GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MINERAL RESOURCES BULLETIN 12

THE TIN DEPOSITS OF WESTERN AUSTRALIA

WITH SPECIAL REFERENCE TO THE ASSOCIATED GRANITES

1980

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WITH SPECIAL REFERENCE TO THE ASSOCIATED GRANITES

by

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PREFACE

Although small by Australian and World standards, Western Australia's tin deposits have yielded concentrates valued at $40 million and have maintained mining communities at Greenbushes and in various parts of the Pilbara.

The present study began at a time when declining production from the Pilbara deposits seemed to indicate that these were nearing depletion. The aim of the study was to assess remaining resources in the established fields and to determine any geological controls of tin mineralization which could assist in locating new deposits. The early recognition by the author that the Pilbara tin fields are related to plutons of "younger" granite led to detailed petrographic and geochemical investigations of these bodies, and of granites associated with tin deposits in other parts of the State. The results of these investigations are given in this bulletin.

Although most of the field and laboratory work used in this bulletin was completed early in 1971, there has been a long delay in finalizing results and preparing the manuscript. Nevertheless, Mr. Blockley has kept abreast of new developments in the industry and it is considered that this bulletin gives a fair picture of tin mining in the State to the end of 1976.

The wealth of basic information, results of field and laboratory investigations, conclusions and prospecting recommendations for tin should prove of considerable assistance to any prospector or company interested in searching for tin deposits in Western Australia.

19th June 1978.

J H Lord
DIRECTOR

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CHAPTER 1

Introduction

PURPOSES, SCOPE AND PROGRESS OF STUDY

This bulletin reports the results of an investigation of Western Australian tin deposits carried out by the author mainly in the period 1968 to 1971. The study had two main objectives:—

(1) to describe the geology of Western Australian tin deposits, and assess, where possible, their economic potential;

(2) to identify the granites responsible for tin mineralization in each field, and to establish petrographic and chemical criteria which might assist the identification of other tin granites in the State.

Tin deposits in the Kimberley region were inspected in mid-1968, and a little later in the same year a brief reconnaissance was made of tin deposits in the Pilbara area. During 1969 the main tin fields of the Pilbara Block were mapped, other Pilbara deposits inspected, and a start was made on petrographic examination of granites collected from the Pilbara and Kimberley areas.

The Greenbushes tin deposits were examined in January and February, 1970, and reconnaissance regional mapping carried out over an area of about 600 km^2 surrounding the tin field. Apart from inspections of deposits in the Murchison and Eastern Goldfields in November, the remainder of 1970 was employed in petrographic and chemical work on granite samples. These investigations continued to 1976, together with compilation of maps of the various fields.

Staff shortages brought on by the mineral boom resulted in the author acquiring other duties in mid-1971 and slowed down the progress of the work. Regional mapping by Dr Hickman, Mr Lipple, Dr Thom and Mr Chin between 1972 and 1975 produced a better understanding of the geology of the Pilbara Block, and improved the knowledge of the distribution of the younger granites. Some of the new information is incorporated in this bulletin.

ARRANGEMENT OF THIS BULLETIN

This bulletin contains: firstly, an introductory chapter giving general information; the next three chapters in which the State's tin deposits are described in broad groups according to their tectonic settings; and finally, a chapter on the petrography and chemistry of granites associated with the State's principal tin deposits. The locations of rock samples mentioned in the text are given in an appendix.

The grouping of tin deposits into tectonic units rather than into gazetted Goldfields and Mineral Fields is a departure from earlier volumes in this series, but follows recent practice of the Commonwealth Bureau of Mineral Resources (Warren, 1972) and the Australasian Institute of Mining and Metallurgy (Knight, 1975). It also allows the reader requiring further geological information to refer more readily to Memoir 2 of this Survey (Geological Survey of Western Australia, 1975) in which a description of the geology of each tectonic unit is given. Some inconsistencies have been inevitable in the arrangement of the text. The first is in the treatment of the Pilbara and Yilgarn Block. In the former, most deposits lie naturally in tin fields or centres and require no further division on a tectonic basis. In the latter, the Greenbushes deposits fall naturally into a tin field, but the other small scattered occurrences are best further grouped by tectonic setting, following the subdivision of the Yilgarn Block into provinces used by the Geological Survey of Western Australia (1975).

Another discrepancy is in the placing of general sections within a chapter. When several fields having similar regional geology, climate and geomorphology are described, a general section on these aspects is placed ahead of the descriptions of individual fields. Otherwise, a general section is included at the beginning of the description of each deposit or field.

The most important tin deposits lie in the Pilbara Block and the Yilgarn Block, and both of these groups are allocated a separate chapter. Information on other deposits and occurrences is collected in a third chapter, although the tectonic grouping is still retained as sub-headings.

ABBREVIATIONS USED

B.A.	Business Area
D.I.	Differentiation Index
D.C.	Dredging Claim
E.A.C.	Extended Alluvial Claim
G.A.	Garden Area
L.T.T.	Licence to Treat Tailings
M.C.	Mineral Claim
M.H.L.	Miners Homestead Lease
M.L.	Mineral Lease
P.A.	Prospecting Area
T.A.	Tailings Area
W.R.	Water Rights

TIN MINING IN WESTERN AUSTRALIA

DISCOVERY OF TIN

The first tin 'find' in Western Australia was reported from the Toodyay district in 1846, but the discoverer "refused to disclose the locality unless substantially rewarded" (Battye, 1913). The discovery was never confirmed.

The earliest commercial tin deposits were found at Greenbushes in 1888 by Mr D. W. Stinton, possibly as the result of a suggestion by the then Government Geologist, E. T. Hardman. Two accounts of the discovery were published in the early part of this century.

Maitland (1900a) writes:

> "The discovery of tin at Greenbushes would seem to have been due to the researches of the late Mr Hardman, a former Government Geologist. This gentleman while engaged upon official duties in the Blackwood District was accompanied by a Mr Stinton to whom Mr Hardman suggested the probable occurrence of tin-bearing deposits. Having this in mind Mr Stinton at the conclusion of the journey returned to Greenbushes and after a time eventually discovered the rich stream deposit worked by the Bunbury Syndicate."

A rather different account of the finding of the Greenbushes field is given by Woodward (1908). He writes:

> "The history of this field may be said to start about the year 1881 or 1882 when the late Mr E. T. Hardman who was at that time Government Geologist made a flying survey of the South Western District. When camping at the Greenbushes Well, he was struck by the stanniferous character of the material excavated from it and made mention of it in his report which appeared in the press. Whilst upon this trip Mr Hardman met Mr D. W. Stinton who being engaged at the time in kangaroo hunting was able to materially assist him with information owing to his intimate knowledge of the district. It appears that Mr Hardman advised Mr Stinton to prospect for tin in this locality, which he did, with the result that in the latter part of 1888 his labours were rewarded by the discovery of what was afterwards known as the Bunbury Lease."

No contemporary records supporting Woodward's version have been found; the press report referred to could not be traced and Hardman's own account (1884) of this trip makes no mention of the Greenbushes area, although he did report finding metallic tin at Nannup. However Mr R. Lock, a Director of Greenbushes Tin N.L., has recently located descendants of Stinton who he states confirmed Woodward's account of the discovery.

In the same year that Stinton reported finding tin at Greenbushes, prospectors moving into the hinterland of the Pilbara Block in the search for alluvial gold, located cassiterite in a number of places.

Simpson and Gibson (1907) record the discovery of tin in the region as follows:

> "The discovery of gold in many parts of the Pilbara field in 1888 and 1889 led to vigorous prospecting of the whole of this part of the State, with the result that tin ore was detected in many of the streams lying between the Yule and Coongan Rivers. The most important, at the time, of these discoveries was that of the Old Shaw, or Eleys Well. Several causes operated against the working of these deposits at the time, viz: the ease with which alluvial gold was to be obtained in the district, the restriction of the size of a tin claim within a goldfield to that of a gold claim, and finally the great cost of transporting the ore to the coast and thence to the tin smelters at Singapore or Sydney. These difficulties were subsequently overcome, and in 1893 over 56 tons of black tin were raised at Eleys and exported."
>
> "No further localities were opened up till April of 1899, when extensive alluvial deposits were first worked at Moolyella. In August, 1900, payable stream tin was located at Cooglegong Creek, and in 1902, lode and stream tin at Stannum, and subsequently at Wodgina."

Tin was found in the Halls Creek Province in 1907, and in the Murchison and Eastern Goldfields Provinces of the Yilgarn Block in 1909. By 1910, almost all of the presently known commercial tin fields in the State had been located. The only important discovery since that time has been the Coondina deposit, and this was apparently known to Aboriginal prospectors for some time before it was first reported in 1964.

PRODUCTION

To the end of 1975, the State's total recorded production of tin concentrate amounted to 33 454 tonnes. Details of the amounts obtained from each tectonic unit are given in Table 1 which contains references to more detailed figures tabulated elsewhere in this bulletin. Table 2 compares production from the Southwestern Province (Greenbushes tin field), the Pilbara Block, and the remainder of the State. This information is also illustrated graphically in Figure 1 which shows annual production and the average yearly price of tin on the London Metal Exchange.

Early mining, mostly of the richer deposits, by individual prospectors or syndicates, reached its peak in 1907 and then declined rapidly. From 1921 to 1952 tin concentrate production for the State was less than 100 tonnes per year. In the late 1950s and 1960s, generally rising tin prices and the introduction of earth moving machinery permitted previously uneconomic ground to be treated and brought about a sizeable increase in tin output with a peak production of 2 037 tonnes in 1972. The effect of this boom was felt earlier in the Pilbara Block than at Greenbushes, probably because the Pilbara deposits were of higher grade and at shallower depth. As a result, by about 1970 accumulated production from the Pilbara Block had overtaken that from Greenbushes for the first time in the history of the two areas. However, sharply increased production from Greenbushes from 1972 onwards has returned

TABLE 1. PRODUCTION OF TIN CONCENTRATE FROM VARIOUS TECTONIC UNITS IN WESTERN AUSTRALIA TO END OF 1975

Tectonic unit	Tin concentrate (tonnes)	Realized value ($ Aust)	Remarks
Pilbara Block	15 747	18 395 490	Tables 3 & 24
Yilgarn Block			
Southwestern Province	17 689(a)	15 861 082(b)	Table 26
Murchison Province	5.5	1 723	Table 29
Eastern Goldfields Province	10.5	16 765	Table 29
Halls Creek Province	1.8	1 923	Table 33
State Total	33 454	34 276 983	

NOTES: (a) Includes 74 tonnes (approx) produced in 1889 and 1890 which are not included in official Mines Department Statistics

(b) Value of production in 1889 and 1890 is not available.

