage-recovery figures. The explanation may be that the bulk of production has shifted to areas remote from the tinrich zones centred around the pyrrhotite core. In these zones the concentration is much higher, and samples of pyrrhotite from the tin-zone fracture commonly contain 1 to 2 per cent tin.

Only about half the total tin content is recovered in the treatment process (Banks, 1941), mainly because of size distribution in the tin-plant feed. The process consists of gravity separation after removal of sulphides by flotation. A small amount of tin is also recovered as lead-tin alloy from drosses at the smelter. Production of tin so far has amounted to roughly 10,000 tons with a total value, at current prices, of more than 33 million dollars.

Origin and relation to intrusions. Although the origin of the Sullivan orebody as a whole has been widely discussed, there has been little reference in the literature to the origin of the tin mineralization. The apparent absence of granitic intrusions from the immediate area, the intricate banding of the sulphide ore, and the general conformity of the orebody with lithic units, suggest an essentially syn-sedimentary origin for the orebody. However, Cairnes (1932), Rice (1937), Pentland (1943), and Swanson and Gunning (1941) assumed an epigenetic replacement origin. Freeze (1966) restated the case for an epigenetic origin, emphasizing what appear to be clear-cut replacement phenomena locally in the Sullivan orebody and generally at the Stemwinder. For the tin mineralization in late fractures an epigenetic origin is beyond dispute, but it seems equally clear that some tin was distributed throughout the massive orebody contemporaneously with the main ore metals.

In either genetic model, the tournalinized zone beneath the central thickest section and barren pyrite-pyrrhotite core of the orebody would represent the feeder zone for hydrother-

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mal ore-bearing solutions, whatever their source¹. The footwall conglomerate may have helped to localize the feeder zone because of its permeability. In the syn-sedimentary model it may mark the sedimentary basin or trough in which the massive sulphides were being deposited. In either model tin, characteristically one of the earliest metals deposited in pneumatolytichydrothermal orebodies, would be concentrated mainly in and near the access channelways, close to the limits of boron fixation. This is compatible with its observed concentration in the footwall zone and around the central iron core. Chalcopyrite, characteristically richer in feeder-zone ore in volcanogenic deposits of supposed syngenetic origin, would also be concentrated in these zones. In the syn-sedimentary model it must be assumed that the bulk of the iron contained in ore-forming solutions continued to precipitate in the area immediately over the source vent, while zinc, lead, some tin, and periodically iron alone migrated laterally along the sea floor before being precipitated. The enrichment in lead relative to zinc near the central core, as noted by Freeze (1966), appears to conflict with the conventional zoning sequence. However, some lead was evidently introduced after fracturing of deposited cassiterite in footwall fractures (Freeze, 1966), and therefore late in the zoning sequence. The observed albitization and chloritization of the hanging-wall zone can only be reconciled with the syn-sedimentary model by assuming continuation or resurgence of metasomatic activity after the deposited metallic sulphides were covered.

The problem of the origin of the deposit involves the question of relative ages of the ore, the ore horizon², and the various intrusions of the area. The age data, which are somewhat conflicting and therefore inconclusive, are tabulated on the next page. Constraints imposed on the theoretical mode of formation of the orebody are more severe in the syn-sedimentary model than in the epigenetic-replacement model.

Rice (1941) and others assumed that the orebody was genetically related to the late Mesozoic regional orogeny and intrusion. Partly in view of the apparent absence of granitic intrusions from the immediate area, Cairnes (1932) and Swanson and Gunning (1944) suggested that the orebody might be genetically related to the Purcell diorite-micropegmatite intrusions, which are of Precambrian age and have numerous small sulphide deposits (mostly copper but some lead and zinc) associated with them. Dykes of similar composition, although extensively replaced by sulphides do cross the orebody (Freeze, 1966) and are therefore younger. However Freeze (1966) presented evidence that tourmalinization occurred after intrusion of the Kimberley Sill, which lies beneath the western part of the orebody. Potassium-argon ratios indicate a considerable range of ages for various sills, bracketing the 1250 million year age indicated for the lead in the deposit by lead-isotope ratios (Leech and Wanless, 1962). It is even conceivable that some sills in the stratigraphically oldest rocks were emplaced before the sediments of the ore zone were deposited (Freeze, 1966). This admits the possibility that syn-sedimentary ores could be related to those old sills.

The isotopically established Precambrian age of the tourmaliniferous and berylliferous granitic stocks 5 to 12 miles southwest of the mine suggest another possible source for orebearing fluids, especially from the standpoint of tin mineralization. Major ancient fault systems could have provided the necessary access. The minimum age of these intrusions, as indicated by K-Ar ratios (765 million years, Leech and Wanless, 1966) is less than that of the lead in the ore as indicated by lead isotopes (1340 million years, Leech and Wanless, 1966). However, the 1260 million year age found for this intrusion by Ryan and Blenkinsop (1971) from Rb-Sr ratios may be more realistic. Conversely, the age of actual deposition of the lead

¹E. R. Kanaswewich (Science, Vol. 16, 1968, p. 1002-1005) postulated, on geophysical evidence, a Precambrian rift extending across southern Alberta toward the Sullivan mine; he suggested that it acted as a channelway for mineralizing solutions from the mantle.

²Stratabound lead-zinc, as well as widespread copper occurrences in the Belt-Purcell terrain are apparently much higher in the stratigraphic sequence than the Sullivan deposit.

	Age		
	Stratigraphic Structural	Isotopic (million years)	
tin, etc. in late fractures ? Cretaceous granite Sullivan ore?			
Hellroaring Creek	cuts Purcell	745-790 (K-Ar)	
granite (Precambrian)	Sills	Leech and Wanless 1260 (Rb-Sr)	
Lamprophyre	cuts ore fold	Ryan and Blenkinsop 765 min (K-Ar)	
Sullivan ore?	(time of original separation)	1340 (Pb-Pb) Leech and Wanless 1200 recalc.	
		Ryan and Blenkinsop	
Purcell Sills	part equiv. to Siyeh (21,000 feet above ore zone). Similar dykes locally mineralized	1500–1100 (K-Ar) (quoted by Freeze)	
Sullivan ore?			
Ore horizon	L-M Aldridge, cut by Precambrian granite, cut by some Purcell diorite but locally mineralized		
Purcell Sills?	possibly some prior to ore horizon (Freeze)		

in its present mineral form may have taken place as late as the 760 million year age indicated by K-Ar ratios for the granite (Leech and Wanless, 1962). Lamprophyre dykes that appear to have been emplaced after the main phase of mineralization but before the local introduction of galena, also yielded a K-Ar age of 765 million years (Leech and Wanless, 1962).

For the base metal mineralization, mafic igneous rocks such as the Purcell diorites seem a more likely source just as the granitic intrusions seem so for the tin concentrations. In view of the extensive granitoid contact phases of some sills it seems possible that these comparatively late granitic intrusions are differentiation-granitization products, co-genetic with the Purcell diorite but emplaced somewhat later. The cassiterite that is widely dispersed through the orebody may be directly related to the base metals exhausted from the dioritic magma as a result of this differentiation-granitization process, while tin in late fractures was introduced after solidification of the granitic magma. However, the Cretaceous White Creek batholith, a compositionally zoned eastern satellite of the Nelson Intrusions (Reesor, 1958) lies only about 12 miles northwest of the Sullivan. It also has associated berylliferous pegmatites, and cassiterite-scheelite-quartz veins in tourmalinized conglomeratic Aldridge strata. Lead deposits near the White Creek batholith also contain essentially non-radiogenic "Precambrian" lead like that at the Sullivan (Leech and Wanless, 1962). These occurrences suggest that tin in late fractures at the Sullivan may have been remobilized and redeposited as late as the Mesozoic orogeny.

Precambrian Shield

Known tin occurrences of the Precambrian Shield comprise a wide variety of types, including pegmatites, tin-bearing massive base-metal sulphide deposits, and several uncommon types in which tin occurs as rare minerals in unusual associations. The tin-bearing

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massive sulphide deposits include the Kidd Creek mine (loc. 36) where recovery of tin, expected to start by the end of 1973, will make it the foremost North American tin producer. Attempts have been made to mine some pegmatite deposits for their tin content, and small amounts of tin have been recovered together with tantalum minerals. The tantalum mineral wodginite, recovered at the Chemalloy property (loc. 30), contains a substantial amount of tin.

The occurrences are practically all in major volcanic-sedimentary residual "greenstone" belts, bounded by granitoid rocks and granitic gneisses. Most are in the Archean Slave and Superior structural provinces, where the youngest granitic rocks are dated at about 2500 million years (Stockwell, 1963). The few occurrences in the younger Churchill and Southern provinces (age about 1,800 million years) are insignificant, mainly mineralogical curiosities. Those in the Grenville Province (age about 900 million years) are also insignificant or dubious. These provinces are characterized by granitic gneisses and other highly metamorphosed rocks. Greenstone belts comparable to those of the Slave and Superior provinces are scarce in the Grenville and the greater part of Churchill Province.

The tin-bearing pegmatites are mostly lithium rich, and mostly confined to lithium-rich districts. Significantly, these lithium pegmatites are also almost confined to the Slave and Superior provinces, whereas beryl-bearing pegmatites are common also in the Grenville Province (though comparatively rare in Churchill Province).

To the writer it is inconceivable that reworking of an original Archean basement, accompanied by widespread potassium metasomatism, could lead to the wholesale expulsion of such "volatile" metals as tin and lithium. In the case of lithium, a remarkable group of occurrences has a bearing on the distribution of lithium, and by analogy, tin, in Slave and adjoining Churchill Province. Five lithium pegmatites in northern Manitoba, some of which have appreciable tin contents, lie in a gently curving belt that extends for about 280 miles, crossing the Archean greenstone belts and the Superior-Churchill boundary. They are all very much alike and are all fresh, but their indicated K-Ar ages correspond to those of the granitic rocks among which they lie-2500 million years deep in Superior Province, 2250 in the "transition" zone, and 1800 million years for the one on the Churchill side of the boundary. This last is the only lithium-rich pegmatite known in the western part of Churchill Province. The model of Precambrian development proposed by Goodwin (1968), whatever its merits may be from other standpoints, provides a rational explanation of the differing pegmatite ages described above. This model essentially postulates that the Churchill Province represents a deeper layer of the crust which owes its younger age to the fact that it was more deeply buried than, and therefore solidified later than corresponding, more mafic, Archean-type rocks. In this model tin and lithium would, because of their similar geochemical behaviour, tend to be driven out of the deeper potassium-rich layers together with magnesium and iron, and concentrated in the upper greenstone belts; the latter have presumably been largely removed by erosion from the upfaulted Churchill Province. The low tin content of granitoid rocks in Superior Province, compared with the volcanic rocks of some greenstone belts (Tables 6 and 7), also suggests that tin was concentrated in the volcanic and sedimentary rocks of these belts. Incidentally, lithium pegmatites and other lithophile-metal occurrences are usually prominent in greenstone belts that contain tin-bearing massive sulphide deposits.

Slave Province

Except for traces of tin reported in some gold-bearing quartz-sulphide veins near Yellowknife (loc. 23), the tin occurrences of the Slave Province are all in the Yellowknife-Beaulieu River District (loc. 24). All except one are pegmatite dykes that contain lithium minerals, columbite-tantalite, and in some cases beryl, with local concentrations of cassiterite.

(24) Yellowknife-Beaulieu District

The bedded rocks, chiefly greywacke and slate of the Archean Yellowknife Super Group, are closely folded and intruded by somewhat gneissic biotite granite, and by bodies of younger muscovitic and pegmatitic granite (Fig. 10, *in pocket*). Cross-folding on north-northwesterly trending axes of previously folded strata coincided with intrusion of the pegmatitic muscovite granite. Metamorphic aureoles surround the large granitic bodies and are particularly conspicuous around the late intrusions, where they are marked by development of cordierite-andalusite-staurolite nodules in the schists. Chiefly within these aureoles lie hundreds of pegmatite dykes as much as thousands of feet long and more than 100 feet wide. Several hundred of these dykes contain rare elements including lithium, beryllium, columbium-tantalum, and tin. Some dykes are internally zoned with respect to lithium and beryllium, and a regional zoning of these elements about younger granitic masses is apparent (Mulligan, 1965), but tin occurrences are too few and widely scattered to show any clear zoning influence.

Tin was found by Jolliffe (1944) in only 22 pegmatites, of which only 7 appear to contain significant concentrations of tin (Fig. 9), and in these it is mainly in local concentrations. These dykes contain tantalite-columbite and more or less lithium minerals. Amblygonite and other phosphate minerals are present in most. Beryl is abundant only in the well-zoned dykes. Tourmaline is a rather rare constituent in the pegmatites of the district, although tourmalin-ized border zones are fairly common, and this is considered significant because tourmaline is common in gold-quartz veins that are locally cut by pegmatite dykes. Except at locality 24(g), no fluorite has been found and no topaz has been definitely identified. However, the association of blue-green apatite with cassiterite at locality 24(a) may have genetic significance. The cassiterite-bearing dykes at the Bore are characterized by an abundance of cleavelandite, quartz, and yellow muscovite, and may be more albitic than the typical lithium-bearing pegmatites of the district (Mulligan, 1965).

Three of the cassiterite-bearing dykes (locs. 24(c),(d),(e)) (Fig. 10) are spatially related to a narrow wedge-like stock of muscovitic granite. Three (locs. 24(a),(b),(f)) lie close to the boundary between nodular schist and less metamorphosed sediments. Locality 16(g) is exceptional, as it has some of the characteristics of a hydrothermal deposit.

(24a) Bore Group

A swarm of subparallel pegmatite dykes lie in a zone extending about 1,650 feet from the south shore of Sproule Lake (Jolliffe, 1944, p. 20-22 and Fig. 6). The mineral composition is variable. Most of the dykes are grey and comparatively fine grained, consisting mainly of cleavelandite and quartz with minor muscovite. Spodumene and amblygonite occur sparingly. Beryl is rather rare, and tantalite-columbite only locally conspicuous. Cassiterite, listed as "relatively abundant" in three dyke-sections, was seen by the writer in two. In dyke section No. 28, grains up to 2 mm across are conspicuous in a streak a few feet long and 1 to 2 inches wide, in a fine cleavelandite-quartz-muscovite assemblage. The borders of the dyke are coloured black by fine-grained tourmaline. Dyke Section No. 20 is composed of a fine grey cleavelandite-quartz-muscovite assemblage with a core-like quartz stringer and aplite streaks. Much of the cleavelandite is in radiating rosettes surrounded by yellow mica, and may be pseudomorphous after potassic feldspar. The border zones are partly tourmalinized. Black cassiterite, in aggregates an inch or more across in the wall assemblages, is locally abundant (Pl. VB). Blue-green apatite is commonly associated with cassiterite, but no fluorite or topaz has been identified. A bulk sample from this section was found to contain 0.41 per cent tin (Jolliffe, 1944). A composite sample of the Bore Group pegmatites taken by the writer was found to contain 85 ppm tin by spectroscopic analysis.