TABLE 2. ANNUAL PRODUCTION OF TIN CONCENTRATE FOR THE GREENBUSHES TIN FIELD, THE PILBARA BLOCK AND THE REMAINDER OF THE STATE (TONNES)

Year	Greenbushes tin field	Pilbara Block	Other	Total
1889	5.1			5.1
1890	68.6			68.6
1891	207.3			207.3
1892	269.2			269.2
1893	174.2	57.4		231.6
1894	377.2	19.3		396.5
1895	281.6			281.6

TABLE 2.—CONTINUED

Year	Greenbushes tin field	Pilbara Block	Other	Total
1896	139.4			139.4
1897	97.1			97.1
1898	69.2			69.2
1899	281.8	58.4		340.2
1900	442.6	394.0		836.7
1901	326.5	419.6		746.1
1902	409.7	219.8		629.5
1903	533.4	296.8		830.2
1904	542.2	326.0		868.2
1905	653.8	442.6		1 096.6
1906	795.8	723.0		1 518.9
1907	782.4	867.3		1 649.8
1908	585.6	409.5		995.1
1909	466.1	298.7	1.5	766.3
1910	322.8	155.9		478.8
1911	417.7	151.0		568.7
1912	437.4	125.3		562.7
1913	465.8	141.3		607.1
1914	248.5	88.8		337.3
1915	251.3	79.9		331.2
1916	286.3	155.6		441.9
1917	241.7	70.1		311.9
1918	300.5	101.1		401.6
1919	248.5	37.3		285.8
1920	193.1	42.1		235.3
1921	53.7	14.7		68.4
1922	16.1	25.1		41.9
1923	28.5	24.8		53.3
1924	53.4	29.0		82.4
1925	56.2	24.3		80.5
1926	62.1	36.0		98.1
1927	59.3	38.0		97.3
1928	55.4	36.0		91.4
1929	38.9	18.1		57.1
1930	0.7	12.0	0.6	13.3
1931	—	6.4		6.4
1932	8.4	7.1		15.5
1933	3.1	12.7		15.8
1934	1.6	11.6		13.2
1935	17.6	0.5		18.2
1936	22.2	4.7		26.9
1937	57.9	2.8		60.7
1938	52.7	0.6		53.3
1939	10.9	1.1		12.1
1940	34.1	3.0		37.1
1941	5.2	5.9		11.1
1942	12.9	10.9		23.8
1943	6.0	4.7	0.8	11.5
1944	0.9	10.0		10.9
1945	32.4	8.6	0.3	41.3
1946	14.8	14.2		29.0
1947	5.8	18.2		24.0
1948	2.0	35.6		37.6
1949	3.2	32.0		35.2
1950	30.8	21.4		52.2
1951	22.8	39.0	0.3	62.1
1952	36.5	62.7	0.1	99.3
1953	42.1	72.7	0.3	114.8
1954	43.5	79.7		123.2
1955	121.5	61.0	0.1	182.5
1956	133.3	230.8	0.1	364.1
1957	49.9	224.7		274.6
1958	14.5	125.9		140.4
1959	23.3	230.4		253.7
1960	20.5	264.9		285.4
1961	19.6	326.2	0.8	346.6
1962	23.2	449.3	0.5	473.0
1963	47.6	537.8	0.1	585.5
1964	58.2	588.1	1.0	647.3
1965	30.2	656.0	0.2	686.4
1966	21.9	572.7	3.9	598.5
1967	113.8	1 141.6	3.2	1 258.6
1968	334.2	1 253.4	0.1	1 587.7
1969	358.2	448.8	0.2	807.2
1970	408.1	363.2		771.3
1971	338.8	523.1		861.9
1972	1 504.3	533.2		2 037.5
1973	849.0	336.7		1 185.7
1974	749.7	130.8		880.5
1975	624.2	343.1		967.3
Total	17 689	15 747	17.8	33 454

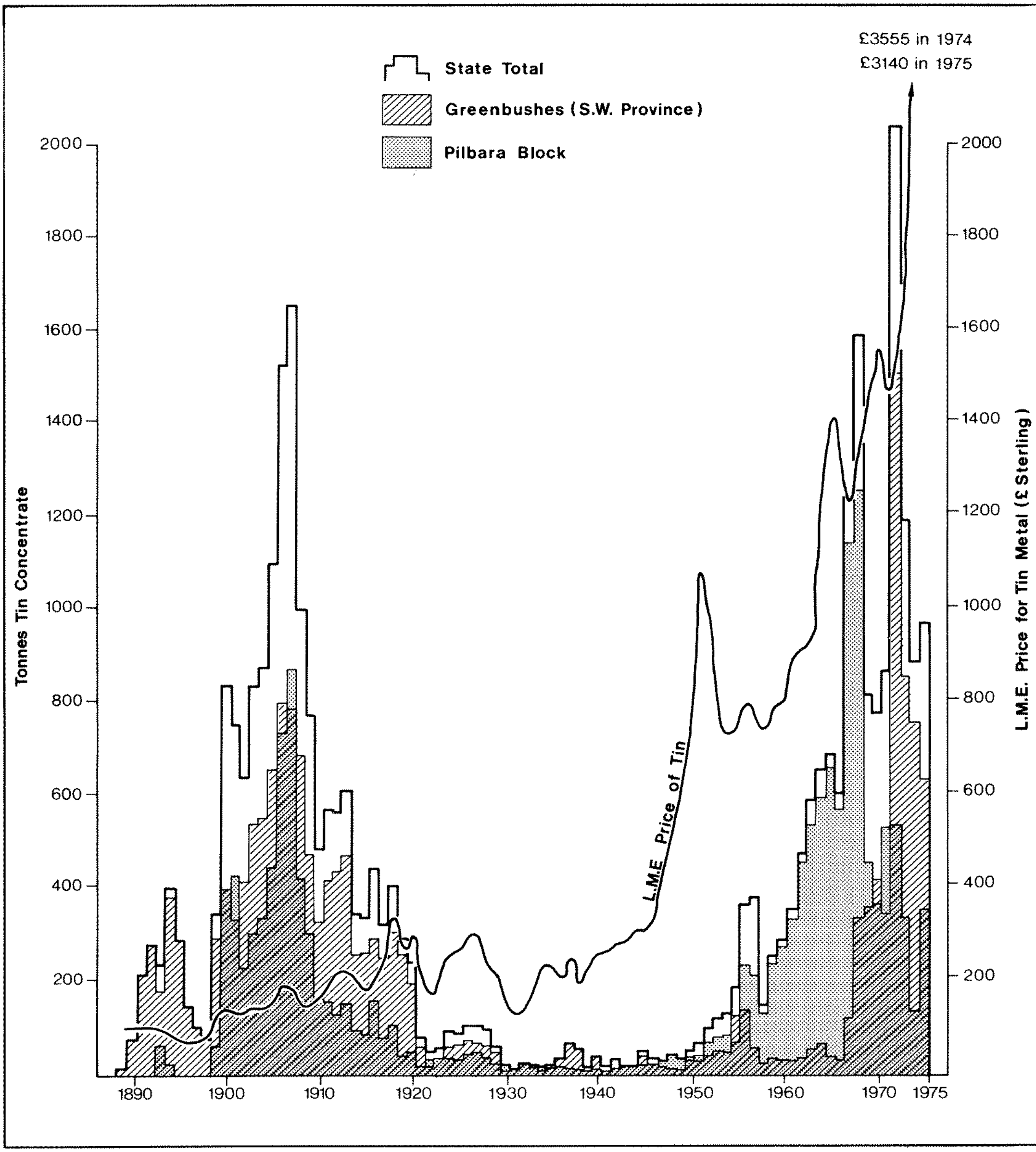

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Figure 1. Bar diagram showing annual production of tin concentrate from the Greenbushes tin field, the Pilbara Block and the whole of Western Australia

that field to its former first ranking position. The increase in production at Greenbushes is due to current large-scale mining of weathered pegmatite.

MINING METHODS

Methods used to mine and treat tin ores in Western Australia are described more fully in Chapters 2 and 3 of this bulletin. The intention here is to contrast the procedures used at Greenbushes and in the Pilbara fields. In the former locality, a reasonably wet climate enables standard methods of mining secondary ores and extracting the cassiterite to be used. A considerable amount of tin was formerly produced by hydraulic sluicing of alluvium and weathered pegmatite, and at two periods of the field's history, floating bucket dredges were used. Dry mining has been restricted mainly to excavating weathered pegmatite and lateritized alluvium.

The tin fields of the Pilbara Block, in distinct contrast to Greenbushes, are set in a semi-arid terrain where water is scarce. Hydraulic sluicing and dredging have never been used, all mining being done by dry methods. Standard practice since the 1950s has been to excavate the dry creek beds using bulldozers and mechanical shovels, and to cart the ground to treatment plants situated on supplies of water, usually at bores. The Pilbara tin miners pioneered the use of the Reichert cone for the treatment of tin ores. The resulting saving in water allowed larger volumes of ground to be treated with the available supplies and contributed to the profitability of the Pilbara mines.

MARKETING OF TIN CONCENTRATES

No tin ore is smelted in Western Australia, all concentrate being shipped through brokers to smelters in New South Wales or Malaysia. The price for tin concentrate is quoted in Australian dollars per metric tonne unit (m.t.u.). One m.t.u. is equivalent to one hundredth of a tonne (10 kg) of contained metallic tin. Hence one tonne of concentrate assaying 70 per cent tin would bring 70 times the unit price, less handling charges:

(70/100 x 1 000 kg = 700 kg = 70 units).

The antimony contents of some Western Australian tin concentrate make it unacceptable to the New South Wales smelter, but these ores can be accommodated by smelters in Malaysia. The latter also pay for tantalum contents above 2 per cent.

World marketing of tin is controlled by the International Tin Council (I.T.C.) whose members are the major tin producing and tin using nations. The I.T.C. attempts to keep the price of tin between predetermined amounts by selling from, or adding to, a buffer stock which it maintains. When these measures fail to keep the price above the minimum agreed figure, the Council may impose export controls on the producing members.

In Australia, such export controls are administered by the Commonwealth Department of Minerals and Energy, which in turn allocates production quotas proportionately to established tin mines on the basis of average production over some past period. In such times of export controls it is difficult for a new producer to break into the market, unless an established mine is unable to meet its full quota.

Information on prices and quotas extant at any time can be obtained from the Western Australian Department of Mines, the Commonwealth Department of Minerals and Energy, and most ore buyers.

PRINCIPAL GEOLOGICAL FEATURES OF WESTERN AUSTRALIAN TIN DEPOSITS

AGE AND TECTONIC SETTING

Figure 2 shows the distribution of Western Australian tin deposits (excluding minor occurrences) and the boundaries of the various Precambrian tectonic units in the State. Almost all deposits lie within the more stable parts of the shield represented by the Archaean Pilbara and Yilgarn Blocks. Proterozoic mobile belts have contributed small quantities of cassiterite from two or three deposits in the Halls Creek Province and contain minor occurrences (some doubtful) in the Gascoyne and Albany-Fraser Provinces. No primary tin deposits are known in rocks younger than the Precambrian.

Where dated, granites associated with tin deposits in the Pilbara Block and the Murchison and Eastern Goldfields Provinces fall into the range 2.6 to 3.1 billion years (b.y.), and a tin-bearing pegmatite at Greenbushes has an age of 2.7 b.y. All primary tin deposits in these units are considered to be Archaean. Granites associated with deposits in the Halls Creek Province have ages between 1.8 and 1.9 b.y., suggesting a Lower Proterozoic age for tin mineralization.

TYPES OF DEPOSITS

Primary deposits

All but one of the primary tin deposits examined were pegmatite bodies, or rocks closely associated with pegmatite. The following broad types were recognized:

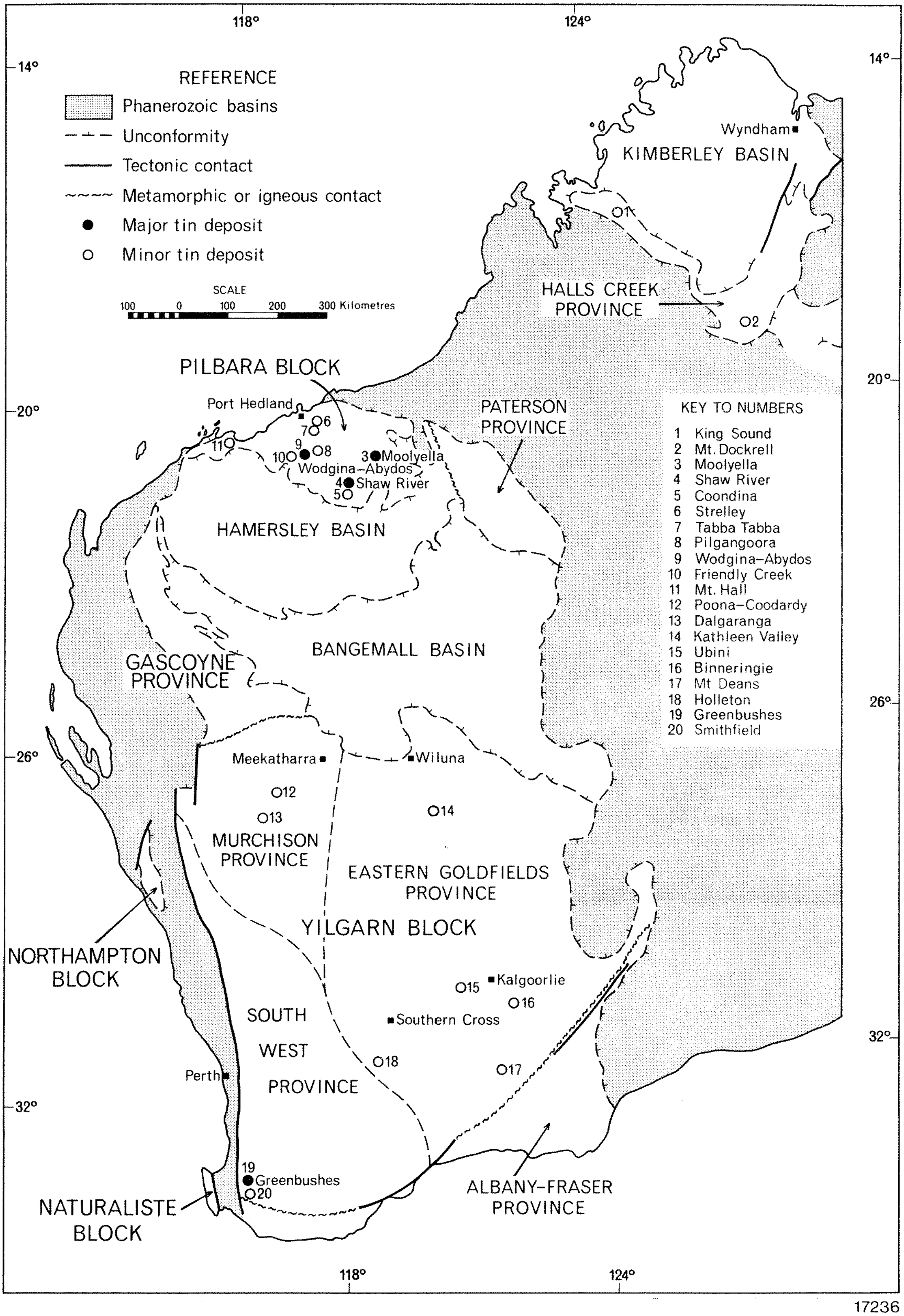


Figure 2. Map showing distribution of Western Australian tin deposits and boundaries of Precambrian tectonic units. Only deposits with recorded productions are shown

Simple pegmatites, usually composed of quartz, albite, and muscovite, contain cassiterite, tantalum, and niobium minerals with rarer lithium and beryllium compounds (e.g. Comet and Bright Star mines in the Wodgina tin field);

Layered aplite-pegmatites made up of bands of fine-grained quartz-albite aplite alternating with coarser quartz-microcline-albite-muscovite pegmatite, carry cassiterite, tantalite and columbite, rare lepidolite, zinnwaldite, and beryl, with spessartine as a common and characteristic accessory (e.g. Moolyella and Coodardy);

Complex rare-metal pegmatites in which cassiterite is often subordinate to tantalite, columbite, beryl, and various lithium minerals and which are usually regularly or irregularly zoned (e.g. Strelley and Mount Deans);

Tourmaline-mica 'lodes' which either follow the edges of pegmatite veins or occupy nearby parallel fractures, and appear to be the last phase of pegmatite mineralization (e.g. Wodgina centre).

The only primary tin deposit not associated with pegmatite is the King Sound mine where quartz veins bearing tin-tungsten were worked on a small scale.

Tin-bearing greisens are found only as lenses in pegmatite, or as minor dykes. Greisens formed in granite are rare and, where sampled, barren of tin. Cassiterite has not been identified as an accessory mineral of granite in Western Australia. Tin-bearing sulphide lodes are unknown in this State, although very minor quantities of sulphides have been reported from pegmatites at Greenbushes and Wodgina.

Secondary deposits

Although Recent eluvium and alluvium have contributed to the tin concentrate taken from all fields examined, the greater proportion of secondary tin ore has come from deposits of 'older' alluvium ranging in probable age from Eocene to Pleistocene. In the Pilbara Block most of the tin ore has been won from buried stream gravels (deep leads) which follow the present valleys but are not always directly beneath the present creek beds. These deposits are to some extent eroded by the present rivers and are thought to be of Pleistocene age. Further sources of cassiterite in the Pilbara fields are deposits of cemented gravels which are now raised above the present streams. These seem to be remnants of a Tertiary drainage system.

At Greenbushes in the Southwestern Province, most cassiterite has come from a widespread fluviatile deposit known as the Old Alluvium, or, in this bulletin, the Greenbushes Formation. The deposit is unrelated to the present drainage system and is possibly of Eocene age.

MINERALOGY

The only tin mineral worked commercially in Western Australia is cassiterite. Small quantitites of ainalite (tantaliferous cassiterite) have been reported from Greenbushes, Ubini, and the Bremer Range.

Economic minerals commonly associated with secondary cassiterite are monazite, tantalite, columbite, manganotantalite, and manganocolumbite. Other rarer minerals include stibio-tantalite, tapiolite, microlite, a number of rare-earth tantalum minerals, gadolinite and, in one locality, wolframite.

In addition to the range of tantalum and niobium minerals, tin-bearing pegmatites commonly contain potentially commercial quantities of lepidolite, zinnwaldite, beryl, and more rarely, amblygonite, spodumene, and lithiophyllite.

Minerals found in non-commercial amounts in tin-bearing pegmatites include spessartine, an unusual green muscovite, tourmaline, magnetite, topaz, zircon, helvite, fluorite, simpsonite, and wodginite. Quartz veins in the King Sound tin mine contain wolframite, arsenopyrite, and scorodite as well as cassiterite.

RELATIONSHIP TO GRANITES

Attempts made during this investigation to relate tin deposits to source granites met with varying success in different parts of the State. In the Pilbara Block, the main deposits are associated with stocks of post-tectonic 'younger' granites intruding an older complex of migmatitic, gneissic, and foliated granite. These younger granites show many features common to tin granites in other parts of the world. They are leucocratic, quartz-rich, biotite or biotite-muscovite adamellites with a chemistry that indicates appreciable magmatic fractionation. They have anomalously high contents of elements such as tin, lithium, beryllium, niobium, and rubidium, and are depleted in lime, magnesia, and iron oxides. Some small tin deposits in the Pilbara Block are associated with the more differentiated phases of the older granite complex.

No clear relationship between tin deposits and granites was found in the Southwestern Province of the Yilgarn Block. All granites examined appeared to be either too small or too unfractionated to be the source of the large tin-bearing pegmatites at Greenbushes. Presumably the tin granites are not exposed.

Investigations of granites associated with minor tin deposits were generally inconclusive. In the Halls Creek Province tin is associated with adamellite rather than granodiorite, but well-fractionated phases are restricted to small aplite dykes. The deposits in the Murchison Province are related to a large batholith of potassic granite, which in places at least contains anomalously high fluorine and lithium. Examination of granites in the Eastern Goldfields suggests that the tin deposits are related to massive granites with more than average contents of potash feldspar, but no highly fractionated granites were found apart from some forming small dykes.

The main conclusion of the study is that any granitic rocks of generally adamellitic or potassic granite composition may yield small tin deposits, but the important commercial tin fields require the presence of reasonably large intrusive bodies of well-fractionated granite. Unfortunately, in the outcrop conditions found in parts of Western Australia, such granites may not be exposed at the surface.