(24b) Freda Claim

According to Lord (1951), a gently dipping dyke is exposed for about 300 feet and is 7 to 16 feet wide. Pegmatitic muscovite granite outcrops about $1\frac{3}{4}$ mile northwest. The dyke varies from fine to coarse grained and is composed of cleavelandite, microcline, quartz, and muscovite, with local concentrations of amblygonite, beryl, and columbite-tantalite. Cassiterite appears to be concentrated mainly in aplitic patches and bands along or near the footwall. It varies from very fine grains to aggregates up to $1\frac{1}{2}$ inches long. Grab samples assayed up to 0.63 per cent SnO₂. Concentrate from a small mill operated in 1946 assayed 1.83 per cent tin together with 46.19 per cent Ta₂O₅ and 31.18 per cent Nb₂O₅.

(24c) Best Bet

A quarry 260 feet long, 20–26 feet wide, and 27 feet deep occupies most of the outcrop area of a lenticular pegmatite over 330 feet long (Mulligan, 1965). The dyke is well zoned, with quartz-amblygonite core pods bordered by very coarse spodumene which merges with cleavelandite-quartz-muscovite wall zones. These contain scattered beryl crystals. Tantalitecolumbite and cassiterite in grains up to 1 inch across are found mostly in muscovite-rich segregations, and also in quartz at the boundaries of large spodumene crystals. A chip sample of muscovite-tantalite-columbite analyzed by the Bureau of Mines, Ottawa, contained 3.72 per cent tin and 3.56 per cent Ta_2O_5 (Rowe, 1952). A sample of mill concentrate analyzed by the Bureau of Mines contained 13.4 per cent tin, 58 per cent Ta_2O_5 , and 8 per cent Cb_2O_5 (Lord, 1951, p. 119). The ore was treated at the mill on the Moose property (loc. 24(f)).

(24d) Tan Group

The Tan claims cover four pegmatite bodies a few hundred feet long and 5 to 10 feet wide. They all contain fairly abundant coarse spodumene and scattered columbite-tantalite crystals, but only Dyke No. 3 contains an appreciable amount of cassiterite. As exposed in a bulldozed trench, this dyke shows a 4-inch border of clear quartz on the hanging-wall, succeeded downward by a 12-inch zone consisting mostly of long, crystal-like aggregates of very fine grained micaceous material. Below this is a zone of coarse green spodumene. Both the spodumene crystals and the yellowish micaceous aggregates are parallel and oriented perpendicular to the hanging-wall. Cassiterite occurs in aggregates up to an inch or more long in quartz-mica segregations, together with columbite-tantalite and tapiolite. The yellow aggregates may be pseudomorphs of potassic feldspar. Rowe (1952) mentioned microcline as one of the components of this dyke, but most of the feldspar appears to be cleavelandite, a platy variety of albite. A bulk sample of 23 pounds of "tantalite ore" from this dyke yielded 32.6 grams of concentrate, which assayed 15.96 per cent tin (Jolliffe, 1944).

A few aggregates of cassiterite up to $\frac{1}{2}$ inch across were found in No. 1 dyke, which contains scattered large crystals of spodumene in a cleavelandite-quartz-muscovite assemblage. No. 2 dyke also contains scattered spodumene crystals. No cassiterite was found, but a composite chip sample taken by the writer was found to contain 190 ppm tin by spectroscopic analysis.

(24f) Moose Group

A large well-zoned pegmatite similar to that at the Best Bet (loc. 24(c)) was extensively quarried and the material treated for tantalite-columbite in a mill on the property prior to 1955. One of three bulk samples was reported to yield about 4.6 pounds of heavy concentrate per ton, with a cassiterite content of 8 per cent (Lord, 1951, p. 120). A sample of mill concentrate supplied by the company assayed only 0.30 per cent tin (Lord, 1951).
(24g) Stannum Group

A coarse granitic or pegmatitic dyke 2 to 5 feet thick extends about 1,450 feet northwesterly from a large body of granite. It contains abundant tourmaline near the granite contact. Farther away there is a considerable increase in quartz, with local concentrations of fluorite and sulphides. A few grains of cassiterite were found in such concentrations. In one specimen it occurs as black radiating prismatic needles in quartz, closely associated with fluorite and pyrite (private report, Geological Survey files). This occurrence appears to be a pneumatic-hydrothermal, rather than a normal pegmatitic type.

Churchill Province

The only significant tin occurrence in the Churchill Province is the Philmore–Yellowknife property. It is very close to the Slave–Churchill boundary whose precise course is here concealed beneath Great Slave Lake. Its host rocks are of the Archean type, and there is no evidence that it should not be included in the Slave Province. The other occurrences are insignificant¹ and the occurrence of native tin in pitchblende ore at the Nesbitt–Labine (loc. 26) is a unique mineralogical curiosity.

(25) Philmore–Yellowknife Gold Mines

Tin occurs with gold, tungsten, and copper minerals and molybdenite in sheared and silicified zones in quartz-mica schist and gneiss. The zones outcrop in an area 7,300 feet long and 750 feet wide covering parts of four islands and are up to 1,500 feet long and 10 feet wide. The rocks in the shear zones are slightly fractured and brecciated, locally cut by quartz veinlets, and partly replaced by quartz and metallic minerals. The tungsten occurs mainly as ferberite. According to Hawley (1939, p. 58), quartz bodies with micaceous borders contain tin, tungsten, and molybdenum. A bulk sample of micaceous and chloritic selvages from quartz masses contained only 0.11 per cent tin and 0.15 per cent tungsten, but another sample contained 0.20 per cent tin and 1.20 per cent tungsten. The tin mineral was not identified but was assumed to be cassiterite. Gold and tungsten were produced from mining and milling operations about 1942, but no tin was recovered.

Superior Province

As in the Slave Province, the tin occurrences of the Archean Superior Province include pegmatitic and related types, but significant concentrations of tin are also found in some massive zinc-copper sulphide deposits. The occurrences are in sedimentary-volcanic belts bounded by granitoid rocks and gneiss. Some of these belts also contain lithium- and beryl-lium-bearing pegmatites, and the pegmatitic tin occurrences generally are lithium bearing. Several other lithium-rich pegmatites contain several hundred parts per million tin, notably in the Georgia Lake area (lat. 49°14', long. 88°01') where cassiterite in very small amount was identified in one complex dyke (Pye, 1965, p. 29). The pegmatite-type bodies that contain the highest concentrations of tin are albite-rich types, notably the occurrence at Red Sucker Lake (loc. 28) and some in the Winnipeg River District (loc. 30).

The tin-bearing massive sulphide bodies of the Precambrian Superior Province listed in Table 1 (locs. 32, 35, 36, 37) are those in which tin minerals or appreciable concentrations in

¹Tin is present in significant amount together with uranium in a unique occurrence of quartz-pebble conglomerate of the Nonacho Group at MacInnes Lake, latitude 61°22', longitude 110°15' (J. C. McGlynn, pers. com.). Not on map or tables. This is apparently a weak paleoplacer deposit.

other minerals have been reported¹. Cassiterite is the only important tin mineral. The Kidd Creek deposit (loc. 36), from which recovery of tin is expected to begin by the end of 1973, averages about 0.14 per cent tin. The South Bay deposit (loc. 32a) contains about 0.3 per cent tin in one systematically sampled part. Although the over-all tin content is not known, this suggests that it may be higher than in any other known massive sulphide deposit in Canada, and enhances the possibility that economic concentrations of tin may be found in massive sulphide deposits in the Shield and elsewhere. At the Geco mine in Manitouwadge area (loc. 35), the massive sulphide ores contain about 0.1 per cent tin.

Tin concentrations up to 250 and 500 parts per million respectively, were reported in some ores of the Noranda and Matagami areas by Roscoe (1965). Colwell (1963) reported 0.043 per cent tin in a sample of sphalerite from Matagami Lake, and 0.084 per cent in samples from Waite Amulet. At Lac Dufault, A. E. Johnston (1966 and pers. com.) found some stannite in the upper part of the orebody, associated with sphalerite. Nearly all the tin-bearing massive sulphide bodies are related to acid volcanic and hypabyssal rocks of rhyolitic composition. This undoubtedly has a bearing on their enrichment in tin. At Manitouwadge, tin enrichment may be related to proximity of granite and pegmatite. The tin content appears to be higher near the granite contact than in the interior of the orebodies. The Trout Bay, Manitouwadge, and Kidd Creek deposits probably contain more galena (and silver) than the typical massive base-metal sulphide of the Canadian Shield, and their enrichment in tin may be related in some way to their lead and/or silver content. The South Bay deposit, on the other hand, contains very little lead, although it has an appreciable silver content.

Ultimately, the tin-bearing sulphide deposits of the Shield, as well as those of the Cordilleran and Appalachian regions, probably reflect higher than average crustal abundance in the specific belts in which they occur. The South Bay mine is in the Birch–Uchi greenstone belt, which has the highest level of tin of all the greenstone belts analyzed (Table 6). Assuming a content of 0.25 per cent tin and 14 per cent zinc in the orebody, the ratio of concentration in the orebody to concentration in the volcanic rocks of the belt (average) is about the same (1250) for tin as for zinc. The second highest in tin is the Timmins–Noranda greenstone belt, where also tin is appreciably concentrated in a number of massive base-metal sulphide deposits, including the Kidd Creek deposit (loc. 36).

The presence of lithium-bearing pegmatites in particular belts may indicate probability of tin enrichment. However, the lithium-rich Preissac-Lacorne area seems to be deficient in tin. Composite samples from the Molybdenite Corporation and Lac Roy molybdenum deposits were found to contain only 2.8 and 1.8 ppm tin, respectively.

(30) Bernic, Shatford, and Rush Lakes (Winnipeg River District)

Among the many lithium- and beryllium-bearing pegmatites of the district, cassiterite occurs in significant amount only in a few albite-rich dykes (Fig. 11). None is of commercial importance as tin deposits. A considerable amount of exploration was done on them about 1929, and shafts were sunk at Bernic Lake (at the site of the present Chemalloy mine) and at Shatford Lake. The dykes on the Rush, Stannite, and Odd claims were re-examined in 1940–1942 by the Federal Department of Mines and Resources. At the Odd claim 2,200 feet of drilling was done. The area has been described by J. F. Davies (1955, 1957).

The area is underlain by Archean metavolcanic and metasedimentary rocks of the Rice Lake Group, which are invaded by some basic intrusions and younger granitic rocks. The

¹Traces of cassiterite occur in zinc ore at Zenmac Metal Mines Limited near Schreiber, Ont. (D. Owens, pers. com.) at lat. 48°59′, long. 87°22′ (approx.). The occurrence is not listed in Table 1 nor shown on Map 1352A. Composite samples from the mill site were found to contain tin as follows: sphalerite-rich 562 ppm, pyrrhotite-chalcopyrite 21 ppm.





bedded rocks between Oiseau River and Bernic Lake form an easterly trending syncline whose axis lies within the metasediments between Oiseau River and Rush Lake (J. F. Davies, 1955). A fault is believed to follow the general course of Oiseau River, and numerous northwesterly striking faults cut the granite north of the river.

The granitoid intrusions include various gneissic and massive granitic to dioritic bodies mostly between Oiseau and Winnipeg rivers, and widespread batholiths of pink to grey microcline granite. The youngest intrusions are bodies of pegmatitic to aplitic muscovitealbite granite (Davies, 1957). The body south of Winnipeg River is complexly banded in patterns marked by trains of mica and garnet, and contains various lithia micas and scattered beryl crystals. These intrusions are probably closely related to the rare-element-bearing pegmatites.

The relatively tin-rich Stannite and Odd pegmatites are in metasediments but the others are in metavolcanic rocks.

West of Rush Lake an albite pegmatite 1,300 feet long and up to 250 feet wide contains accessory tourmaline, spodumene, and a little beryl, and very small amounts of cassiterite, arsenopyrite, and sphalerite. The Stannite deposit, about 2,000 feet north of the west end of Rush Lake, contains some spodumene and very minor beryl in a coarse quartz-feldsparmuscovite assemblage. On the north side near its west end the dyke consists of an aggregate of quartz and pale yellow mica, and is in contact with quartz-mica schist. This quartz-mica border phase contains cassiterite crystals up to $\frac{1}{2}$ inch across in small bunches in a zone about a foot wide and only a few feet long.

At the Odd claim, about 4,000 feet north of Rush Lake, the eastern part of a pegmatite dyke consists mainly of a fine- to medium-grained assemblage of albite, yellowish mica, and tournaline. Cassiterite grains are scattered throughout the albite phase. On surface, over a length of 320 feet and a width of 4.7 feet, the dyke averaged 0.35 per cent tin. Drilling revealed a lower grade at depth. The coarsely pegmatitic west end of the dyke contains only scattered crystals of cassiterite. A chip sample across the dyke taken by the writer was found to contain 0.08 per cent tin.

At the Shatford Lake occurrence, cassiterite was found in a pegmatite dyke exposed on a small reef. The pegmatite lies between garnet gneiss on the north and pillow lava on the south. Cassiterite, in crystals up to $\frac{1}{4}$ inch across, was found mainly in a quartz-muscovite zone about $2\frac{1}{2}$ feet wide. A little fluorite was also reported. A shaft 112 feet deep was sunk by the Manitoba Tin Company in 1929 on a nearby island, and a crosscut 167 feet long was driven towards the discovery. The quartz-muscovite phase was not encountered underground, and the tin content was found to be very small.