ACKNOWLEDGEMENTS

Thanks are due to the Managements of Greenbushes Tin N.L., British Metal Corporation (Cooglegong Tin), Kathleen Investments Ltd (Pilbara Tin) and J. A. Johnston and Sons for making available their records and facilities.

The Government Chemical Laboratories assayed a considerable number of tin concentrates and ores, and determined uranium and thorium on a suite of granite samples. Mr P. Wilson of the Agricultural Division of the Laboratories determined fluorine in solutions supplied by the writer.

Much of the chemical work on granites associated with tin deposits was carried out by the author at the University of Western Australia while studying for a higher degree. The co-operation of Professor R. T. Prider and his staff is gratefully acknowledged.

CHAPTER 2

Pilbara Block

HISTORY AND PRODUCTION

The tract of semi-arid country comprising the Pilbara Block was first explored by F. T. Gregory in 1861, and settled by graziers in about 1863. Copper ores were discovered at Roebourne in 1872, and gold in the same area in about 1887. Alluvial gold found at the old Pilbara camp in 1888 drew prospectors into the interior, and resulted in the discovery of tin.

The initial discoveries were followed by a period of active tin mining which lasted until about 1918. During this time, tin was mined mainly from high grade deposits by prospectors working independently, or in small groups, using hand tools and simple concentrating equipment. The one exception was the Cassiterite mine at Wodgina, where lode tin was mined and treated by a small company using crushing machinery. At the peak of this period of mining, Simpson and Gibson (1907) estimated that there were 400 men at Moolyella, and 80 at Cooglegong.

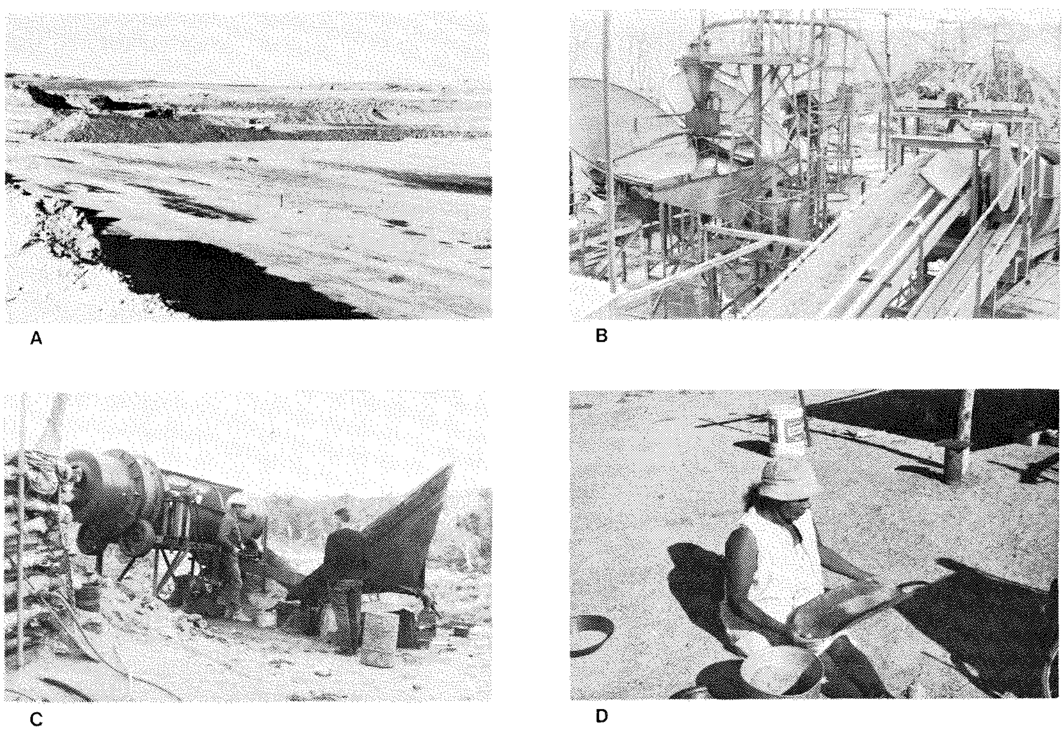


Figure 3. Photographs of tin mining in the Pilbara Block.
A. Open cut on Moolyella Creek, 1969.
B. Cooglegong Tin Pty Ltd's plant at Spear Hill, 1972.
C. Yule River Tin Syndicate's plant at Friendly Creek, 1969.
D. Aboriginal prospector, Mollie Dann, treating tin-bearing alluvium in a yandy dish near Cooglegong

When the higher grade deposits were exhausted, tin production fell off appreciably, and there was little further mining until rising prices and the introduction of modern earth-moving machinery enabled previously unpayable ground to be treated. Production rose from 61 tonnes of tin concentrate in 1955 to a peak of 1253 tonnes in 1968, but then declined again due to depletion of payable deposits.

During this last bout of activity, most of the tin was obtained by companies, or well-equipped syndicates, using bulldozers, scrapers and mechanical shovels to mine the tin-bearing ground (Fig. 3A), and fleets of trucks to cart the ore to treatment plants (Figs. 3B, 3C) located on suitable water supplies. One or more such plants have operated at the centres of Moolyella, Cooglegong, Eleys, Coondina, Abydos and Pilbara. In these plants, preliminary concentration of the tin-bearing wash is effected in Reichert cones after screening out over-size material (usually +12.7 mm) in rotating trommels. The concentrate from the cones is then fed through jigs, and after drying, through electro-magnetic separators to remove the last of the garnet, magnetite and tantalite. Some of the smaller producers send their cone concentrate to the Marble Bar State Battery for upgrading before marketing. Significant quantities of tantalo-columbite are recovered as a by-product of tin mining.

Aboriginal prospectors in the Pilbara produce small but steady quantities of tin concentrate from minor deposits unsuitable for large scale mining, and from remnants of ore left by the various companies in the larger mines. The ore mined by Aboriginal men is first pounded between stones to free the cassiterite, then concentrated dry, usually by Aboriginal women, in a yandy dish (Fig. 3D). Table 2 shows the annual production of tin concentrate since 1893, and Table 3 lists production from individual centres.

TABLE 3. PRODUCTION OF TIN CONCENTRATE FROM INDIVIDUAL FIELDS AND CENTRES IN THE PILBARA BLOCK TO THE END OF 1975

Field or centre	Tin concentrate (tonnes)	Realized value ($ Aust)	Remarks
Moolyella	7 620.30	8 973 530	See Table 5
Shaw River	6 584.33	7 123 203	See Table 11
Wodgina	478.01	114 617	See Table 14
Coondina	613.36	1 471 637	See Table 17
Friendly Creek	119.82	316 710	See Table 18
Tabba Tabba	131.92	32 103	See Table 19
Pilgangoora	13.71	15 102	See Table 21
Pinga Creek (Abydos)	37.15	78 593	See Table 23
Minor Centres and Sundry Claims	148.67	269 995	See Table 24
Total	15 747.27	18 395 490	

CLIMATE

The Pilbara Block has a semi-arid climate typical of the western sides of continents at higher tropical latitudes. The average annual rainfall is from 280 to 355 mm per year, with about 70 per cent of this concentrated in the summer period from December to March. Monthly rainfall data for Marble Bar are tabulated in Table 4. They show the wide variation that may take place from year to year, making arithmetical averages almost meaningless when applied to problems of hydrology. Most of the rain results from tropical cyclones generated in the Indian Ocean and travelling south-westerly to strike the coast. These bring heavy falls lasting over periods of two or three days, and often result in destructive flash floods.

Evaporation rates in the Pilbara are about 2.5m per year, and greatly exceed rainfall.

Marble Bar, the main centre for the tin mining industry, has long been renowned for its high temperatures. The mean maximum temperature is the highest in Australia, exceeding 38°C for six months and averaging 35.7°C over the whole year. Similar high temperatures are recorded throughout the inland part of the Pilbara Block, although in the coastal towns the temperatures are moderated by the ocean. Details of average monthly temperatures recorded at Marble Bar, are listed in Table 4.

Because of the high temperatures and difficulties of working in the wet season, some mining and many exploration companies suspend operations during the summer months.

WATER RESOURCES

Due to the low and erratic rainfall, tin miners in the Pilbara region have often had trouble obtaining sufficient water for their needs. The many rivers and creeks in the area flow for only a short period during the wet season, and in the drier years may not flow at all. For most of the time, the rivers contain only isolated pools of water separated by stretches, in places many kilometres long, of sand and shingle. Several potential dam sites have been investigated in the Pilbara Block (e.g. Gordon, 1968), and it is anticipated that large dams may eventually be constructed.

Most of the water at present used in the Pilbara Block is obtained from wells and bores, although some of the tin mines obtain supplies from dams constructed during the course of their operations. Groundwater is obtained from alluvium, and weathered and jointed bedrock. The better supplies are usually found close to rivers and creeks where recharge is greater. Places where such creeks cut dolerite dykes, quartz veins, or interconnected veins of pegmatite may yield particularly large supplies.

Bores put down near the tin fields have yielded a reported maximum of 1750m³ per day of water, although most supply considerably less than this amount. Allen (1966) estimated that one bore in every two or three sunk into weathered granitic rock underlying alluvium will yield more than 108m³ per day. Of 89 bores sunk into Archaean rocks (mainly granitic) along the Mount Newman Mining Co. Pty Limited railway, 26 obtained supplies of 108m³ per day or better (of which five were between 540 and 1080m³ per day), 25 produced quantities of less than 108m³ per day and 38 were recorded as yielding no water.

Up to 720m³ per day of water have been obtained from bores and wells sunk in metamorphic rocks close to Marble Bar near the junction of Sandy Creek and the Coongan River. Wells put down in similar rocks at Wodgina, but close to the headwaters of the local stream, produced only small supplies.

Groundwater in the vicinity of tin deposits may have fluorine contents exceeding that considered safe for humans. For example, two bores at Johnston's camp near Eleys contain 3.2 and 6.5 ppm F respectively.

Further information on water supplies in the Pilbara Block can be obtained from the Hydrogeology and Engineering Geology Division of the Geological Survey of Western Australia.

PREVIOUS INVESTIGATIONS

REGIONAL GEOLOGY

The first comprehensive geological survey in the Pilbara Block was undertaken by Maitland (1904, 1905, 1906, 1908) whose work laid the foundations of all subsequent investigations and whose conclusions dominated geological thought on the area until the mid-1960s. Woodward (1911) carried out a similar survey of the West Pilbara Goldfield.

The results of a survey of that part of the Pilbara Block lying within the Marble Bar and Nullagine 1:250 000 Sheets was published by Noldart and Wyatt (1962). This work was followed by further regional mapping which included the Port Hedland (Low, 1965), Roebourne (Ryan, 1966), Pyramid (Kriewaldt and Ryan, 1967), and Balfour Downs (de la Hunty, 1964) 1:250 000 Sheet areas, all of which contain tin deposits. Upon the completion of the regional mapping, Ryan (1964, 1965) was able to review the geology of the Pilbara Block and attempt correlations between the various exposures of the layered sequences.

Another regional mapping programme covering the Marble Bar, Nullagine, Yarrie and Port Hedland Sheets commenced in 1972 and was completed in 1976. Some results have been published by Hickman and Lipple (1975, 1979), Hickman (1975a, 1975b, and 1977) and Lipple (1975).

TIN DEPOSITS

A number of descriptions of individual tin mines or fields have been published. The more comprehensive are those for Wodgina and Stannum (Maitland, 1904), Moolyella (Maitland, 1906), Moolyella and Cooglegong (Montgomery, 1907; Sullivan, 1939) and the Wodgina district (Blockley, 1971). More detailed lists of references precede the descriptions of each centre.

TIN GRANITES

The first recognition of a 'tin granite' in the Pilbara Block was by Maitland (1919) who observed: "Sections are to be seen near the tin mining centre of Wodgina, in the Pilbara Goldfield, showing an ancient intrusive granite which has been invaded by a newer, (though still old) tin-bearing granite". In a later section of the same publication, it seems that the term "newer granite" may in fact have referred to the tin-bearing pegmatites, for he uses pegmatite and granite as synonyms when writing of these (Maitland, 1919, Chapt. 2, Pt 3, Sect. 3, p.5).

TABLE 4. RAINFALL AND TEMPERATURE INFORMATION, MARBLE BAR

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Rainfall													
Average (mm)	72.4	73.7	54.4	21.1	22.6	23.6	13.2	5.3	1.0	4.6	8.9	34.3	335.0
Highest (mm)	309.6	234.7	388.6	240.5	149.3	158.7	133.9	34.3	24.1	116.3	61.5	243.1	741.7
Lowest (mm)	0	0	0	0	0	0	0	0	0	0	0	0	71.1
Highest one day (mm)	145.8	119.4	304.8	136.1	69.6	104.6	62.7	31.7	24.1	84.3	60.5	150.4	304.8
Av. no. wet days	7	6	4	2	2	2	2	1	0	0	2	4	32
Temperature													
Mean maximum(°C)	41.2	40.8	39.4	36.1	31.1	27.2	27.0	29.9	34.3	37.8	41.1	41.9	35.7
Mean minimum (°C)	26.0	25.9	24.9	20.8	16.3	12.6	11.3	13.1	16.5	20.4	24.0	25.6	19.8
Highest maximum (°C)	49.2	48.3	46.7	45.0	39.4	33.9	35.0	37.2	42.6	45.6	47.2	48.3	49.2
Lowest minimum (°C)	18.9	13.9	15.3	11.1	5.6	1.1	2.2	3.9	5.6	10.0	14.4	17.2	1.1
Av. No. days over 100°F (37.8°C)	27.9	22.1	18.9	8.8	0.2	0	0	0	2.0	12.6	24.2	28.7	145.4

Noldart and Wyatt (1962) made a study of the granitic rocks of the eastern Pilbara Block during their regional survey. They recognized that these could be divided into magmatic, gneissic and granitized types, but due to the broad scale of their work, mapped the first two types as one unit. They regarded some of the granitic complexes as having a magmatic origin (although with marginal granitization) and others as having been formed by widespread granitization with partial anatexis giving rise locally to magmas.

At the completion of their survey, Noldart and Wyatt (1962, appendices 1 and 2) submitted forty-four samples of granitic rocks to the Government Chemical Laboratories for chemical and mineralogical work in the hope that some features would be found to distinguish granites related to tin deposits. No field relationships appear to have been supplied with the rocks. Six of the samples were analysed qualitatively and found to contain traces of tin. Two of these were selected for further work, and were crushed and concentrated to give small fractions of heavy minerals. Two samples of granite from areas of the State known not to be tin bearing were similarly treated and the heavy mineral concentrates from all four samples were analysed for tin by emission spectrography. No significant difference was found between the tin contents of the granites from tin-bearing and barren areas, and accordingly it was concluded that this method was not likely to be a successful prospecting tool. However, from more recent work on tin granites in other parts of the world (see Chapter 5) and from data resulting from the present investigation, it is now known that most of the tin in tin granites is concentrated in the biotite, and that primary cassiterite is a rare constituent. It is also apparent from its reported locality, mineral assemblage and silica content that at least one of the Pilbara granite samples (2/4815) was from the older granitic complex and hence not related to tin mineralization.

Determinations of SiO_2 carried out on the samples ranged from 53.2 per cent to 85.4 per cent, indicating that a wide variety of granite types were represented.

Modal analyses of the samples enabled two groups to be separated out, one by the presence of accessory fluorite, and the other by accessory sphene and zircon. It was noted that some of the fluorite-bearing granites came from areas in which tin had been mined, and on the basis of this it was recommended that the localities from which the others had been collected should be prospected for tin. One of these localities, Split Rock, subsequently recorded a small production of tin concentrate, although tin had been reported in that area in 1903.

In general, the lack of information on the appearance, occurrence or mutual relationships of the granites examined, made the results of the laboratory work of little use to the man in the field.

At an early stage in the present investigation, Blockley (1970) noted that the majority of the tin deposits in the Pilbara were found close to intrusions of younger granite within the granitic domes. He gave brief descriptions of the mineralogy and appearance in outcrop of these granites.

Subsequently two of the principal plutons of younger granite, together with older granites which they intrude, were dated by Dr J. de Laeter of the Western Australian Institute of Technology. Results of this work reported by de Laeter and Blockley (1972) and de Laeter, Lewis and Blockley (1975) indicated ages of $2\,614 \pm 93$ m.y.* and $2\,551 \pm 125$ m.y. respectively for the Moolyella and Cooglegong Adamellites. These dates contrast with ages of $3\,056 \pm 358$ m.y. and $2\,889 \pm 81$ m.y. obtained from the older granites intruded by each of the two bodies. The isotopic work also showed marked differences between the initial Sr^{87}/Sr^{86} ratios of the two ages of granite; these ratios in the two younger plutons were 0.7397 ± 0.0419 and 0.7303 ± 0.028 respectively compared to values of 0.7016 and 0.7020 for the older granites.

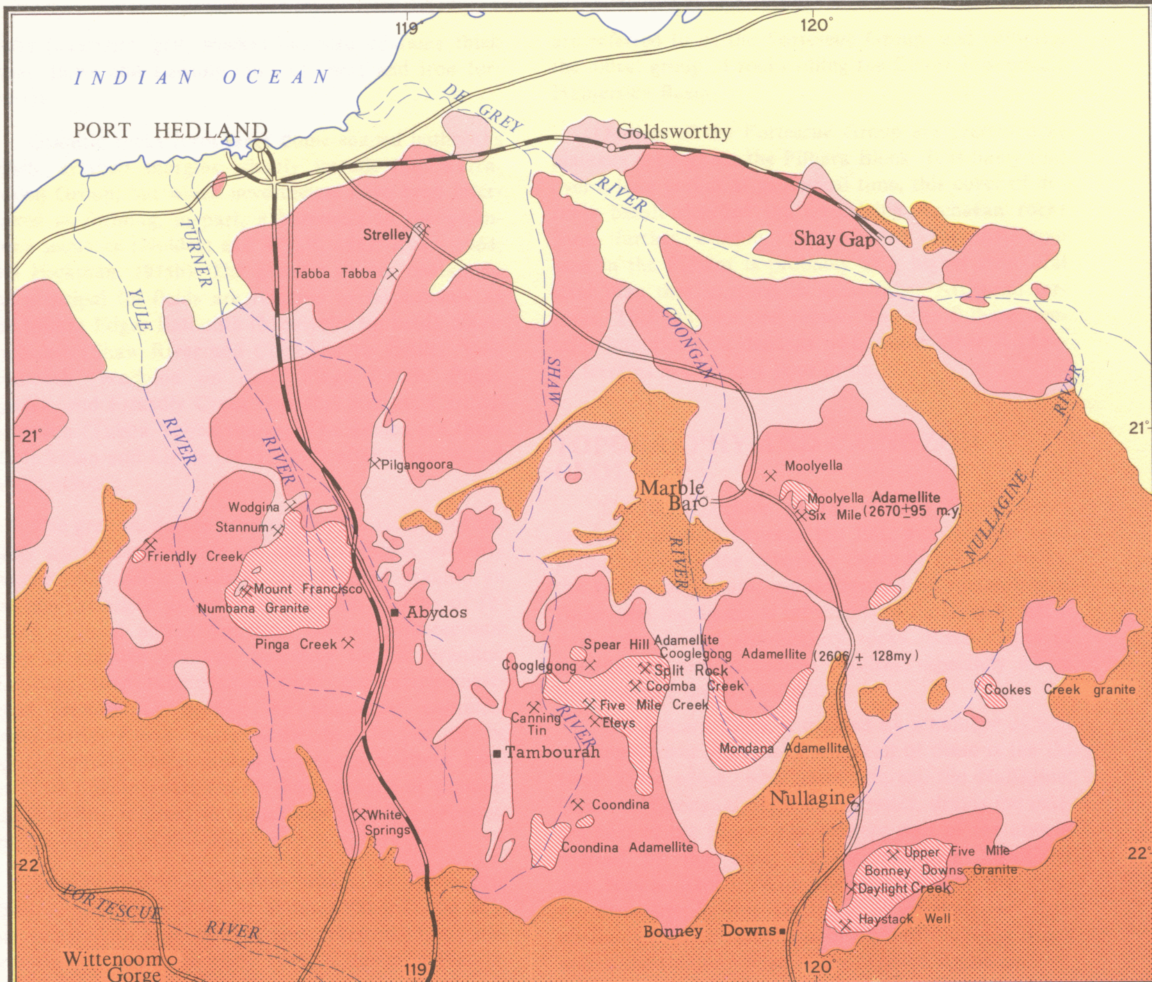
OUTLINE OF PRECAMBRIAN GEOLOGY

The Pilbara Block is a nucleus of Archaean rocks between the Phanerozoic Canning Basin to the north and the Lower Proterozoic Hamersley Basin to the east and south.