At the Bernic Lake occurrence a shaft was sunk and some underground exploration done by Jack Nutt Tin Mines prior to 1930. The surface dykes, generally flat-lying, consist of albite, quartz, pale yellow mica, and abundant black tourmaline. Cassiterite occurs in narrow fine-grained dykes and in the fine-grained margins of thicker ones. The large flatlying pegmatite, which is currently (1970) being exploited for tantalum minerals by Chemalloy Minerals Limited, lies immediately beneath (J. F. Davies, 1957; Hutchinson, 1959; C. M. Wright, 1961). It is a complex zoned body with perthite-albite-quartz-muscovite wall zones, a spodumene-rich intermediate zone, lepidolite and pollucite inner zones, and quartz-amblygonite core. An albitite unit consisting mainly of sugary albite and fine white mica with occasional remnants of coarse microcline, forms an extensive layer in the lower part of the pegmatite. In part it overlies the lower wall zone but in part it interfingers with the lithiumrich units. The albitite zone contains only a little cassiterite but a significant amount of wodginite, a rare tin tantalate with about 13 per cent SnO₂ (Nickel *et al.*, 1963). In a pilot mill test of the tantalum ore a final concentrate was produced containing 49.67 per cent Ta_2O_5 and 8.5 per cent SnO₂ (Raicevic, 1968). Production of tantalum concentrate started in 1969, but the writer understands that no payment is received for its tin content.

Minor cassiterite occurrences in the district include the Crocodile Claim, $1\frac{1}{2}$ miles northwest of Shatford Lake, where the dykes consist mainly of albite with quartz-muscovite assemblages near the walls. Another similar dyke on the Success claim, 1,300 feet east of the Crocodile, also contains minor cassiterite (Bateman, 1943). A little cassiterite is associated with lepidolite at the Annie and Bear (Silverleaf) pegmatites south of Winnipeg River.

A tin sulphide mineral was reported in vein deposits on an island near the northeast shore of West Hawk Lake, about 50 miles south of the district, but samples taken by Bateman (1943) showed no trace of tin.

(32a) South Bay Mines, Dent Township, Ontario

The South Bay mines property of Selco Mining and Development Limited (Fig. 15) is in the southeast corner of Dent Township, about 50 miles east of Red Lake in Kenora District, Ontario. The orebody as a whole is a stratiform massive pyrite-sphalerite-chal-copyrite deposit associated with the late rhyolitic phase of a differentiated volcanic pile (Pollock *et al.*, 1972). The average ore contains about 16 per cent zinc, 2.7 per cent copper, a little lead, about 3.7 ounces of silver per ton, and a few tenths of 1 per cent tin as fine-grained disseminated cassiterite. The deposit has been estimated to contain about 1 million tons of ore. Production started in 1971.

The ore is in several lenses in rhyolitic metavolcanic rocks, mainly tuff and lapilli tuff, near their contact with comparatively homogeneous quartz feldspar porphyry, which is considered to be a shallow subvolcanic intrusive phase. This latter rock has a distinctive appearance, with phenocrysts of quartz and feldspar a few millimetres in length, which stand out in relief against the fine-grained siliceous matrix on the weathered surface.

The area is on the east limb and near the axis of a regional north-northeasterly trending syncline. The rocks of the ore zone are folded into a tight northeasterly trending synform with a core of felsic tuffs enclosed in quartz feldspar porphyry (Pollock *et al.*, 1972, Fig. 2). The orebodies were folded together, with the wall-rocks forming a complex pattern of folded lenses which plunge northeastward with the lineation of the wall-rocks (Pollock *et al.*, 1972, Fig. 2). Fig. 2).

The grade of metamorphism is low; the rocks are sheared and altered to sericite and carbonate. This alteration of the wall-rocks increases in intensity toward the ore zone. The banded nature of the ores and spheroidal structure of much of the fine-grained pyrite are compatible with the low metamorphic grade of the country rocks.

Zoning of the orebodies with respect to zinc and copper is not marked, but pyrite with minor chalcopyrite predominates near the wall-rock contacts, and is locally disseminated in the wall-rocks. In some places pyritic stringers and pyrite-bearing quartz "gash" veins extend several feet into the footwall porphyry.

Cassiterite, in subround grains ranging from 5 to 60 microns, is widely disseminated in the silicate gangue and among the sulphide minerals. It is preferentially associated with sphalerite, mostly at or near contacts of sphalerite with gangue minerals. Occasionally large subhedral pyrite crystals enclose cassiterite together with gangue minerals (Bridge, 1972). Cassiterite is rarely enclosed by chalcopyrite. No tin, other than fine dispersed cassiterite, was detected by electron microprobe scanning in the sulphide minerals (Bridge, 1972). The cassiterite contains traces of Ag, As, Zn, Cd, and Pb, but no Cu or Fe (Bridge, 1972).

Forty-five samples taken systematically in an area 180 feet long and 30 to 40 feet wide on the 50-foot level ranged from 0.07 to 0.76 per cent tin (Bridge, 1972, Appendix I). Bridge

reported the median tin content of the samples as 0.31 per cent. The arithmetic mean of the analyses listed is 0.23 per cent. Plotting and contouring of the analytical data listed by Bridge on his sample location chart (Bridge, 1972, Appendix II) show a general increase in tin content from the lateral boundaries (presumably the wall-rock contacts) toward the central zone of the area sampled, but the highest tin values are closer to the northwest (porphyry) contact. Corresponding zinc analyses, similarly plotted, do not show a similar distribution pattern.

Samples taken from the 150-foot level (South Bay mines) contained less than 0.02 per cent tin, but those samples were also very low in zinc and copper (less than 1 per cent). Harris (1972) reported the tin content of a bulk sample of chips of massive sulphides as 0.33 per cent, by chemical analysis. Harris also reported traces of wolframite and scheelite in the ores. Composite samples taken by the writer from three ore lenses intersected by drillholes UG2 and SB30 ranged from 0.12 to 0.24 per cent tin by X-ray fluorescence analysis, but these are probably below the true values. A composite sample of the quartz "gash veins" in the footwall was found to contain 88 parts per million tin by spectroscopic analysis. The average tin content of the deposit is not known, but it is probably the highest of all the massive sulphide deposits so far known in Canada.

Massive sulphide deposits at Elbow Lake and Snakeweed Lake, about 8 and 16 miles respectively southwest of the South Bay mine, also contain cassiterite and stannite in small amounts (Harris, 1972). These deposits are all in the Birch–Uchi greenstone belt, in which the volcanic rocks have the highest average tin content of the four greenstone belts surveyed (Baragar and Goodwin, 1968) (see Table 6). Assuming a metal content of 0.25 per cent tin and 14 per cent zinc in the orebody, the ratio of concentration in the orebody to concentration in the volcanic rocks is about the same (1250) for tin as for zinc. Composite samples taken by the writer of the rocks near the mine area were found to contain tin as follows: rhyolitic tuff (Unit 2) 7.7 ppm, quartz-feldspar porphyry (Unit 3) 3.9 ppm, granodiorite west of mine (Unit 4) 2.5 ppm, granodiorite south of mine area 7.5 ppm. The relatively high tin content of the host rocks suggests a syngenetic, volcanogenic origin for the tin as well as the base metals.

(32b) Trout Bay Deposit, Mulcahy Township, Ontario

The Trout Bay massive sulphide deposit of Cochenour Willans Gold Mines, Limited, is about 4,000 feet southwest of Trout Bay, about 20 miles west of Red Lake, Ontario. It occurs in a sequence of metavolcanic and metasedimentary rocks intruded by gabbroic sills. The mineralized host rock is a carbonatized chlorite-anthophyllite schist, apparently an altered mafic rock. Minor stannite and rare cassiterite have been identified in a complex mineral assemblage consisting chiefly of pyrrhotite, sphalerite, and chalcopyrite, with lesser galena and a number of unusual antimony, silver, cobalt, and nickel minerals (Cabri *et al.*, 1970). Stannite occurs as inclusions in sphalerite and chalcopyrite, and on the borders of sphalerite grains.

(34) Linklater Lake

At the occurrence, on the south shore of Linklater Lake, trenching has exposed 18 narrow granitoid dykes cutting across greywacke and iron-formation in a zone 1,500 feet long and 50 feet wide. The dykes average 6 inches in width and 30 feet in length. They are composed of pink feldspar, quartz, and muscovite, with minor tourmaline and scattered concentrations of cassiterite. They are partly felsitic but mainly granitoid, with a distinct augen structure due to lenticular porphyroblasts of feldspar. The texture is cataclastic, with shattered

feldspar grains partly recrystallized and consisting mainly of plagioclase, probably albite. Microscopic grains of cassiterite and beryl were seen in some thin sections, and topaz and fluorite were tentatively identified.

Channel samples taken by San Antonio mines from the dykes in 1948 ranged from trace to 1.83 per cent tin. Chip samples taken by the writer from various dykes ranged up to 0.2 per cent tin by spectroscopic analysis.

Although the dykes are apparently restricted to a zone of iron-formation, a sample of magnetic country rock was found to contain only 0.7 ppm tin, whereas the nonmagnetic rock contained 4.4 ppm.

Several pegmatites in the area contain beryl and one was reported to contain cassiterite. No lithium occurrences are reported, but lithium-rich pegmatites are abundant farther east in the same sedimentary-volcanic belt.

(35) Manitouwadge Area, Gemmell and Mapledoram Townships, Ontario

The Manitouwadge area (Fig. 16), is about 40 miles northeast of Marathon, Ont., at the northeast corner of Lake Superior. It contains two important producing mines, the Geco, owned by Noranda, and the Willroy and its affiliates. The areal geology has been described by Pye (1957), and Milne (1969, 1970). In the area, a number of large and small massive zinc-copper-lead-silver deposits are emplaced in predominantly metasedimentary upper units of a metamorphosed volcanic-sedimentary sequence that is intruded by granitoid and abundant pegmatoid bodies. Tin occurs in small but significant amounts as cassiterite and in the lattices of the sulphide minerals in some of the orebodies and their bordering rocks.

The bedded sequence consists of mafic metavolcanic rocks overlain by well-bedded biotitic, quartzofeldspathic metasediments with garnet, amphibole, sillimanite, and graphite prominent in some horizons. These are overlain in turn by iron-formation interbedded with other quartzofeldspathic gneisses of similar composition, in which minor felsic metavolcanic units have been recognized (Milne, 1970). Included in the latter sequence are a muscovitic zone, and gneisses with abundant biotite, garnet, sillimanite, cordierite, and anthophyllite.

The bedded rocks outline a major east-northeasterly trending syncline, whose core is occupied by granitoid rocks and granitic gneisses. The numerous "basic" to granitoid bodies and pegmatite bodies that invade the metasedimentary-volcanic gneisses are most abundant near the granitoid core of the syncline. The "basic" dykes, according to Brown *et al.* (1960), are dark in colour but are composed chiefly of quartz, microcline, and biotite, with minor plagioclase and hornblende. The pegmatites, some of which are of slightly different ages and cut one another, are all simple and essentially unzoned types with occasional tourmaline but apparently no other rare constituents. Both the basic dykes and the pegmatites are more or less mineralized in contact with the sulphide bodies.

The syncline plunges eastward at 10 to 40 degrees, steepening generally from west to east. The bedded rocks plunge beneath the granitoid core rocks of the core. Lineation and minor structures conform to the main synclinal structure over much of the area, but a secondstage deformation is marked by a muscovite-quartz schist zone, which extends westward along the south limb of the syncline through the Geco and some of the Willroy orebodies. Inclusions of pegmatite, granodiorite, muscovite schist, and gneisses are present in the orebodies in this zone. Several major transverse faults cut the bedded rocks and extend into the granitic core of the syncline. One of these, the Fox Creek Fault, cuts and offsets the Geco orebody.

The orebodies are lenticular and essentially stratiform bodies that lie along the south limb and at the nose of the main syncline, and are progressively steeper in dip from west to east. Some are localized by drag-folds which plunge eastward following the major structure. The Geco, Willroy, and Nama Creek orebodies are generally in the uppermost part of the metasedimentary-volcanic sequence, being near the igneous-type rocks of the core, and in part separated from them by cordierite-anthophyllite, garnet, biotite, and sillimanite gneisses. However, the orebodies are not strictly conformable; they lie at slightly different stratigraphic horizons, and locally cut fold structures, foliation, and intrusive rocks (Milne, 1970). The Geco and Willroy Nos. 1 and 6 orebodies are associated chiefly with the muscovite-quartz schist zone, which was interpreted as a fault by Brown *et al.* (1960). The host rock of the Nama Creek orebody is mainly pegmatite, and the Lun-Echo and Willroy No. 2, 3, and 4 orebodies are closely associated with iron-formation (Timms and Marshall, 1959).

The main sulphide minerals of the orebodies are pyrite, pyrrhotite, sphalerite, chalcopyrite, and minor galena, in varying proportion, with several ounces of silver per ton. In some places, as at Geco, massive sulphide ore is partly enveloped by disseminated ore. The massive ore has pyrite predominating over pyrrhotite, and contains nearly all the zinc, lead, cadmium, and silver, as well as most of the chalcopyrite. The disseminated ore consists chiefly of pyrrhotite, with lesser pyrite and chalcopyrite. The ores, though locally well-banded, are characteristically coarse-grained, granoblastic, and poikiloblastic (Suffel *et al.*, 1971). They contain typically metamorphic minerals such as gahnite, and have evidently been deformed and metamorphosed together with the enclosing rocks. Some degree of metal zoning is evident. At Geco, copper predominates over zinc in the lower part of the massive sulphides, and extends farther up the mass along its edges (Brown and Bray, 1960). At Willroy the copper and silver content increases with depth, with a corresponding decrease in zinc (Timms and Marshall, 1959).

Range and mean content of tin in different rock types, Geco Mine						
Rock type	No. of analyses	minimum	(per cent) mean	maximum		
Massive sulphides	56	0.006	0.095	0.32		
Disseminated sulphides	5	0.001	0.03	0.114		
Pegmatite	31	0.006	0.02	0.14		
Granodiorite	10	0.006	0.04	0.24		
Biotite-sillimanite gneiss	1	0.02	0.02	0.02		
Sericite, sericite-sillimanite schist	25	0.01	0.07	0.19		
Biotite hornfels	33	0.01	0.14	1.20		
Biotite-sillimanite hornfels	3	0.05	0.05	0.07		
Ouartz-biotite hornfels	17	0.03	0.11	0.30		
Quartz-sillimanite hornfels	19	0.004	0.06	0.32		
Quartz-diorite	1	0.03	0.03	0.03		

Available information on the tin content of the Geco orebodies and their enclosing rocks has been compiled in detail by Banerjee (1972) and is summarized below.