The Archaean rocks consist of volcanic and sedimentary assemblages intruded by, and folded between, massive granitic domes (Plate 1). Within the layered rocks two distinctly different stratigraphic sequences can be recognized, namely the Warrawoona and Gorge Creek Groups (Hickman and Lipple, 1975, following Noldart and Wyatt, 1962). The older Warrawoona Group is made up mainly of mafic to felsic volcanic rocks with intercalated chert, iron formation and minor clastic sediments. It is intruded by mafic and ultramafic sills, which in places make up a considerable proportion of the outcrop of the Group. The assemblage of rocks it contains is typical of 'greenstone' sequences found in most Archaean terrains.

The younger Gorge Creek Group overlies the Warrawoona Group with local unconformities or tectonic breaks. It consists largely of clastic sedimentary

* All Rb-Sr ages have been recalculated to conform to a decay constant of $\lambda = 1.42 \times 10^{-11} y^{-1}$



REFERENCE

PHANEROZOIC		Marine and terrestrial sediments
PROTEROZOIC		Mount Bruce Supergroup
ARCHAEAN		Gorge Creek Group Warrawoona Group Mosquito Creek Group
		Granitic complex undifferentiated
		Younger granite—with age where known

SYMBOLS

- Geological boundary
- Major road
- Railway
- Town
- Homestead
- Tin mining centre
- Watercourse

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF PORTION OF THE PILBARA BLOCK
SHOWING
TIN DEPOSITS AND YOUNGER GRANITES

20 0 20 40 60 80 100 km

Based on Blockley (1970) and G.S.W.A. mapping rocks (quartzite, grit, wacke) but also contains thick basalt flows and sizeable units of chert and iron formation.

Granitic rocks form large dome-shaped batholiths which, at their margins, clearly intrude the Warrawoona Group, but which nevertheless have been interpreted as forming, in part, a basement to the greenstone sequence (Noldart and Wyatt, 1962; Ryan, 1964; and Hickman, 1975b). The granitic domes containing the principal tin fields are referred to respectively as the Mount Edgar Batholith (Moolyella tin field), Shaw Batholith (Shaw River and Coondina tin fields), Yule Batholith (Wodgina tin field, Pinga Creek, Pilgangoora, and Friendly Creek deposits) and the Carlindi Batholith (Tabba Tabba centre). The names are those of Hickman and Lipple (1975, 1979) after Noldart and Wyatt (1962).

The granitic domes examined in the vicinity of the main tin fields comprise an oldest complex of early tectonic migmatitic, gneissic, and foliated granite; an intermediate-aged group of syntectonic plutons of foliated granite; and a youngest late or post-tectonic suite of massive granites, including the tin granites. Although field relationships show the intermediate-aged granites to intrude the migmatite complex, radiometric Rb-Sr dates show both types to be approximately coeval and to have ages of about 2 900 to 3 100 million years (m.y.). Both groups of granites are therefore referred to collectively as 'older granites' for the purpose of this study.

The post-tectonic granites which, as noted previously, have been dated at about 2 500 to 2 600 m.y. are referred to here as 'younger granites'. Their distribution, as known in early 1975, is shown in Plate 1. Important tin deposits are associated with the Moolyella, Cooglegong, Spear Hill, Coondina and Numbana bodies which are named on the plate. Another possible tin granite, tentatively identified during this investigation but not outlined until 1975 (Hickman, 1977) occupies an area of about 400km^2 west of the Tabba Tabba tin-tantalite centre. It is not shown on Plate 1.

Petrographic descriptions and chemical analyses of granites from the Pilbara Block are presented in Chapter 5.

Following the intrusion of the younger granites and some later felsic dykes, the Pilbara Block was eroded to approximately its present level, although there is evidence that the granites may have had more relief than at present. About 2400 m.y. ago basaltic lava, extruded from a large number of fissures now represented by dolerite dykes, covered most of the Block. These lavas, together with associated sediments, are referred to as the Fortescue Group, and comprise the oldest group of rocks filling the Lower Proterozoic Hamersley Basin.

Outliers of the Fortescue Group are preserved as plateaux throughout the Pilbara Block. It is likely that over a long period of geological time, this cover of durable basalt shielded the underlying Archaean rocks from further erosion. Consequently the Archaean seen in the Pilbara is probably at a higher structural level than that exposed in most other Archaean terrains. This may be one reason why the Pilbara contains important tin deposits while most other Archaean terrains are notably poor in tin.

TOPOGRAPHY AND CAINOZOIC GEOLOGY

The land surface of the Pilbara Block shows marked contrasts between the flat, monotonous sand plains overlying the extensive tracts of granitic rocks, the ranges of serrated ridges formed by metamorphic rocks, and the dissected tablelands of flatlying Proterozoic volcanic and sedimentary rocks. Black ridges of dolerite are also prominent features, especially where they traverse the granite plains.

The Pilbara Block is drained by a number of well developed river systems. The largest of these is the De Grey River which, with its tributaries, the Nullagine, Oakover, Coongan, Shaw and Strelley, drains the eastern part of the Block. The western part of the area is drained by the Yule, Turner, Sherlock, Maitland and Nickol Rivers. With the exception of the west-northwesterly flowing De Grey, all of the rivers flow northerly from the tableland of Proterozoic rocks which marks the southern edge of the exposed Archaean.

Three erosion surfaces older than the present one can be recognized in the Pilbara Block. The oldest is similar to, and probably the same age as, the Hamersley Surface (Campana and others, 1964). The others have been named the Peawah and Yule surfaces by Kriewaldt and Ryan (1967).

The Hamersley Surface is preserved mainly on the higher ridges where it takes the form of a smoothly undulating capping of duricrust. In places (e.g. Wodgina and Abydos) these cappings drape over the sides of the ridges and merge with pisolitic limonites of the Poondano Formation (McWhae and others, 1958).

These deposits are bog iron ores laid down in the rivers extant at the time that the oldest surface formed. They now form strings of elongated mesas standing about 15 metres above the general level of the country. There is no direct evidence for the age of the Hamersley Surface and the coeval limonite deposits, although they are usually assigned to the Tertiary era by analogy with other lateritic deposits in the State, and because an unconformable relationship exists between the Mesozoic Yarraloola Conglomerate and pisolite deposits in the lower part of the Robe River (Harms and Morgan, 1964).

The Peawah Surface is represented by deposits of river gravels, some cemented by kankar, preserved as low mesas or ridges close to present drainage channels. Correlation between these deposits is not possible, and they may have been laid down at different times during the period of erosion that followed the uplift of the Hamersley Surface and eventually produced the Yule Surface. Kriewaldt and Ryan (1967) considered the surface to be of possible Pleistocene age. Deposits of alluvial tin ore are associated with the Peawah Surface at Friendly Creek, Coondina and near Cooglegong.

The youngest Yule Surface is best seen in the extensive areas of sand plain formed over the granitic rocks of the Pilbara Block. In the Port Hedland area, Brandt (1964) suggested that the surface was formed prior to the deposition of the Mesozoic sediments and has subsequently been resurrected, although lowered, by the stripping-off of weathered granite. Further south, the Yule Surface is obviously younger than the Hamersley Surface, and can only be pre-Mesozoic if the latter surface is much older than previously supposed. Kriewaldt and Ryan (1967) regarded it as being almost certainly of Pleistocene age.

The development of the Yule Surface was accompanied by infilling of the stream valleys. Where preserved, such valleys are broad, very shallow, and have low gradients. Water flows down them in a series of braided channels, or simply in sheets over the almost flat valley floor. The braided channels in many of the present rivers are probably inherited from the streams of the Yule Surface.

The alluvial deposits of the Yule Surface consist of clay-bound gravels and grits ranging upwards to sandy or silty clays. They contain most of the tin deposits worked in the Pilbara Block, and are more fully described in the accounts of individual tin fields.

During the present cycle of erosion, the larger rivers and creeks have cut downwards to expose bedrock over parts of their lengths, and their tributaries are actively cutting back into the sand plain and infilled valleys of the Yule Surface. It is likely that some former alluvial tin deposits have been removed by this erosion but, fortunately, the erosion has not yet extended headwards to the smaller tributaries, and consequently many deep leads have been preserved.

Alluvium formed in the present cycle of erosion consists mainly of loose sand and shingle, and is generally poor in tin.