In the massive sulphides the tin content generally increases with increase in copper-zinc ratio. Electron microprobe analyses by Banerjee indicated that chalcopyrite averages 0.1 per cent tin content, whereas sphalerite averages 0.05 per cent. The copper concentrates also contain more tin than the zinc concentrates. In addition to this tin, presumably held isomorphously in the lattices of the sulphide minerals, cassiterite occurs in unknown amount in the massive sulphides. Nichol (1958) and Hawley and Nichol (1961) reported cassiterite in tin-rich pyrite

samples. Cassiterite reported by Banerjee in massive sulphides was mainly from the contact zones of massive sulphides with pegmatites, where the tin content increases sharply from the pegmatite and granodiorite toward the massive sulphide ore. In such areas cassiterite is intimately associated with gahnite and other high-temperature metamorphic minerals, commonly in ocellar structures. This association with metamorphic minerals seems significant in view of the relatively high tin content of some of the high metamorphic grade wall-rocks.

Definite information on the tin content of the Willroy, Nama Creek, and Lun-Echo orebodies is lacking, although some is known to be present. Composite samples collected by the writer from the Nama Creek surface pit were found to contain 235 ppm tin by X-ray fluorescence analysis, whereas tin was not detected in a composite from a pit at the Lun-Echo property. Quantitatively, the analyses are considered dubious, but the difference seems significant. The Nama Creek orebody is mainly in pegmatite bordered by high-grade gneisses of the biotite-amphibole-garnet-cordierite-anthophyllite-sillimanite groups, whereas the ore at the Lun-Echo is dominantly in iron-formation, with no sign of pegmatite or other igneous-type rocks in the vicinity.

The "hornfelsic rocks," best developed at the north margin of the Geco orebody, have the highest tin content of all the samples analyzed (see Table). The term hornfels is somewhat misleading, as there is rapid transition from "biotite hornfels" with green biotite, quartz, plagioclase, apatite, and zircon, to rocks with cordierite, anthophyllite, hornblende, garnet, sillimanite, etc. as the orebody is approached (Banerjee, 1972, Chap. 4). Cassiterite, generally associated with gahnite and cordierite, occurs throughout the gradational series. These rocks are close to the massive sulphide orebodies, and are sheared and moderately mineralized. Cassiterite is associated with sulphides, especially chalcopyrite. "Sericite schist," presumably the muscovite-quartz schist that is the dominant host rock of the Geco and some Willroy orebodies, is next highest in cassiterite, according to Banerjee. This also grades into other lithological types, notably quartz-sillimanite schist or gneiss at Geco, and cassiterite is again commonly associated with gahnite, cordierite, and anthophyllite. The pegmatites contain cassiterite only rarely, and then only in contact with massive sulphides. The contact zones appear to be especially rich in tin. In these zones, cassiterite is intimately associated with gahnite, which also forms veinlets in pegmatitic material. Molybdenite and galena are occasionally found in pegmatite near massive sulphides (Banerjee, 1972). Molybdenite occurs in siliceous copper ore in some stopes at Willroy (E. Autio, pers. com.). Fluorite, occasionally found at Geco (R. Weeks, pers. com.), may belong to this association. Coarse pink feldspar of pegmatite at the Nama Creek open-cut is altered to green material to a depth of several inches in contact with sphalerite-rich ore. This alteration is found also at Geco, where it is ascribed to the development of epidote (Banerjee, 1972).

Pegmatite remote from the orebodies evidently contains much smaller though still significant amounts of tin. Composite samples collected by the writer were found by spectroscopic analysis to contain tin as follows: pegmatitic granite north of old Geco open-cut, 4.1 ppm; pegmatite (tourmaline-bearing) near office, 1.4 ppm; pegmatite, No. 4 shaft quarry, 8.0 ppm; Willroy, pegmatite from discarded core, 7.9 ppm; granodiorite, quarry near main Geco shaft, 3.8 ppm. The tin content of about 8 ppm found by the writer in some of the pegmatite composites is 3 to 4 times the normal concentration in granitic rocks. Tin contents of 0.02 to 0.04 per cent in pegmatites from north of the Willroy mine were reported by Banerjee (1972). If these pegmatites were unmineralized, one may be justified in suspecting that the analytical values reported for tin in trace ranges are too high¹.

¹Composite samples of pegmatite from the ore zones at Geco and at Willroy, taken by the writer, were found to contain 0.15 per cent tin by spectrograph (0.12 by X-ray fluorescence), and 15 ppm, respectively. One of "sericite schist" at Willroy was found to contain 85 ppm.

The origin of the orebodies is controversial. Suffel et al. (1971) suggested that the orebodies were originally synvolcanogenic deposits, stressing uncertainty about the sedimentary nature of the bedded rocks prior to metamorphism. Some of these rocks, notably the biotitegarnet-amphibole and biotite-garnet-cordierite-anthophyllite gneisses, which are commonly at or near the north border of the Geco, Willroy, and Nama Creek orebodies, have been designated "metasediment or tuff" by Milne (1970). Incidentally, Milne (1969) suggested that if the observed thickening of stratigraphic units prevails around the nose of the Manitouwadge Syncline, it would appear that the syncline is centred on an original depositional basin. Brown et al. (1960) and Timms and Marshall (1959) implied an epigenetic replacement origin for the orebodies. Milne (1970) pointed out that "Pegmatite intrusion postdates the main regional tectonism, and the formation of the muscovite-quartz schist postdates the pegmatite intrusion and the main regional metamorphism; thus the orebodies have been localized in their present position after the main regional tectonism and metamorphism." The complex and spectacular drag-folding at Geco, involving both banded ore and unreplaced wall-rocks, is confined to the ore zone (R. Weeks, pers. com.). This suggests that the orebody was formed in a fault zone. However, another possibility is that pre-existing, essentially syngenetic orebodies along the same stratigraphic horizon as the fault acquired their present form partly by plastic flowage into the fault zone. Under the high temperature-stress conditions prevailing during metamorphism and intrusion, much remobilization and replacement action would also undoubtedly take place.

It seems clear from the close association of tin with the base metal sulphides, especially chalcopyrite, that some tin was genetically linked with the base metals. Banerjee (1972), stressing the close association of cassiterite with galnite, suggested that tin was released from solid solution in sphalerite to form cassiterite, while the zinc combined with alumina to form galnite. However this does not explain the apparently higher tin concentration in the thermal aureoles than in the massive sulphides. The abundance of cordierite in the tin-rich zones indicates that the source-beds were high in Mg as well as Al, either as montmorillonite clays or mafic pyroclastics. Tin (and also zinc) might have been concentrated in these beds, for example, by adsorption from the sea water. The pegmatites are simple types, quite conceivably formed by ultrametamorphism connected with the granitization to the north, and were evidently incapable of incorporating much tin. Thus it seems possible that tin in original sedimentary and (or) volcanic rocks was concentrated by these granitization-pegmatization processes within the thermal aureole. This implies that the tin content of the original rocks was higher than that of the granite and pegmatite which have replaced them. An extensive program of rock geochemistry might throw some light on this question.

(36) Kidd Creek (Ecstall Mining Limited), Timmins Area, Ontario

The Kidd Creek property of Ecstall Mining Limited, controlled by Texas Gulf Sulphur Co., is in the northeast part of Kidd Township, about 15 miles north of Timmins, Ont. (Fig. 17). The deposit is a very large and rich massive zinc-copper-lead-silver sulphide deposit in dominantly rhyolitic pyroclastic rocks of a volcanic extrusive-intrusive complex. The deposit, at present the largest zinc-silver-cadmium producer in the world, is estimated to contain more than 90 million tons of ore grading about 7 per cent zinc, 1.33 per cent copper, and 4.8 ounces of silver per ton (Bright, 1972a). The ores as presently mined contain an average 0.14 per cent tin as disseminated fine-grained cassiterite. Recovery of tin at the rate of 1.5 million pounds per year, expected to start by the end of 1973, will make this the most important tin producer in North America.

The areal geology has been described by George and Leahy (1968) and Bright (1972 a,b). The property is in the "North Timmins" fault block, which is one of the thickest and most

felsic-rich parts of the Abitibi greenstone belt. The bedded rocks consist of mafic to intermediate flows and pyroclastic volcanic rocks, passing upward into felsic pyroclastic rocks and merging into sedimentary rocks around the margin of a structural sedimentary basin. The Kidd Creek deposit is on the northern edge of this basin (Bright, 1972b). It is also on the southern flank of the Carnegie–Prosser anticlinorium, a complex, folded, domical structure containing at least two major vent areas. The pyroclastic-flow sequence in the area of Kidd Creek mine was probably derived from a volcanic centre to the northeast in Prosser Township, an area of coarse rhyolitic fragmentals intruded by an epizonal quartz feldspar porphyry stock (Bright, 1972a).

In the area of the open pit (Fig. 17, P1. VI), the rocks and ores are complexly folded and faulted, and the deposit is divided into a north zone and a south zone by transverse faults. The felsic rocks in which the orebody is emplaced are chiefly light to dark grey silicified rhyolite lapilli tuffs and agglomerates with graphitic and cherty horizons. Massive dark rhyolite with small subhedral quartz and feldspar phenocrysts and flow lines forms much of the northeast wall of the pit. Similar light-weathering rock in the outcrop on the east rim of the pit is there in contact with rhyolite breccia that consists mainly of angular aphanitic fragments commonly a foot or more across. This coarse breccia was interpreted as a volcanic pipe by Pike and Middleton (1971).

The north zone of the orebody consists of two main types of ore. To the west, massive pyritic ore consisting of pyrite with varying amounts of sphalerite and minor chalcopyrite, galena, and native silver, is associated with the graphitic horizon (Ecstall Mining Limited, geological staff, 1972). The writer understands that this "C" ore has the highest tin content, averaging about 0.21 per cent. Composite samples taken by the writer were found by X-ray fluorescence analysis to contain tin in the following amounts: pyritic ore, 520 ppm; sphalerite-rich ore, 2,400 ppm; sphalerite-galena ore, 1,420 ppm; cherty rhyolite with lesser sphalerite, etc., 1,640 ppm. The eastern part of the north zone is typified by siliceous copper ore, containing chalcopyrite in stockworks and disseminations, with little silver or tin.

The south zone ore is composed primarily of sphalerite, chalcopyrite, and pyrite, with varying amounts of siliceous material or chert. The south extremity of the zone is marked by massive chalcopyrite. This south zone ore is said to average 0.12 per cent tin. A composite sample of mixed pyrite-sphalerite-chalcopyrite ore taken by the writer was found to contain 685 ppm by X-ray fluorescence analysis.

The tin occurs as cassiterite in small inclusions from 5 to 110 microns across in sphalerite and gangue (Petruk and Owens, 1965). According to company reports, it is mostly less than 28 microns in size. In pilot-plant operation about 75 per cent of the tin was found to be in the zinc tails (which would contain the bulk of the pyrite). Most of the remainder is in the zinc concentrates, and should be recoverable from the zinc leaching-plant residues (R. Tait, pers. com.). The tin plant, scheduled to be in operation by the end of 1973, is expected to yield initially 1,400 tons per year of cassiterite concentrate containing about 54 per cent tin (Financial Post, Apr. 28, 1972).

Composite samples, taken by the writer, of apparently unmineralized rhyolite-breccia and cherty rhyolite from the outcrop area on the east rim of the open pit were found to contain 7.9 and 6.3 ppm of tin, respectively, by spectroscopic analysis. The next nearest readily accessible outcrop of rhyolitic volcanic rocks is near the Canadian Jamieson mine, about 14 miles southwest of the Kidd Creek property. Composite samples of these rocks and one of andesitic tuff (?) were found to contain 3.9, 5.1, 5.4, and 1.4 ppm tin respectively. A sample of the granitoid rock along the road just northwest of the Canadian Jamieson mine was found to contain 6.8 ppm tin. This is a leucocratic, hypabyssal-looking body, with a few quartz veins and specks of disseminated sulphides. The granitic body shown on Ontario Division of

Mines Map 2046, about 3 miles northeast of the Kidd Creek property, is a similar, probably hypabyssal leucocratic granite with disseminated pyrite and fluorite and a little molybdenite (E.G. Bright, pers. com.)¹. It is in an area of coarse rhyolitic fragmental rocks, and the area is thought to be the source of the rhyolitic rocks in the vicinity of the Kidd Creek property (Bright, 1972a). The anomalously high tin content of rhyolites and presumably related hypabyssal intrusions in the belt trending northeasterly through the Kidd Creek deposit suggests that such hypabyssal granitic plutons were the ultimate source of most of the tin in the deposit, perhaps transported and concentrated together with the base metals through fissures in the volcanic pile. A little wolframite and arsenopyrite are present in the ore (Petruk and Owens, 1965), and a fluorite-quartz vein was found during deep development at the mine (E.G. Bright, pers. com.). These occurrences suggest a deeply buried granitic source of lithophile metals in the mine area. A scheelite-quartz vein was found near the Kam Kotia mine (southwest of the Kidd Creek mine) and scheelite, tourmaline, molybdenite, and bismuth are more common in the gold deposits of the Timmins area than in most other gold belts (E.G. Bright, pers. com.). The presence of these substances, commonly related to tin, is in keeping with the relatively high tin content of the volcanic rocks in the Timmins-Noranda belt (see Table 6).

(37) Lac Dufault Mine, Abitibi County, Northwestern Quebec

The Lac Dufault mine, in the southwestern part of Dufresnoy Township, is about 8 miles north-northwest of Noranda, Que., and is one of a large number of massive zinc-copper sulphide deposits in that area. They include the Waite Amulet mine, where Colwell (1963) reported 0.084 per cent tin in sphalerite. The Noranda ores contain about 250 ppm tin (Roscoe, 1965). The Lac Dufault orebody is the only one in northwestern Quebec in which tin minerals have so far been recognized. Johnson (1966) found stannite at the upper contact of the ore. Sakrison (1966) found abnormal tin concentrations in the rocks adjacent to the ore.