MOOLYELLA TIN FIELD

GENERAL INFORMATION

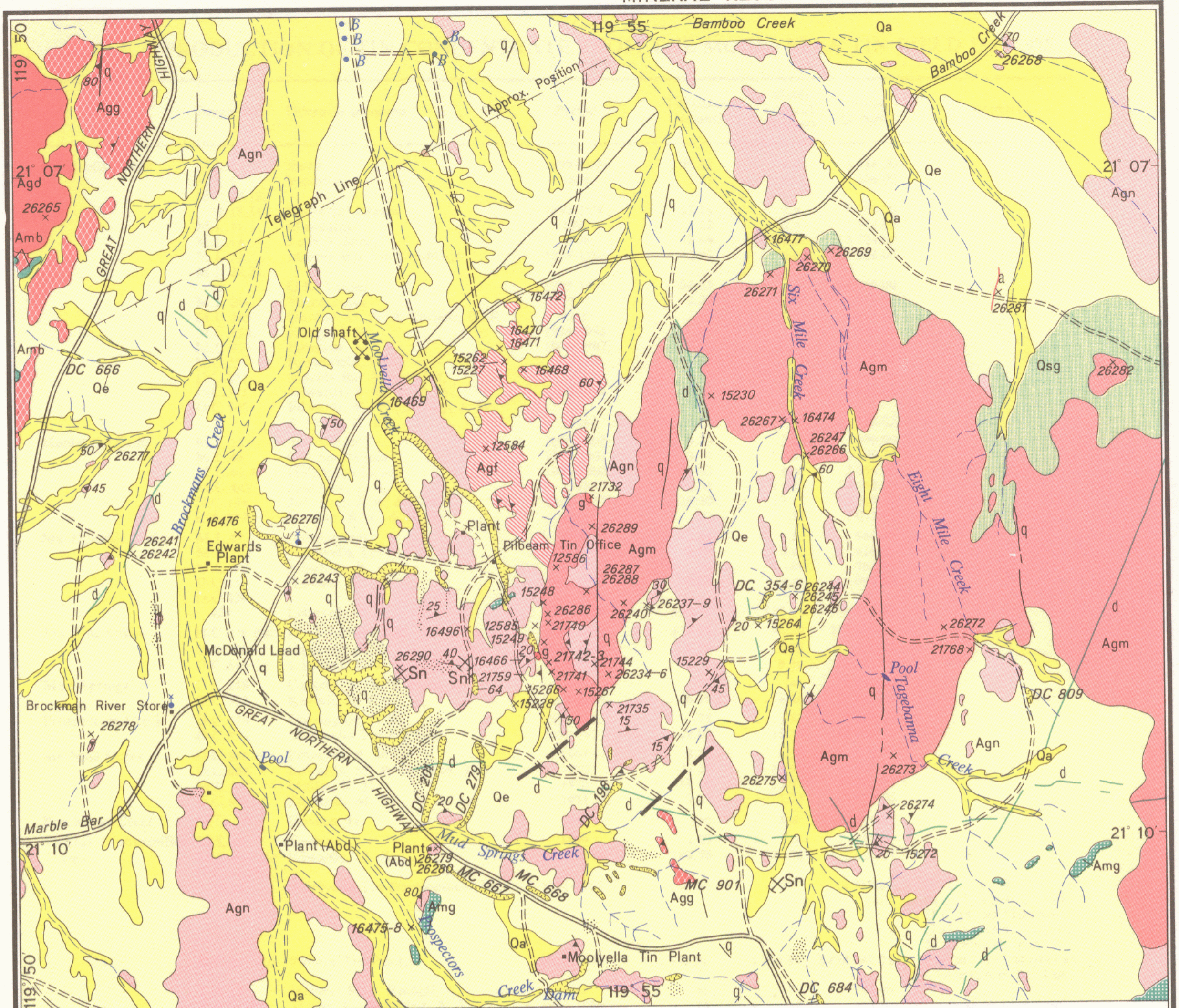
The Moolyella tin field covers an area of about 100 km^2 centred about 19 km east of Marble Bar, close to the Great Northern Highway. The principal workings are grouped about a range of low hills at the head of Moolyella Creek, and consist chiefly of alluvial diggings on Moolyella Creek, MacDonalds Lead and Huntsman Gully. Other deposits have been mined in or close to Mud Springs Creek, Prospectors Creek, Six Mile Creek, Eight Mile Creek, and in two places on the western side of Brockman Creek.

The total production of tin concentrate reported to the Mines Department amounts to 7 620 tonnes, details of which are presented in Table 5. Further information on tin production from the field is given in Table 6, which shows the quantities of lode tin treated at the Marble Bar State Battery. It is evident that some of this production is not included in Table 5.

Only some of the production from Moolyella can be attributed to specific areas within the field, the majority of tin having been won either from unregistered claims, or produced by the larger operators who have carted ore from several parts of the field to a central treatment plant. Records kept by one of these operators, Pilbara Tin Pty Ltd, are reproduced in Table 7 and give an indication of the grades of ore mined. Although the tin concentrates from Moolyella are reported to contain 3.5 to 4 per cent Ta_2O_5, only about 15 tonnes of tantalite have been produced from the field.

According to Maitland (1904), the field was discovered in 1898, in which year 76.5 tonnes of tin concentrate were mined. Production rose to 585 tonnes in 1907 but then declined, and from 1921 to 1958 averaged less than 20 tonnes per year. Early attempts at large-scale mining were unsuccessful, but higher prices and improved machinery changed the outlook in the 1950s.

The revival of tin mining in 1958 was due largely to the activities of Mineral Concentrates Pty Ltd, a company formed of local tin miners and Perth businessmen. In 1964 this company was bought by Kathleen Investments Ltd and its name changed to Pilbara Tin Pty Ltd. Almost from its inception, the company became the major tin producer in the Pilbara, and for a time was the only operator in the Moolyella tin field, owning or controlling almost all of the tin-bearing ground. Prior to July 1970, all ore mined by Pilbara Tin Pty Ltd was carted to a treatment plant near the company's offices. The first plant located here proved inefficient, and was replaced by another (the No. 2 plant) built nearby. Although designed to treat



REFERENCE

QUATERNARY

- Qa — Alluvium—unconsolidated river sands and gravels, flood plain and sheet wash deposits
- Qe — Eluvium—red brown loam with pegmatite strew; mainly overlies migmatite and gneissic granite
- Qsg — Coarse sand with feldspar and mica; mainly overlies Moolyella Adamellite

PROTEROZOIC TO ARCHAEAN

- d — Dolerite dyke
- a — Acid dyke
- q — Quartz vein

YOUNGER GRANITES (2670 m.y.)

- Agm — Massive, medium to fine grained biotite—muscovite adamellite — MOOLYELLA ADAMELLITE
- g — Greisen associated with Moolyella Adamellite
- Agd — Leucocratic granodiorite

OLDER GRANITES (3125 m.y.)

- Agf — Foliated biotite granodiorite
- Agn — Gneissic granite with areas of migmatite
- Agg — Migmatite—amphibolite with lit-par-lit injection of granitic material
- Amb — Meta-basalt
- Amg — Meta-gabbro

SYMBOLS

- Geological boundary
- Fault—concealed
- Metamorphic foliation (with dip) 35
- Highway
- Road
- Track
- Eluvial tin workings
- Alluvial tin workings
- Treatment plant
- Cut in pegmatite
- Shaft in alluvium
- Tailings dump
- Sample numbers × 15256
- Watercourse
- Pool
- Well and windmill
- Bore B

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE MOOLYELLA TIN FIELD

1 0 1 2 3 4 km

TABLE 5. PRODUCTION OF TIN CONCENTRATE FROM THE MOOLYELLA TIN FIELD 1899-1975

Area	Tenement	Operator or name	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)	Remarks
Moolyella Creek	M.L.5	Swan	1899-1900	26.42	n.a.	3 434.00	
	M.L.6	Victoria	1899	1.52	n.a.	226.00	
	M.L.10,12, 15,18,31	Universal Leases	1899-1900	52.52	n.a.	8 760.00	
	M.L.11	Mandalay	1900	1.12	n.a.	142.00	
	M.L.13	Lady Vosper	1900	32.66	n.a.	3 724.00	
	M.L.22	Marble Bar Tin Syndicate	1899-1901	42.93	n.a.	5 924.00	
	M.L.20,21, 23	O.K. Leases	1899-1901	104.65	n.a.	12 066.00	
	M.L.29	Three Jacks	1900	2.29	.77	316.00	
	M.C.745	Gordon, G. N. & Turbett, D. R.	1965	1.12		2 644.90	
	M.C.653	Flegg, H. N.	1964-1965	.49	.30	895.20	
	M.C.815	Edwards, M.	1966-1967	3.56	2.39	6 497.52	
	D.C.257	Brownfield, P. R.	1962	.83	.57	1 198.50	
	D.C.257	Marble Bar Mining Co.	1963	3.13	1.97	3 862.50	
	D.C.535	Edwards, J. M. & M. A.	1966-1968	11.47	7.42	22 421.29	
	D.C.705	Edwards, R. W., Jeffrey, J. M. & Jones, D. V.	1966	.70	.48	1 325.02	
Huntsman Gully	M.L.16	Sportsman	1899-1900	9.23	n.a.	990.00	
	M.L.46	Old Sportsman	1900-1901	12.19	n.a.	1 400.00	
	M.L.43,44	Huntsman Leases	1900-1902	33.02	n.a.	3 654.00	
	M.C.449	Johnston, J. A.	1958	22.38	14.94	24 162.60	
	D.C.196	Johnston, J. A. & Sons	1956-1957	28.30	19.27	33 319.68	
	P.A.2733	Gordon, R. F. & G. N.	1965	.51	.34	1 015.60	
MacDonalds lead	M.L.45	Independent	1900	15.24	n.a.	1 844.00	
	M.C.152	Moolyella Tin Ltd	1939-1940	2.59	n.a.	919.50	
	M.C.448	Johnston, R.	1956	.70	.44	764.80	
	D.C.15	Hansen, H.	1942-1943	5.03	n.a.	2 096.00	
	D.C.228, 229	Leonard, H. V.	1959-1966	464.77	319.91	766 624.29	
Tin King Creek	D.C.276 etc.	D. D. Mining Co.	1963-1967	139.28	94.29	257 031.97	
	D.C.276	Edwards, R. W.	1966-1967	6.39	4.20	11 315.49	
	D.C.546	Edwards, R. L. & F. J.	1966-1970	12.53	8.36	23 221.07	
Mud Springs	D.C.258	Cassells, R. B. & Rose, K.	1965	.74	.46	1 484.00	
	D.C.305	Russell, H. H.	1963-1966	6.49	4.46	11 241.20	
Prospectors Creek	D.C.474	Dorrington, A.W.	1964-1965	.77	.54	1 622.30	
	D.C.493	Moolyella Tin Pty Ltd	1969-1971	22.07	15.35	45 931.42	
Six Mile Creek	D.C.586 etc.	Edwards, R. W.	1967	3.75	2.50	6 873.57	
	D.C.684	Edwards, M. R. & Olive, J. B.	1970	23.20	15.96	43 772.24	
	M.C.871	Mallet, G. H.	1970	19.42	13.99	43 005.07	
	D.C.585	Edwards, M.	1971	2.63	1.73	4 919.00	
Brockman Creek	M.C.148	Hansen, H.	1940	.56	n.a.	194.00	
Several or unspecified areas	M.L.19	Carbine	1899	2.03	n.a.	200.00	
	M.C.691 etc.	Edwards, M. R.	1964-1974	184.76	121.71	350 001.84	
	D.C.14,16, 19,22	Moolyella Tin Development N.L.	1941-1952	20.55	n.a.	12 534.84	D.C.14 & 22 on Moolyella Creek; D.C.16 on Huntsman Gully; D.C.19, on MacDonalds lead
	D.C.201 etc.	Pilbara Tin Pty Ltd	1958-1974	2 975.45	1 933.94	5 874 849.21	Formerly Mineral Concentrates Pty Ltd
	T.A.13	Burney, R. & Rinaldi, A.	1963	.55	.39	732.40	
	P.A.2750	Mallet, G. & Billing, A. T.	1965-1966	.21	.12	315.30	Location uncertain
	Sundry claims	Various	1901-1972	3 196.61	n.a.	777 750.29	
	M.C.700	Edwards, M. R.	1973	6.00	4.09	11 791.15	
	D.C.201 etc.	Pilbara Concentrates	1975	116.94	83.98	584 516.00	
	TOTAL			7 620.30		8 973 529.76	

85 m³ of ore an hour, this plant was beset by mechanical troubles, and throughput averaged only about 33 m³ per hour. These difficulties, together with increasing cartage distances, caused the company to experiment with a semi-mobile plant using jigs instead of cones to concentrate the tin ore. When this proved successful on a pilot scale, the present No. 4 plant was built with a capacity of 33 m³ per hour. It has provisions to recycle the water used in order to compensate for the increased demands of the jigs as opposed to cones.