The Lac Dufault area lies within a large elliptically-shaped area of alternating basic, intermediate, and siliceous Archean volcanic rocks bordered by conglomerate and greywacketype sediments on the north and also on the south, mainly beyond a major fault zone. In the central part of the area these volcanic rocks are intruded by the Flavrian Lake albite-granite stock, which is ringed by quartz diorite and gabbro dykes. To the east of this body, the ring dykes are cut by the Lac Dufault granodiorite stock. The Lac Dufault and several other orebodies are grouped around the western margin of this latter stock. The volcanic rocks of the area, like the intrusions, are abnormally rich in sodium and poor in potassium. They comprise basalt, andesite, dacite, and rhyolite. According to Sakrison (1966), the rhyolitic rocks are mainly pyroclastic, although he considers that some small domical masses of quartz feldspar porphyry in the area might be classified as flows. The Flavrian Lake albite-granite is similar in composition to the rhyolitic rocks, which suggests that it is derived from magma of similar composition (Sakrison, 1966). The Lac Dufault granodiorite is similar in composition to the area, and texturally appears to have been emplaced in country rock that was already hot (Sakrison, 1966).

The major fault zone to the south is the east-striking Cadillac-Bouzan fault. Another major fault zone, the east-southeasterly striking Porcupine-Destor fault, partly coincides with the belt of sedimentary rocks to the north. Several prominent east-northeasterly striking faults, including the Horne Creek fault near Noranda, cut the intervening area.

The Lac Dufault, Waite-Amulet, and Vauze deposits west of Dufault Lake are in or near the crest of a southeasterly plunging anticline between the Flavrian Lake and the Lac

¹Three composite samples taken by the writer were found to contain only 1 to 2 ppm tin by X-ray fluorescence and spectrographic analyses.

Dufault intrusions. In this area, the abundance of thick lenticular acidic volcanics and associated dykes and sills indicates proximity to an ancient volcanic centre (Roscoe, 1965). Through the volcanic sequence, both the acidic and the basic units become more siliceous in ascending order (Roscoe, 1965). The massive sulphide deposits of the area are typically stratiform. The Lac Dufault and nearby Waite–Amulet and Vauze orebodies lie at or near the top of the Waite Rhyolite, at or near its contact with the overlying Amulet Andesite (Johnson, 1966). The Waite Rhyolite is considerably richer in silica (up to 85 per cent) than rhyolitic rocks lower in the section, and marks the horizon of sharpest upward increase in the section (Roscoe, 1965). The rhyolite unit is 600 to 1,000 feet thick and is generally tabular but is thicker in the vicinity of the Lac Dufault, Vauze, and Waite–Amulet orebodies than elsewhere (Sakrison, 1966). Near the contact with the overlying andesite near the Lac Dufault and Vauze mines the Waite Rhyolite grades upward into bands of cherty tuff less than 10 feet thick. These bands consist of a rhythmic alternation of chert and fine-grained tuff bands. The tuff bands contain sparse disseminated pyrite, pyrrhotite, and sphalerite (Johnson, 1966).

Metamorphism of the volcanic rocks is generally limited to low-grade chloritization, sericitization, and silicification, but bodies of cordierite-bearing rocks known as "Dalmatianite" occur in the fractured and mineralized rhyolite below the Lac Dufault, Waite, and Amulet orebodies. They are ascribed to magnesium metasomatism related to proximity to the Lac Dufault stock. Gahnite has been reported in the alteration zone at the Amulet mine (Sakrison, 1966).

At the Lac Dufault property a massive sulphide orebody (A) is underlain by a fractured zone (B) containing vein and disseminated sulphides. The massive sulphide body, a lenticular body about 650 feet long, 400 feet wide, and 150 feet thick, lies in the plane of the contact between hanging-wall andesite and footwall rhyolite. It consists of pyrite, pyrrhotite, sphalerite, chalcopyrite, magnetite, and traces of galena, and carries about 2.6 ounces silver and 0.04 ounce gold per ton. The massive sulphide body is zoned, with zinc-rich layered sphaleritepyrrhotite-pyrite ore at the stratigraphic top and increasing copper content with depth. The underlying B orebody is crudely elliptical, with its long axis parallel to that of the massive sulphide body, and connected with it by two pipe-like fracture zones. This orebody is relatively rich in chalcopyrite, together with pyrite, pyrrhotite, and some magnetite and sphalerite. The sulphide assemblages of the Lac Dufault orebody have banded, augen, and boudin structures, particularly at the top of the massive sulphide orebody where angular and rounded aggregates of fractured pyrite grains lie in a matrix of sphalerite and disseminated pyrite. Sulphide veinlets penetrate into and surround fragments of andesite at the contact. These features are believed to be the result of deformation related to a low-angle bedding-plane fault at the top of the orebody (Johnson, 1966).

The only tin mineral that has been recognized is stannite, and it has been found only at the upper contact of the massive sulphide orebody. There, numerous prismatic grains of stannite up to 15 microns long occur in a $\frac{1}{4}$ -inch band of rock. They become less numerous away from the contact, and at distances of greater than 1 inch they are absent. The long axes of the grains are roughly parallel to the sulphide-volcanic contact, and also to oriented flakes of chlorite in the andesite (Johnson, 1966). However, Johnson (1966, Table 7) reported the results of five analyses for tin in sphalerite taken from the top of the orebody to a point 400 feet lower in the mineralized stringer zone. He found that the tin content increased over this distance from 0.005 per cent at the top to 0.3 per cent at the bottom. He assumed that this tin is held isomorphously or as submicroscopic impurities in the sphalerite, and suggested that sphalerite originally containing FeS, CuS, and SnS has recrystallized at the sulphideandesite contact, facilitating the formation of stannite. It is improbable that sphalerite can contain as much as 0.3 per cent tin isomorphously. If exsolved stannite is in fact absent from this sphalerite, it seems more probable that unrecognized fine-grained cassiterite is present, as it is in most of the tin-bearing massive sulphide orebodies of this type. The tabular form of the stannite crystals suggests that they may be pseudomorphous after "needle cassiterite," which is a characteristic form in low-temperature deposits. However, sulphidization of cassiterite in the presence of magnetite and pyrrhotite is difficult to visualize. The presence of stannite in this assemblage must indicate some form of disequilibrium.

Roscoe (1965) reported the tin content of massive zinc-copper ore of the Noranda area as 250 ppm, compared with 500 ppm in the Matagami area, and "not detected" in the Chibougamau and other areas of northwestern Quebec.

Sakrison (1966, Table 7) reported the tin content of the host rocks of the Lac Dufault orebody as follows (ppm):

	Mode	Mean	Median	Range
Waite Rhyolite	0.5	1		
Amulet Andesite	2.5	4.4		
Tuff			4	21

The low tin content of the rhyolite parallels its low lead content which is ascribed to its low potassium content. However, the lateral distribution chart (Sakrison, 1966, Fig. 12) shows that most of the samples within the outline of the orebody contain more than 2.5 ppm, while those outside it contain less than 1 ppm, and he stated that tin occurs in "abnormally high amounts close to the sides of the massive sulphide orebody and in the altered and mineralized zone beneath it." At the same time, the top of the rhyolite is considered to be depleted in tin. The tin content of the Amulet Andesite is abnormally high, significantly higher than typical and esites of Japan and New Zealand and of areas in the Canadian Shield that have been tested, if the analyses are assumed to be comparable (see Table 6). The lateral distribution chart for the andesite shows the higher tin values (up to more than 7.5 ppm) to be scattered throughout the area, but an enrichment in tin is noted in the base of the andesite near the ore. There is also a general increase in potassium content at the base of the andesite. In the tuff the median values and ranges for tin and other elements concentrated in the ore are higher than the background values in either the rhyolite or the andesite. This is considered to indicate a relationship between it and the ore. Sakrison (1966) also considered that "Stratigraphically below and adjoining the Lake Dufault massive sulphite orebody is a highly altered, fractured, and mineralized zone which almost certainly was the channel for ore-forming solutions" (in rhyolitic rocks). These solutions are believed to have deposited their metals and sulphur on emerging into water covering the rhyolitic rocks at the end of a volcanic cycle. The massive sulphide body so formed was subsequently covered by andesitic lava, marking the beginning of a new cycle.

It is not clear why tin was concentrated at the uppermost surface of the deposit, if in fact it was. The tin may be related to late intrusive phases, and localized by late fault movement along the base of the hanging-wall andesite. More information on the distribution of tin in the deposit seems necessary before its origin can be realistically assessed.

(37a) Normetal Mine, Abitibi County, Northwestern Quebec

The Normetal mine, in the northern part of Desméloizes Township, is near the mapped contact between Archean rhyolitic and basic volcanic rocks. Its position in the Abitibi belt appears to correspond to that of the Kidd Creek deposit (36) more closely than does the Lac Dufault-Noranda area. A pegmatite containing lithium and caesium minerals and a little beryllium and tin lies between, about 26 miles west of Normetal.

The deposit is a massive copper-zinc "replacement" body in rhyolite agglomerate, one of the coarser fragmental beds in a series of rhyolite tuffs and lavas. A quartz porphyry sill-like body and numerous small pipe-like bodies of intrusive rhyolite transect the ore zone (Brown, 1948). The metallic sulphides are pyrite, sphalerite, and chalcopyrite with subordinate pyrrhotite and galena. No tin minerals have been reported, but Nichol (1958) reported analyses for tin as follows: pyrite, 0.001 to 0.084, average 0.022; pyrrhotite, 0.001 to 0.46, average 0.23; chalcopyrite, 0.001 to 0.01, average 0.025 per cent¹.

Pyrrhotite can hold only very small amounts of tin in solid solution. If the high analytical values listed above are correct, it can be assumed fine inclusions of cassiterite are present in the ore.

Other Tin Concentrations in the Eastern Part of Superior Province

In the Matagami area of Abitibi Territory, northwestern Quebec, a number of massive zinc-copper sulphide deposits occur mainly in rhyolitic rocks bordered on one side by basic volcanics and on the other by a lenticular body of anorthosite. Mattagami Lake Mines, Ltd. (lat. 49°44', long. 77°43') in Galinée Township, the main producer, is working a massive zinc-copper orebody with some silver and a little gold. No tin minerals have been reported, but Roscoe (1965) reported 500 ppm tin in massive zinc-copper ores of the area.

At the Opémiska Mine (lat. 49°48', long. 74°52') in Chibougamau District, Quebec, 0.12 per cent tin was found in one bulk composite sample (R.H.McMillan, pers. com.). At the property several major chalcopyrite veins transect mainly the gabbroic portion of the Ventures Sill, a layered Archean ultramafic-mafic sill. The deposits yield copper, gold, and silver, but also contain significant amounts of MoS_2 , WO_3 , and locally zinc and nickel. Quartz is the most abundant non-metallic constituent (McMillan, 1972).

Traces of stannite were found in a heavy liquid concentrate of ore from a molybdenite property in La Motte Township, Quebec (Mathieu, 1964). This locality is in the Preissac-Lacorne district (approx. lat. 48°20', long. 78°00), an important area of molybdenum, lithium, and beryllium pegmatitic deposits related to late phase muscovitic granite. Tin was detected in samples of muscovite taken by the writer from some pegmatites. However, composite samples from the Molybdenum Corporation mine, the Lac Roy molybdenum deposit, the Quebec Lithium pegmatite deposit, and the Valor pegmatite were found to contain less than 3 ppm tin.

Southern Province

The only tin occurrence in this province is the Vermilion mine (about 22 miles west of Sudbury, Ontario), which is of interest only as a mineralogical curiosity.

Vermilion Mine, Denison Township, Ontario

The Vermilion mine referred to here is a gold-bearing quartz-pyrite-chalcopyritepyrrhotite deposit from which sperrylite (Pt As_2) was originally reported (Dana and Ford, 1932). According to Wells (1889), a sample of sperrylite ore was found to contain 4.6 per

¹Composite samples of mill heads and tails supplied by the company in 1973 were each found to contain only 9 ppm tin by X-ray fluorescence.

cent tin by chemical analysis. It was also stated that the sands from the stamp mill yielded grains which proved to be SnO_2 by chemical analysis and optical examination. The description is vague but the occurrence seems to be supported by a statement that cassiterite was found in superpanner concentrates of sands from the Vermilion River, in the same district (Haultain, 1942). This cassiterite was apparently identified only by blowpipe tests¹.

Grenville Province

No significant tin concentrations are known in the Grenville Province, and the only previously reported occurrence (loc. 42) is considered highly dubious.

The basement rocks, which include important amounts of crystalline limestone in the western part, are of generally high metamorphic grade. In the latter respect they resemble those of the Churchill Province, where also tin occurrences are extremely rare and insignificant. Lithium occurrences are likewise, with one minor exception, unknown, although pegmatites are common and many contain beryllium and /or rare-earths. However, few analyses for tin appear to have been made and the minor concentrations reported here indicate that tin is not entirely absent from the province.

(40) Lyndoch Township, Ontario

The occurrence is a pegmatite dyke that contains beryl and rare-earths, including lyndochite, euxenite, columbite, and cyrtolite. Ellsworth (1932) reported 0.92 and 0.56 per cent tin in a columbite-like mineral and 0.12 per cent tin in lyndochite, by chemical analysis. D.D. Hogarth (pers. com.) identified cassiterite associated with euxenite. The non-magnetic fraction of a heavy mineral concentrate taken by the writer was found to contain 0.01 per cent tin by spectroscopic analysis.

(41) Clyde Forks, Lanark County, Ontario

A small vein deposit in crystalline limestone contains mercurian tetrahedrite, stibnite, bornite, chalcopyrite, and a little cinnabar, in a gangue consisting mainly of barite, Traces of tin were reported in bulk samples. A composite sample taken by the writer was treated by flotation. Tin was not detected by semiquantitative spectroscopic analysis in the sulphide concentrate, but was detected in the cleaner tails. Apparently tin is present in some nonsulphide form.

(42) Buckingham Township, Quebec

At "Graphite City," graphite was formerly mined from veins and cracks in gneiss, granular limestone, pegmatite, and "granular eruptive rocks." Cassiterite was tentatively identified by optical means in micaceous portions of the gneiss, and the presence of tin in a heavy mineral concentrate was considered to be proved by bead tests (Osann, 1899). Heavy mineral concentrates of samples of graphitic and of micaceous gneiss collected by the writer were found to contain nil to 1.2 ppm tin by spectroscopic analysis. The occurrence is considered dubious.

¹Cassiterite has been definitely identified in the sperrylite ore by X-ray diffraction (H. R. Steacy, pers. com.).

Evans-Lou Pegmatite, near Wakefield Lake, Quebec

The locality, not shown on Map 1352A, is in Lot 29, Range VI, Portland Township, about lat. $45^{\circ}46'$, long. $75^{\circ}42'$, and is about 25 miles north of Ottawa. Sphene, which occurs in pegmatite with wakefieldite and other rare-earth minerals, was found to contain 0.16 per cent tin by spectroscopic analysis of a sample supplied by D. Hogarth. It also contains niobium and 5.5 per cent ytterbium (Miles *et al.* 1971).

The location is about 4 miles northeast of the Leduc pegmatite, from which a sample of lepidolite taken by the writer was found to contain 0.061 per cent tin by spectroscopic analysis. This is the only significant lithium occurrence known in Grenville Province.

Appalachian Region

The Appalachian Region contains a considerable number of significant tin occurrences. Some attempts to develop mineable orebodies have been made in the New Ross area, Nova Scotia (loc. 48), and much exploration and development work has been done on the Brunswick Tin Mines (Mount Pleasant) property in New Brunswick (loc. 46). The major granitic intrusions of the region are of Devonian age (Acadian Orogeny), and tin occurs in or on the fringes of the main belts of these intrusions in New Brunswick and Nova Scotia.

The New Ross (48), Burnt Hill (44), and Square Lake (47) occurrences in particular are in areas characterized by the presence of muscovite-bearing granite, in addition to the common biotite granites of the region. This is taken to indicate either post-batholithic intrusion by late-stage differentiates rich in volatile fluids, or extensive post-magmatic alteration by such fluids. The Mount Pleasant deposit is in rhyolitic volcanic rocks of fairly definitely post-Devonian age, but may be genetically related to one of a series of granitic stocks thought to be post-Devonian in age.

Quebec Appalachian Belt

The belt of folded lower Paleozoic rocks south of the St. Lawrence River is most noted for its ultramafic rocks (and associated asbestos deposits), which were intruded during the Ordovician Taconian orogeny. However, a number of Devonian granitic intrusions are scattered through a belt lying farther to the southeast. In this belt the only clearly documented occurrence of tin is the very minor concentration in Talon Township (loc. 43). However, several vague references have been made to its occurrence in the Megantic area, where molybdenite occurs with lead-zinc-silver sulphides on Lot 13, Range V, Whitton Township. W. D. McCartney (pers. com., 1964) reported finding stannite in a polished section from that vicinity.

Central New Brunswick Granitic Belt

The belt of Devonian granitic intrusions extending through central New Brunswick contains significant tin occurrences in the Burnt Hill tungsten deposit (loc. 44) and the tinbearing sulphide ores of the Bathurst district (loc. 45). It also contains several molybdeniteberyl occurrences, and the tin content of granitic rocks in all these areas appears to be substantially higher than the crustal average (Table 6).

In the general area of the Burnt Hill mine, where bodies of muscovitic and miarolytic granite and alaskite are found (Poole, 1960, 1963), samples of different types of granite collected by the writer ranged from 6 to 12 ppm tin where unaltered, but contained up to 160 ppm where evidence of greisenization was found. The stock just north of Brunswick Mines (Bath-

urst District) is a muscovite-biotite granite with associated beryl-molybdenite occurrences, and contains 12–14 ppm tin. Muscovite-biotite granite near a berylliferous pegmatite in the Keswick area (Poole, 1957a) contains 20 ppm tin. The Pokiok River area, farther south, was thought to be the source of a specimen of cassiterite in an old collection (W. J. Wright, 1940c).

(44) Burnt Hill Mine Area

Although its tin concentration is evidently low, the Burnt Hill deposit is of interest as an example of a wolframite-molybdenite-cassiterite vein deposit in a greisenized granite environment. The deposit was known by 1870 and has been mined intermittently since at least as early as 1917, when it was described by Young (1917).

It has been described more recently by W. J. Wright (1940a) and by Potter (1969). The property was most recently reactivated about 1967, and a considerable amount of exploration and new development has since been carried out.

At the mine, a number of subparallel fissure veins up to 6 feet thick cut slightly schistose slate and quartzite near the southern tip of a body of pink alaskitic muscovite-bearing granite. This is apparently a border phase of a large batholith of Devonian porphyritic biotite granite, but similar granite occurs in several places within the batholith (Poole, 1960). These muscovitic phases may be late stage differentiates, slightly younger than the main batholith. The country rocks at the mine are not appreciably metamorphosed, but the argillaceous members change to spotted schists as the granite contact is approached.

The veins form a northwesterly striking system, cutting across the bedding of the sedimentary rocks and paralleling a prominent system of joint planes and granitic dykes in these rocks. Individual veins are as much as several hundred feet long but they are commonly discontinuous and branching. They probably fill tension fractures. The walls are sharply defined, with local silicification and sericitization of the country rocks, but generally without the muscovite-rich borders that characterize most greisen veins. However topaz, another characteristic mineral of greisen deposits, is second in abundance only to quartz in the vein material.

Common vein minerals in addition to quartz, topaz, and wolframite, include fluorite and beryl. Beryl, in radiating bursts of fine green needles, is found mainly near the walls. Molybdenite is fairly abundant although much less so than wolframite. Arsenopyrite, pyrrhotite, pyrite, chalcopyrite, sphalerite, galena, and native bismuth, are present in relatively minor amounts.

The quartz is milky and generally massive but is in part euhedral. The veins are not distinctly banded, but quartz, wolframite, and beryl are commonly aligned perpendicular to the walls, and locally produce crude comb structures. Topaz is in crude crystals up to an inch long, generally in aggregates, and is dull green. Wolframite occurs as brownish-black tabular crystals up to 4 inches long. Cassiterite occurs sparingly as microscopic grains associated with wolframite (Victor, 1957, Fig. 7). The wolframite, a sample of which was found to contain 0.03 per cent tin by spectroscopic analysis, probably also contains inclusions of cassiterite. The minerals are essentially contemporaneous.

Composite samples of dump material taken by the writer were found to contain only about 0.01 per cent tin by spectroscopic analysis. Cassiterite appears to be somewhat more abundant in greisen veins closer to and within the granite on Burnthill Brook. A composite sample of these was found to contain 130 ppm tin. The granite apparently extends beneath the mine area at a depth of about 600 feet (Potter, 1969, p. 106). A sample of greisenized granite from the 800-foot mark of a diamond-drill core was found to contain 160 ppm tin. Samples of greisenized granite taken elsewhere within the batholith contained up to 24 ppm tin (Table 6).

(45) Bathurst Area (Brunswick Mines, etc.)

Many of the massive and vein base-metal sulphide deposits of the Bathurst District contain small amounts of tin. These deposits are emplaced in Ordovician and Silurian volcanic and sedimentary rocks, intensely folded and faulted, and intruded by granitoid rocks which mark the north end of the central New Brunswick granitic belt (Tupper *et al.*, 1968, Fig. 1).

Southwest of Bathurst numerous essentially stratabound zinc-lead-copper massive sulphide deposits, of which Brunswick No. 6 and No. 12 and the Captain deposit are known to contain tin minerals, occur within a roughly circular area about 35 miles in diameter. In this area a central zone consisting mainly of acid tuffs, agglomerates, and flows is partly surrounded by an intermediate zone characterized by mafic flows and tuffs and an outer zone of argillaceous rocks and greywacke (McAllister, 1959). The host rocks of the orebodies include quartz, feldspar, sericite, and chlorite schists, chert, graphitic slates, and iron-formation. Magnetite iron-formation is especially prominent at Brunswick No. 6, which adjoins the old Drummond iron mine, and there it grades laterally into sulphide ore.

Brunswick No. 12 lies $4\frac{1}{2}$ miles west of, and Brunswick No. 6, 3 miles south of a large wedge-shaped stock of Devonian muscovite-biotite granite which contains molybdenum and beryl occurrences, and carries 12 to 14 parts per million tin. At both properties the massive zinc-lead-copper ores contain 0.05 to 0.1 per cent tin, mainly as stannite and cassiterite (Aletan, 1960). Stannite is preferentially associated with chalcopyrite and sphalerite, and cassiterite with pyrite and gangue. Stannite floats with the copper concentrate and cassiterite goes mostly to tailings. No tin is recovered.

The Captain deposit is about 25 miles south-southwest of Bathurst. It contains small amounts of stannite and cassiterite, together with pyrite, chalcopyrite, arsenopyrite, sphalerite, galena, and cobalt minerals. Stannite is closely associated with chalcopyrite and sphalerite, as inclusions and rims around these minerals. Cassiterite occurs as inclusions from 10 to 150 microns in size, within silicate gangue minerals (Tupper, *et al.*, 1968, and pers. com.). A small body of granophyric granite lies a short distance south of the deposit.

Northwest of Bathurst a number of vein sulphide deposits occur in mainly Silurian sedimentary rocks north of the "Millstream Break." In that area tin minerals have been reported at the property of Nigadoo River Mines Limited, about 12 miles northwest of Bathurst. The sulphide deposits are in veins and lenses along a fault that cuts sedimentary rocks at a high angle and continues through a quartz-feldspar porphyry stock (Davies, et al., 1969). The primary minerals include pyrite, marcasite, pyrrhotite, arsenopyrite, sphalerite, galena, and chalcopyrite, and small amounts of tetrahedrite, native bismuth, cassiterite, stannite, and canfieldite. Cassiterite occurs mainly in massive pyrrhotite veins, whereas stannite occurs principally in foliated marcasite-pyrite veins. Canfieldite has been identified in galena concentrate (Boorman and Abbott, 1968). A sample of mineralized material collected by the writer from a waste dump was found to contain 195 ppm tin by X-ray fluorescence. A sample of apparently barren porphyry was found to contain 64 ppm tin. The deposit is about 3 miles northeast of the Nicholas-Denys granitic stock, with which molybdenum and tungsten minerals are associated. Samples of this granite taken by the writer ranged from 1.9 to 4.6 ppm tin. Tin is moderately concentrated in stream sediments east (downstream) and north of the stock, but is much more strongly concentrated around the larger stock in the Elmtree River area, about 4 miles to the north (Boyle, et al., 1968, Maps 12-1967 and 13-1967).

At the Keymet (abandoned) property, which is about 3 miles east of the latter stock, no tin was detected by X-ray fluorescence in a sample of heavy sulphide collected by the writer from dumps, but a sample of kaolinized coarse quartz feldspar porphyry was found to contain 150 ppm tin by spectroscopic analysis.

Property	Pyrite	Chalcopyrite	Sphalerite	Galena
Keymet	0.003	0.1	0.002	N.D.(01
Nigadoo	0.004	0.2	0.02	0.10
0		0.1-0.2		
		0.2		
Brunswick 12A	0.02	0.05	0.02	0.03
Brunswick 12B	0.05	0.06	0.08	0.14
	0.05		0.30	
			0.08	
Brunswick 6A		0.05	0.01	0.04
Brunswick 6B		0.002	0.10	N.D.(01)
Reference	Sutherland, 1967	Sutherland, <i>et</i> <i>al.</i> , 1971	Sutherland, <i>et al.</i> , 1969	Boorman and Abbott, 1968

Data on the tin content of concentrates (except for pyrite) of these ores may be summarized as follows:

Stannite was reported in chalcopyrite from Nigadoo and Brunswick No. 12, and in sphalerite from Nigadoo and both Brunswick concentrates. Canfieldite was reported in galena from Nigadoo. Tin contents of other deposits reported are generally lower.

According to Neymann and Schnaar (1971) and Erskine (1971), the distribution of tin among mill feed and concentrates at Brunswick No. 6 and No. 12 is as follows (per cent):

	Mill Feed	Copper	Lead	Zinc	Bulk
No. 12	0.03	0.15	0.10	0.06	
No. 6	0.05				0.04

Data on the tin content of rocks in the Bathurst area were reported by J. L. Davies (1961, Table 6) as follows:

	Detected in	N.D. in	Range, ppm	Av., ppm
Porphyry Division				
(acid volcanics)	64	15	6-1	1
Felsic volcanics	2	2	1-1	1
Greenstone Division	43	30	4-1	1
Mafic intrusions	5	8	1-1	1
Felsic intrusions	3	0	50-2	27
Slate Division	0	7		
Sedimentary rocks of Greenstone				
Division (slate, phyllite)	7	0	1-1	1
Sedimentary rocks of Greenstone				
Division (iron-formation, etc.)	4	0	20-1	5

From this it appears that the tin content of greenstones is about the same as that of intermediate volcanic rocks of the Shield (Table 6). Felsic and acid volcanic rocks are apparently lower, and sedimentary rocks with the exception of iron-formation are very low. The data for felsic intrusions are too few to be significant.

Southern New Brunswick Granitic Belt

The southern granitic belt (Fig. 12), including the St. George batholith, contains the Mount Pleasant deposit (loc. 46) and the Square Lake occurrence (loc. 47). The Mount Pleasant deposit is the largest known Canadian deposit in which tin ranks as a major metal. It is emplaced in a younger volcanic complex off the north flank of the main batholith. The Square Lake occurrence lies within the batholith, but is related to muscovitic and aplitic phases that may be somewhat younger than the main body. Both areas have other minor occurrences of broadly related types.

The Mount Pleasant rhyolitic complex lies on a line of granitic satellites off the north flank of the St. George batholith (Fig. 12: a,b,c,d). They may be hypabyssal intrusions, also of postbatholithic age. Recent age determinations on them indicate an age range of 320 to 338 ± 18 million years (Ruitenberg, pers. com. 1960), whereas the St. George batholith is dated about 381 million years (Martin, 1970, p. 310). These granitic satellites have various rhyolitic and porphyritic phases with locally muscovitic and altered zones. Several of them, including the True Hill, Beech Hill, and Tower Hill intrusions (described as adamellites), have tin mineralization or anomalously high concentrations of tin associated with them (Ruitenberg, 1967, p. 91,116–117; and 1968), and they contain up to 20 ppm tin (Table 6).



FIGURE 12. Tin deposits and geological setting, southern New Brunswick.

Other tin concentrations include vein deposits between True Hill and Mount Pleasant that carry cassiterite and contain up to 0.4 per cent tin. On Beech Hill, angular float containing 0.4 per cent tin was found. Around the southwest border of the Tower Hill intrusion, Ruitenberg (1968) found tin concentrations in soils and bedrock. There altered muscovitic granite is cut by quartz veins and shows a little molybdenite on fracture surfaces. A composite sample of that part of the granite body taken by the writer was found to contain 20 ppm tin, whereas the biotite granite phase of the northern part of the intrusion contained 6 ppm. Evidently, this zone of satellite intrusions is anomalously rich in tin. The main concentrations are probably related to northwesterly trending faults.

In the main batholith, the uniform grey granite along the Magaguadavic River contains only 3 to 5 ppm tin. However, a deep red southern border zone north of St. George was found to contain 25 ppm tin. Similar red granite occurs in the border zone south of Square Lake and a composite sample of that part of the batholith was found to contain 30 ppm tin. Mineralized greisen probably containing cassiterite occurs along the contact south of Square Lake (Ruitenberg, 1969b). The southern contact zone of the main batholith therefore appears favourable for tin mineralization.

Rapakivi granite has been reported in several parts of the batholith, including the Square Lake area. Martin (1970) considered that the granite of this southern New Brunswick belt is a hypersolvus type reflecting epizonal emplacement, whereas that of the central New Brunswick belt is a subsolvus type representing mesozonal emplacement. The criteria for this view are the relative scarcity of pegmatites and the presence of rapakivi granite and of hypabyssal and volcanic equivalents in the southern belt. In this connection, the relative scarcity of beryl in the southern belt may be significant.

(46) Mount Pleasant (Brunswick Tin Mines)

The property, on a prominent ridge known as Pleasant Mountain, is about 22 miles north of St. George, N.B. (see Figs. 12,13).

The deposit is in altered feldspar and quartz-feldspar porphyries and pyroclastic rocks which form part of a lower Carboniferous volcanic sequence. To the north and east, these form gently dipping sheets and are overlain by Carboniferous red beds. These volcanic rocks overlie Ordovician and Devonian metasedimentary rocks and the Devonian St. George batholith, and are reported also to intrude the batholith (Ruitenberg, 1967, p. 93).

In the Mount Pleasant area volcanic rocks correlated with these are assumed to intrude one another. They are in large part highly altered and contact relationships are obscure. The contact of the volcanic rocks with Ordovician sediments is marked by a broad zone in which brecciated metasediments are intruded by quartz-feldspar porphyry. This porphyry is well exposed above the north adit. It is a light brownish weathering aphanitic rock with phenocrysts of quartz and altered feldspar up to $\frac{1}{8}$ inch across. Towards the top of the ridge this gives way to slightly darker greenish porphyry with relict feldspar phenocrysts but none of quartz. Near the summit this feldspar porphyry becomes progressively more altered and silicified, with sparse mineralization on the margins of the north mineralized zone. There the rocks are highly variable in appearance, light coloured, completely silicified phases alternating irregularly with green rocks in which the feldspar phenocrysts have been in part destroyed, leaving small vugs. The vugs are lined with small quartz crystals, and contain fine sericite, kaolin, or chlorite. Some contain fluorite and/or sulphites, mainly sphalerite and arsenopyrite, and cassiterite.

Much of the rock in both the north and the "Fire Tower" mineralized zone consists of fine to coarse breccia composed of generally angular but locally rounded fragments of various



FIGURE 13. Mount Pleasant tin deposit, New Brunswick.

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material, chiefly volcanic porphyries similar to the surrounding rocks. They have been variously interpreted as volcanic, explosion, and tectonic breccias. Probably all three types are present and have resulted from a prolonged sequence of events but are not definitely distinguishable from one another.

Chiefly associated with the breccias, and especially well exposed in the Fire Tower zone, are many dyke-like bodies of yellowish aphanitic rock, commonly well banded in tortuous patterns roughly parallel to their irregular contacts. They appear to be intrusive rhyolites but are too silicified and altered for identification. These dykes are mainly clustered around two central bodies of highly altered quartz-feldspar porphyry which Ruitenberg (1967) correlates with the Seeley's Formation, the youngest rocks of the volcanic sequence. He interprets these two central bodies as volcanic vents.

The orebodies are ill-defined lodes that are relatively rich in tin-base metal or tungstenmolybdenum minerals, and are determined mainly from assay data. They are in the zone of altered feldspar porphyries close to the central bodies of quartz-feldspar porphyries or within them. The tin lodes are mostly in brecciated rocks close to the leucocratic rhyolite dykes that are clustered around the central rhyolitic cores.

Mineralogy

Cassiterite is the principal tin mineral. It occurs as light brownish euhedral to anhedral grains and aggregates. Some euhedral crystals show zoning in bands parallel to their boundaries and some are twinned (Pl. 11A). Most of the cassiterite in greisen and sulphide ores ranges from 10 to 200 microns in size, but in fluorite-rich ore about half is in grains exceeding 300 microns (Petruk, 1964). Very little is visible to the naked eye.

Cassiterite is mainly associated with fluorite, but in greisen-type ore topaz may be the chief associated mineral next to quartz (Pl. IIA). Zones rich in kaolin carry the highest concentrations, and chlorite and fine sericitic mica are usually present. Fine-grained tourmaline is a less common associate. Arsenopyrite is the most abundant and characteristic sulphide mineral, followed by sphalerite, and in contact with these, cassiterite is commonly corroded.

An estimated 15 per cent of tin in the ore is in the form of stannite. It is mostly seen at grain boundaries between cassiterite and arsenopyrite or sphalerite, and may have replaced cassiterite in this association. It also forms globules and lamellae in sphalerite, commonly with chalcopyrite, in typical exsolution texture (Pl. IIB). It is pale brownish pink in polished section and slightly anisotropic. Several varieties of stannite are present (Boorman and Abbott, 1967). Some of the sulphide minerals, especially stannite, contain unusual amounts of indium. Petruk (1964) found up to 0.3 per cent indium in sphalerite from a vein that contained 2.28 per cent tin. Boorman and Abbott (1967) reported up to 0.98 per cent indium in chalcopyrite concentrates, mostly in stannite and sphalerite impurities.

In addition to arsenopyrite, sphalerite, and minor chalcopyrite, the sulphides include pyrite, galena, molybdenite, a little tennantite, and bismuthinite and wittichenite (copperbismuth sulphide), accompanied by native bismuth. Molybdenite is prominent only in the Fire Tower zone and a few parts of the north zone, and is closely associated with wolframite. Molybdenite is commonly visible in hand specimen, but wolframite is extremely fine grained.

The main non-metallic mineral is quartz, which forms the fine-grained matrix of the ore. Some quartz is in larger grains and in some places it forms a mosaic of euhedral crystals with narrow fine-grained reaction rims. Quartz veinlets are increasingly abundant toward the mineralized zones, where most of the rock is silicified.

Fluorite is abundant in the mineralized zones, both in greisen and sulphide ore. It is mostly purple but varies from colourless to almost black. A brown variety is seen in some tin-rich ore. Pale fluorite occurs as large euhedral crystals in large kaolin masses. Topaz is abundant in typical greisen zones, as microscopic crystals and dense aggregates (Pl. IIA). Closely spaced masses several inches across are conspicuous in some tin-rich areas of the north zone underground.

Chlorite has replaced ferromagnesian minerals throughout the alteration zone. It occurs as formless masses of fine flakes and is commonly mixed with cassiterite and sulphides in the ore. Fine sericitic mica and clay minerals replace original feldspar and accompany chlorite. Kaolin is the chief constituent of some large formless masses and of dyke-like bodies which apparently were originally rhyolite dykes. Massive veins of fluorite border some of these dyke-like bodies, and contain as much as 25 per cent cassiterite locally. Some masses of kaolin have the form of steeply dipping pipes up to 20 feet in diameter, which may represent the intersection of fractures with rhyolite dykes, or of two fractures or dykes. Other minerals present in small quantity include rutile, zircon, and secondary arsenic and iron minerals.

Distribution of tin and other ore metals and relationship to rocks, alteration, and structure.

Tin is mostly concentrated in the north mineralized zone. The south, or Fire Tower zone, is lower in over-all grade, but a considerable amount of tin is contained in sphalerite and chalcopyrite-rich sections. Molybdenum and tungsten are concentrated mainly in the southern zone, with some on the west flank of the north zone.

Tin is erratically distributed throughout the orebodies, generally without clearly defined vein structures, and seems to be related mainly to degree and type of rock alteration¹. The richest tin lodes are composed of irregular veins a few inches to a foot thick, or closely spaced groups of subparallel veins totalling as much as 25 feet thick. They are chiefly in topaz- and fluorite-rich zones in breccias adjacent to rhyolitic dykes, which are disposed mainly around the central cores. In general, highly silicified rocks contain only minor amounts of tin. The highest concentrations have been found near the margins of highly kaolinized bodies, which represent the extreme manifestations of hydrothermal alteration.

Structural control of mineralization is not so readily decipherable, although it follows logically from the geological environment that structural control exists. The volcanic pile, which is host to the deposits, lies within the belt of presumably hypabyssal granitic intrusions off the north flank of the St. George batholith, as previously described. The existence of this belt suggests some fundamental major fault structure. The disposition of the volcanic pile and the intrusive bodies within the belt suggest the influence of subsidiary intersecting structures. The latter are indicated by northwesterly striking faults on Ruitenberg's (1967) map, and on the geological map of New Brunswick (Potter *et al.*, 1968; see Fig. 11). In the area of Pleasant Mountain, a major northwesterly trending fault is intersected and offset by northeasterly trending faults.

Within the deposit the structure is extremely complex and evidence of structural control has been largely obliterated by pervasive alteration and late hydrothermal activity. Most parts of the orebody are highly fractured and jointed, but the attitudes of fracture surfaces are highly erratic. They evidently result mainly from late post-ore stress adjustment but should reflect to some extent the previous history of deformation stress and movement. Some inferred faults and shear zones in the north zone adit have been correlated with surface features. Statistical analysis of fracture attitudes has also been used in determining the fault pattern shown on Ruitenberg's (1967) map of the property. It may be concluded that the development of the volcanic pile itself, and its subsequent alteration and mineralization, were controlled in large part by faults, shears, and tension fractures in a deep-seated zone of

¹A halo of potassium enrichment is associated with the deposit (Ruitenberg and Buttimer, 1972).

crustal weakness. However, the precise effect of these structures on the distribution of mineralization is obscure.

Origin. The volcanic affinity of the Mount Pleasant deposit is self-evident, and it has many features in common with the Bolivian tin-silver deposits that are associated with Tertiary volcanic rocks'. However, its proximity to the St. George batholith, its spatial relationship to the satellite granitic intrusions, and the strongly marked relationship of cassiterite mineralization to greisenized rocks suggest a hypabyssal origin for this mineralization. This inference is supported by the presence of anomalous tin concentrations related to the satellite intrusions in the belt north of the batholith. The possible presence of a hypabyssal intrusion beneath the volcanic pile is suggested by a high-grade metamorphic zone and veinlets of fine adamellite encountered in deep drillholes on the west side of Mount Pleasant (Ruitenberg, 1967, p. 116). Fine biotite-rich rock with granitoid texture was seen by the writer in core from a deep hole drilled in 1970. In 1972 deep drillholes in an area southwest of the North Zone encountered tin mineralization associated with granitoid rocks at 300 to 400 feet below sea level. Chip samples of core taken by the writer from a fine porphyroid and a fine granitic phase of what appeared to be a volcanic-intrusive transition zone were found to contain 85 and 110 ppm tin respectively. It is therefore possible that the volcanic pile is the extrusive equivalent of an underlying late hypabyssal granitic intrusion, and that the greisenization, primary cassiterite mineralization, and final argillic alteration are all genetically related to such an intrusion. However, it is also possible that weak tin and base-metal concentrations related to the Devonian granitic intrusions were remobilized by fluorine and sulphur-rich fluids accompanying subsequent volcanic activity, and deposited in previously consolidated volcanic rocks.

Metal zoning. There are some indications of local zoning of tin and base metals within the deposit. The sulphides were undoubtedly introduced later than the primary cassiterite mineralization. It has been suggested that in the Fire Tower mineralized zone, tin-base metal ores grade downward into tungsten-molybdenum ores (Parrish and Tully, 1971). However, the orebody as a whole clearly represents a typical "telescoped" deposit.

Reserves. No recent estimates of reserves in the north zone have been published. In its annual report of 1963, Mount Pleasant Mines Limited announced reserves as of April 1964 as follows:

	Zone	Tons	Grade (per cent)			
			Sn	Zn	Cu	Pb
Proved ore	North	272,000	0.6	2.3	(0.30)	(0.36)
Probable ore	North Fire Tower	310,000	0.6	2.4	(0.30)	(0.36)
	(No. 7 lode)	165,500	0.43	3.73	0.40	1.18
Possible ore	North Fire Tower	430,000	0.6	2.35	(0.30)	(0.36)
	(No. 7 lode)	862,000	0.4	3.7	0.4	1.18
Total		2,039,000				

¹Boorman and Abbott (1968) reported 0.153 and 0.210 per cent silver in two concentrates of galena from Mount Pleasant. As the latter contained 5.78 per cent tin, inclusions of a tin-silver mineral such as can-fieldite may be suspected.

		Grade (per cent)			
	Tons	Tin	Zn	Pb	Cu
North Zone (to 1000-foot depth)	3.8 million	0.56	2.26	0.15	0.22
Fire Tower Zone (to 600-foot depth)	739,800	0.53	3.56	0.65	0.34

However a press release (Northern Miner, Sept. 1964) quoted the following estimate:

Until recently, work by Brunswick Tin Mines Limited has concentrated on the south and Fire Tower zones and has been directed mainly toward exploration for tin-base metal and tungsten-molybdenum-bismuth orebodies in that part of the property. A calculation of grades for molybdenum, tungsten, and bismuth (but not tin) in the southern end of the orebody for elevations from ± 400 to -200 feet has been published (Parrish and Tully, 1971). Parrish and Tully also estimated that the No. 7 lode developed by the Sullivan Mining Group at 900 feet elevation on the north side of the Fire Tower Zone contained 250,000 tons averaging (as a percentage) Sn 0.7, Zn 4.5, Cu 1.2, and 0.7 ounce silver per ton. Another tin-rich zone, the "Copper Zone," at the south end of the Fire Tower plug was reported to contain chalcopyrite, sphalerite, fluorite, and tin mineralization. It was described as an ovate body about 600 feet high and up to 200 feet in diameter, containing about two million tons of ore. Quantitative assay data were said to be not available at the time. The Copper Zone was said to merge into the upper part of the main tungsten-molybdenum-bismuth orebody.

In 1972 drilling was in progress on a new zone with important tin mineralization associated with a deep granitoid intrusion southwest of the North Zone. Chip samples taken by the writer from a fine porphyroid and a fine granitic phase of what appeared to be a transition zone between volcanic and intrusive rocks were found to contain 85 ppm and 110 ppm tin respectively. The Annual Report for 1972 of Sullivan Mining Group contained the following statement with reference to Brunswick Tin Mines (Mount Pleasant), in which the Sullivan Group now have the controlling interest:

The main exploration achievement of the year was the indication of a large mineralized area in Brunswick Tin's North Zone which could prove as important as the already defined Fire Tower Zone, half a mile to the south.

The reserves of the Fire Tower Zone now stand at 29.5 million tons with an average grade of 0.20% tungsten, 0.09% molybdenum, 0.08% bismuth, 0.04% tin, 0.07% copper, 0.35% zinc, 0.08% lead, 4% fluorspar and of about one ounce of indium per ton. This tonnage has been indicated by previous diamond drilling which also revealed the existence within this deposit, of two richer parts likely to contain about 5 million tons at a grade 50\% higher than the quoted averages.

All the diamond drilling during the last fiscal period was conducted on the North Zone to explore a pipe-like porphyritic intrusive body similar to that of the Fire Tower Zone. The favourable intrusive has a length of about 1,600 feet, varies in width between 500 and 800 feet and has a nearly vertical attitude. It has been partly explored to a vertical depth of 1,400 feet.

Parts of the intrusive porphyry carry tungsten-molybdenum-bismuth mineralization typical of the Fire Tower Zone. Two of the mineralized areas within the North Zone, although not well defined, already show possibilities of several million tons.

The most interesting results provided by the drilling of the North Zone consist of tin mineralization intersected in almost every one of the twenty-two holes drilled below the vertical depth of 300 feet. Many intersections of various lengths and grades were obtained. So far, there are within this zone, twenty-four intersections of thirty feet or more (up to 70 feet), with a grade above 0.5% tin. Half of these carry between 1% and 3% of this metal. Most of the intersections are located in the porphyritic intrusive, at vertical depths ranging from 300 feet to 1,200 feet. (Tin intersections reported by predecessors before 1967 occurred mostly in volcanic rocks adjacent to the intrusive).

(47) Square Lake

The Square Lake occurrences lie within a belt extending northwest for more than 2 miles from Square Lake, about 2 miles southwest of Welsford, New Brunswick. In that area a number of east-southeasterly trending quartz-greisen veins cut granitic rocks of the St. George batholith. Ruitenberg (1969a) shows a sketch map of part of the area, and W. J. Wright (1940b) published a map and description of the mineralized occurrences.

The granitic rocks of the area include coarse-grained biotite granite, rapakivi granite, and aplite porphyry, with irregular contacts. The granitic rocks contain muscovite, and are extensively altered near the veins. The quartz veins vary from 2 inches to 3 feet thick and are occasionally more than 100 feet long. The walls of the veins and joint planes in the granite are commonly bordered by greisen, in zones up to 12 feet wide. These zones are made up of muscovite, quartz, topaz, and locally, some fluorite. Metallic minerals include wolframite, molybdenite, arsenopyrite, pyrite, chalcopyrite, and a little bismuthinite.

According to W. J. Wright (1940b), two bulk samples showed no tin. However, the writer found cassiterite in several thin sections of quartz-muscovite-topaz greisen. A composite sample taken by the writer from greisen veins near Square Lake was found to contain 400 parts per million tin by spectroscopic analysis, but a fluorite-rich sample contained only 42 parts per million.

Another possible occurrence of cassiterite lies a few miles south of Square Lake, near West Lake in the Nerepis area (Ruitenberg, 1969b). There a siliceous alteration zone along the granite contact contains fluorite, topaz, tourmaline, and arsenopyrite, with small amounts of wolframite, molybdenite, and possibly cassiterite.

Nova Scotia Granitic Belt

The only known substantial tin concentrations in Nova Scotia are in the New Ross area (loc. 48). They are on the borders of an area mapped as muscovite granite (Faribault, 1908, 1924, 1931). This area appears to be significantly richer in tin (average of samples taken by the writer : 26 ppm) than the surrounding biotite granite (average 5 ppm), although it includes a large proportion of granite indistinguishable from the "biotite granite."

The tin concentration at McQuarrie Brook (loc. 49) is likewise in an area of muscovitebiotite granite, a sample of which was found by the writer to contain 11 ppm tin. The locality is on the northern boundary of the main granitic belt, apparently in a zone of major dislocation, and this zone may be favourable for tin concentrations.

Vague reports of cassiterite in surficial material or float at or near Tangier, Shelburne, Rawdon, Malaga, and Country Harbour, were referred to by Malcolm and Faribault (1914, p. 284). At Malaga, cassiterite in minute quantity was reported in tailings from the Battery lead (Hoffman, 1890, p. 26T).

(48) New Ross Area, Nova Scotia

The minor but significant tin deposits of the district are quartz-greisen veins, porphyry dykes, and pegmatites, that occur in an area of muscovite-biotite granite near its boundary with biotite granite and granodiorite (Fig. 14). The boundary is marked in part by a wedge-shaped area of quartzites and slates of the Cambrian or early Ordovician Goldenville Formation, and most of the occurrences are adjacent to its contact with the muscovite-biotite granite (Faribault, 1908, 1924, 1931, and Fig. 14).



FIGURE 14. Geology and tin occurrences, New Ross area, Nova Scotia.

The "biotite granite" is a coarse-grained to porphyritic grey massive rock composed of plagioclase, potash feldspar, quartz, and abundant black biotite. It is the common type throughout southern Nova Scotia. The muscovite-biotite granite is quite distinctive in appearance, being generally reddish and altered-looking, and variable in texture with granitic, aplitic, and pegmatite phases. Muscovite is conspicuous, but biotite is usually present, and in many places the rock grades into normal biotite granite. In others, pegmatite, aplite, and porphyritic phases show intrusive relationships to the biotite granite. The average tin content of the ten composite samples of muscovite granite taken by the writer is 26 parts per million, whereas the average of three samples of biotite granite taken just outside the area is 5 parts per million¹. It seems clear that the whole area of "muscovitic granite" has been enriched in tin with reference to the normal "biotite granite." Part of this tin, and main concentrations, must have come from sources below the present level of erosion.

At the Turner Tin prospect, near Mill Road (a, Fig. 14) three subparallel tin-bearing veins have been found cutting muscovitic granite near Gold River (Messervey, 1933; Douglas and Campbell, 1941). A quartz porphyry dyke approximately parallel with the veins is offset about 45 feet by an assumed fault in the bed of the river. The main or Discovery vein is exposed in trenches and two shafts for about 200 feet from the river bank. It averages about 4 feet in thickness and consists of quartz stringers in fine greenish silicified rock. Muscovite occurs only as scattered flakes, and the contacts of the vein are mainly gradational. The quartz stringers are locally vuggy, with patches of purple fluorite and disseminated copper-stained sulphides, mainly chalcopyrite. Cassiterite and topaz were identified in thin sections. A composite sample of vein material taken by the writer was found to contain 0.12 per cent tin by

¹Six composite samples of biotite granite collected between Middleton and Ridge Road contain from 2.8 to 4.9 ppm tin and average 4.0. Two samples of coarse muscovite-biotite granite 15 miles north of New Ross contain 13 and 18 ppm tin.



FIGURE 15. South Bay mine, Dent Township, Ontario.



FIGURE 16. Manitouwadge area, Ontario. (Generalized after E. G. Pye, 1957)

Kilometres

GSC



FIGURE 17. Plan of general geology, Kidd Creek mine (loc. 36) (after Ecstall Mining Limited).



FIGURE 18. Compositional variation among binary and ternary sulphide of Sn, Cu, and Fe (after Scherbina, 1972)

spectroscopic analysis. Analyses reported by Douglas and Campbell (1941) range from 0.10 to 0.36 per cent tin. No production has been reported. The other veins are now almost completely concealed by debris. According to old descriptions, they were similar "greisen" and quartz veins, but smaller, and contain less tin than the Discovery vein. The quartz-porphyry ("elvan") dyke also contains about 0.08 per cent tin in fine quartz veinlets.

East of Lake Wallaback (b, Fig. 14), a stripped area 175 feet by 65 feet exposes partly greisenized muscovite granite and pegmatite, in contact with older quartzite. A composite sample of normal granite was found to contain 69 parts per million tin, whereas rusty greisenized material contained 200 parts per million and dark heavily stained material near a small pit at the contact contained 0.19 per cent tin by spectroscopic analysis. A sample of pegmatite stringers was found to contain 56 ppm tin. No cassiterite was definitely identified and no fluorite or topaz was seen in thin sections of the tin-rich material, which consists of a granular mosaic of quartz and albite, with minor muscovite.

At Reeves Farm (c, Fig. 14) an old pit reported to be 20 feet deep was sunk on a pegmatite lens about 20 feet long in aplitic muscovite granite near its mapped boundary with biotite granite. Little is left of the original exposure, but the dump consists of decomposed coarse feldspar and large subhedral quartz crystals. According to Faribault (1908, p. 32), cassiterite was found with quartz crystals, fluorite, amblygonite, lepidolite, and zinnwaldite in zones of decomposed feldspar in the central part of the dyke. None of these minerals was found in the dump, and no tin was detected by spectroscopic analysis of dump material.

A tin occurrence is shown on Faribault's map (1931) near Lake Ramsay. An old pit at the site has been filled and no exposure is to be seen in the area.

Near New Russel (d, Fig. 14), molybdenite occurs with fluorite, malachite, and chalcopyrite, mostly in greisen bordering a pegmatite dyke. A sample of this material was found to contain 250 parts per million tin by spectroscopic analysis.

Recent work in the New Ross area has included soil sampling and mapping by Frobisher, Ltd. near Wallaback Lake in 1958. In 1962, mapping and geochemical sampling were done by the Nova Scotia Department of Mines (Shea and Wallace, 1963), and some diamond drilling was done at the Turner Tin prospect. Such efforts to find workable tin deposits have evidently been unsuccessful. It seems possible that better concentrations existed in or above the upper contact zone of the muscovitic granites, above the present level of erosion. If so, tin should be concentrated in stream sediments on the southeast (direction of ice movement) side of known occurrences. Heavy mineral concentrates of four samples panned from Gold River at the bridge near New Ross were found to contain from 0.43 to more than 1 per cent tin by spectroscopic analysis.

Newfoundland

(50) Grey River, Burgeo-La Poile, Newfoundland

The minor occurrence of tin, associated with tungsten minerals in a quartz vein at Grey River (loc. 50), is the only one so far reported from Newfoundland. The locality, about 2,000 feet north of the settlement of Grey River, is underlain by Ordovician (?) schist and gneiss of probable sedimentary and volcanic origin, near their contact with pre-Carboniferous granite and gneiss. Quartz veins of a system at least 4,000 feet long contain wolframite, minor scheelite, and "smaller amounts" of cassiterite. The central portion, some 2,000 feet long, averages 1 per cent WO_3 over 3 feet (Northern Miner, Dec. 29, 1966). Accessory minerals include pyrite, base metals, sulphides, molybdenite, and fluorite (Fogwill, 1970). An exploratory drift was being driven by the Buchans Unit of American Smelting and Refining Company in 1970.

The geological environment of much of Newfoundland is similar to that of New Brunswick and Nova Scotia. Moreover, minerals with which tin is commonly associated, such as fluorite, wolframite, molybdenite, and beryl, occur in various areas. A sample of molybdenite-bearing granite from Rencontre Lake, supplied by F. D. Anderson, was found to contain 68 ppm tin by spectroscopic analysis. Samples of granite from the area of the fluorite deposits at St. Lawrence, supplied by W. H. Poole, were found to contain 6, 9, and 10 ppm tin. The province should be favourable for tin occurrences.

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PLATES I to VI



PLATE IA

201760-E

High grade cassiterite ore, tin zone, Sullivan mine (loc. 22(k)). Mainly cassiterite (grey) with pyrrhotite (dark), minor quartz and tourmaline (light). Plane polarized, \times 15 (from thin section loaned by Cominco Ltd.)





201760

Tourmalinized footwall conglomerate, Sullivan mine. Subangular argitlaceous and subrounded quartzite clasts typical. Minor pyrrhotite and quartz in interstices. Plain light, \times 2.2.





112378-E

Tin greisen ore, Mount Pleasant, N.B. (loc. 46). Cassiterite (C) mixed with sulphides and chlorite, in topaz (T)—quartz—fluorite greisen. Plane polarized, \times 50.



PLATE IIB

201751

Tin sulphide ore. Mount Pleasant, N.B. (loc. 46), showing irregular blebs of stannite (S) and rodlike forms of chalcopyrite (C) in exsolution pattern in sphalerite (grey). Lightest grains arsenopyrite and pyrite. Reflected light, \times 50.



PLATE IIIA

201964

Typical quartz—muscovite—cassiterite greisen, Yukon Tungsten property, Cassiar District (loc. 16(1)). Cassiterite (C) (dark) occurs as discrete and dendritic growths mainly in quartz (Q) at or near its boundary with plumose greenish muscovite (M). Reflected light, $\times 1\frac{1}{2}$.



201760-J

PLATE IIIB Stannite ore from tin shoot, Snowflake adit, Snowflake—Regal Silver property (loc. 22(a)) showing stannite (black) and pyrite (medium to dark grey) in quartz (light). Reflected light, \times 4.



PLATE IVA Wood tin, Klondike District (loc. 3). Part of a rounded pebble, showing colloform banded structure. Dark bands richer in iron oxides, lighter bands nearly pure cryptocrystalline cassiterite. Plain light, \times 15.



PLATE IVB

Cassiterite pebble, Dublin Gulch (loc. 4(j)). Mainly angular cassiterite grains, with fragments of quartz—tourmaline rock from nearby lode deposit. Polarized light, \times 15.



PLATE VA

113124-B

Stanniferous andradite garnet, from skarn near Ash Mountain, Cassiar District (loc. 16 (u)). Tin content higher, and iron lower, in darker bands. Plain light, \times 4.



PLATE VB

201964-D

Cassiterite in pegmatite, Bore Group, Yellowknife—Beaulieu District (loc. 24 (a)). Cassiterite (C) (dark grains with light highlights), associated with yellowish muscovite (M), quartz (Q), and blue apatite (A), in cleave-landite feldspar (F). Plain light \times 2.



PLATE VI Open pit at Kidd Creek zinc-copper-lead-silver-tin deposit of Ecstall Mining Limited (Texas Gulf) near Timmins, Ontario, looking northeast. Bottom of pit is more than 400 feet (112 m) below horizon.

201964-F

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