During 1975, Kathleen Investments sold its interest in Pilbara Tin Pty Ltd, and the name was changed to Pilbara Concentrates Pty Ltd.

During the period 1958 to 1975, significant quantities of tin were also produced by H. V. Leonard, M. R. Edwards, J. A. Johnston and Sons, D. & D. Mining Co., and Moolyella Tin Pty Ltd. Each of these operators maintained treatment plants, the locations of which are shown on Plate 2.

TABLE 6. DETAILS OF TIN ORE TREATED AT THE MARBLE BAR STATE BATTERY

Operator	Tenement number	Year	Ore crushed (tonnes)	Tin conc. recovered (kg)	% Tin conc. in ore
Mineral concentrates	M.C.409	1963	30.5	77.6	.25
Flegg, H.N.	M.C.654	1963	27.4	196.0	.71
Flegg, H.N.	M.C.654	1965	58.7	161.1	.27
Total	M.C.654		86.1	357.1	.41
Flegg, H.N.	P.A.2675	1963	19.3	27.2	.14
Mallet, G.	D.C.354(?)	1965	37.3	113.4	.30
Mallet, G.	D.C.354(?)	1965	27.9	32.7	.12
Mallet, G.	M.C.871	1966	16.0	102.5	.64
Edwards, J.	M.C.815	1966	30.5	113.4	.37
Edwards, J.	M.C.815	1966	122.9	408.3	.33
Edwards, J.	M.C.815	1966	53.6	181.5	.34
Edwards, J.	M.C.815	1966	41.6	181.5	.44
Edwards, J.	M.C.815	1966	53.3	181.5	.34
Edwards, J.	M.C.815	1966	89.4	243.2	.27
Edwards, J.	M.C.815	1966	91.4	154.3	.17
Total	M.C.815		482.7	1463.7	.30
Edwards, R.L.	D.C.546	1966	17.3	42.6	.25
Reich, G. & Party	M.C.893	1966	32.5	18.6	.06
Dorrington, C.	P.A.2778	1966	7.6	44.5	.59

TABLE 7. DETAILS OF PILBARA TIN PTY LTD'S OPERATIONS—1964-1968

	Over-burden mined (cu.m)	Ore mined (cu.m)	Over-burden ratio	Grade (kg/cu.m)	SnO_2 recovered (tonnes)
Moolyella Creek and tributaries	37 384	10 113	3.7:1	3.08	31.5
MacDonalds lead and tributaries on MCs 408,409	483 608	147 217	3.3:1	3.32	487.7
Huntsman and MacDonalds leads west of Bamboo Creek Road	64 900	94 674	0.68:1	3.44	327.2
DCs 262, 266	0	41 750	0:1	2.22	93.5
MCs 384, 488, 708, DC 37	0	66 111	0:1	2.22	147.3
MCs 666, 667, 669	0	10 294	0:1	2.22	23.4

References

The first geological report on the Moolyella tin field was published by Maitland (1904). It was accompanied by a map showing some of the tin-bearing pegmatites and the extent of the workings at that time.

Montgomery (1907) gave useful information on the alluvial claims being worked at the time of his visit, with some notes on newly discovered tin-bearing areas some distance from the older workings. Mining operations on the field in 1909 were described by Cleland (1910a and b), at which time there were fifty men engaged in mining deep leads and retreating old tailings.

Sullivan (1939) reported on the field for the Aerial Geological and Geophysical Survey of North Australia. He described the alluvial and eluvial workings (most of which were abandoned at the time) and attributed the source of the tin to pegmatite and tin-bearing granite. The map accompanying his report shows the positions of the deep leads on Moolyella Creek, Huntsman Gully and MacDonalds Lead, and presents the results of a sampling programme carried out to test a patch of eluvial ground.

An investigation of the groundwater resources of the field was described by Allen (1966). The map which accompanies his report shows alluvium and granite, but does not distinguish between outcrop and areas of shallow soil cover.

A private assessment of the ore reserves in the field was made by Kenneth McMahon and Partners for Kathleen Investments Pty Ltd in 1964, and in 1968 Ishihara Sangyo Kaisha Ltd sampled four tailings dumps*. Exploration programmes, consisting of drilling, pitting, or trenching various deposits of alluvium, have been carried out by Pilbara Tin Pty Ltd and Moolyella Tin Ltd.

Water supplies

The normal water requirements of the tin treatment plants in the Moolyella field are drawn mainly from ponds constructed in worked-out portions of the tin leads, but are supplemented from a number of bores. In periods of drought, most surface-stored water dries up, and the mines are entirely dependent on ground water. All domestic water comes from bores.

From a study of about 38 bores drilled into alluvium and weathered granite in the northern part of the field Allen (1966) concluded that pressure water, usually confined beneath a layer of clayey weathered granite, occurred in all bores drilled to more than 10.7 m depth. Groundwater was first encountered at depths between 4.3 and 11.6 m, and the depth at which the water rested after rising in the holes ranged from 6.1 to 10.7 m. Water occurred in both weathered and fresh gneissic granite. In the former it was obtained from relic joints, and particularly from weathered quartz veins and pegmatites, which apparently contain interconnected vugs. In the unweathered granite, water was

*The Geological Survey of Western Australia holds a large quantity of Company exploration records to many of which public access presently is restricted. Where such records are in the form of titled reports, they are referred to by author and date, and listed in the References. Where the records held comprise mainly maps, bore logs or tabulations not organized into titled reports, sufficient information is given in the text to identify the material, but no listing is made in the References.

These reports will be progressively placed on open file as tenements are dropped.

TABLE 8. ANALYSES OF BORE WATER, MOOLYELLA TIN FIELD

Bore No.	19	4	29
Sample No.	11142	11143	11144
Specific conductivity 20°C (micromhos)	1200	710	1000
Appearance	Clear with grey deposit	Clear with slight grey deposit	Clear with slight brown deposit
Colour	Colourless	Colourless	Colourless
Odour	Earthy	Nil	Nil
pH	7.1	7.2	7.3
Mineral matter	*ppm*	*ppm*	*ppm*
Ca	62	29	47
Mg	26	9	19
Na	200	134	172
K	3	2	2
HCO_3^-	357	285	383
$CO3^{--}$	Nil	Nil	Nil
SO_4^{--}	58	29	34
Cl	247	95	151
SiO_2	41	28	37
Fe	0.6	0.1	1.0
Total by conductivity	840	500	700
Total by evaporation	770	480	670
Total hardness	262	109	195

obtained from primary joints, exfoliation joints, quartz veins and weathered pegmatites enclosed in fresh granite. Supplies obtained during Allen's investigation ranged from almost nothing to 385 m^3 per day. Fifteen of the 38 bores yielded 108 m^3 per day or better. Analyses of three water samples given by Allen are reproduced in Table 8.

Those bores or wells which were in use or from which production was planned at the time of the present investigation, are listed in Table 9, the information being derived from Allen (1966) and the various operators on the field. Yields of up to 1080 m^3 per day were also reported by Pilbara Tin Pty Ltd from bores sunk near the confluence of Brockman Creek and the Talga River, but no further details are available.

GEOLOGICAL INFORMATION

Crystalline rocks

The Moolyella tin field is underlain by granitic rocks of the Mount Edgar Batholith (Hickman and Lipple, 1975). Four granite types can be mapped in the field. The oldest consists of mixed gneissic and foliated granite which, near the western edge of the field, intrudes mafic rocks of the Warrawoona Group, the contact being marked by a one kilometre-wide zone of migmatite. In places the gneissic granite contains rafts of altered gabbro, or irregular inclusions of amphibolite, but in general it ranges from tonalite to adamellite in composition (see Chap.5).

Near the tin workings, the older granite is intruded by an oval stock of foliated granite and an irregular pluton of massive "tin" granite, named, because of its economic importance, the Moolyella Adamellite. Contacts can be seen which show that the Moolyella Adamellite has intruded both the gneissic granite (Fig.17) and the stock of foliated granite. The intrusive origin of the foliated granite is, however, inferred only from the facts that its outcrop truncates the most common direction of banding in the gneissic granite, and that it contains schlieren of gneissic granite.

A stock of altered granodiorite intrudes the contact between the migmatite and the Warrawoona Group at the western edge of the field. It is more metamorphosed, and hence probably older than the Moolyella Adamellite, but its relationship to the intrusive foliated granite is unknown.

Three late-stage phases of the Moolyella Adamellite can be recognized, namely, aplite dykes, greisen lenses, and pegmatite veins. The aplite dykes are mainly composed of sugary-textured albite, quartz, and green mica and were intruded along joints within the granite. The greisen forms as small joint-controlled pipes within the Moolyella Adamellite and as lenses up to 50 m long, at, or close to, the contact of this granite. The greisen is made up chiefly of quartz and muscovite, with accessory fluorite. No cassiterite was detected in samples of the greisen, and it is apparent from the distribution of the tin workings, that little or no tin ore has been shed from them.

TABLE 9. INFORMATION ON WELLS AND BORES IN THE MOOLYELLA TIN FIELD

Designation of well or bore	Owner	Locality	Yield m^3/day	Depth (m)	Quality (ppm TDS)
Edwards Well	Edwards, M.R.	M.C.700	650	16.5	Good
No.4 Bore	Pilbara Tin Pty Ltd	W.R.119	215	18.3	480
No.7 Bore	Pilbara Tin Pty Ltd	W.R.118	108	25.6	
No.8 Bore	Pilbara Tin Pty Ltd	W.R.118	385	21.3	
No.19 Bore	Pilbara Tin Pty Ltd	M.C.882	132	21.3	770
No.22 Bore	Pilbara Tin Pty Ltd	W.R.109	215	24.1	
No.29 Bore	Pilbara Tin Pty Ltd	W.R.121	215	19.2	700
No.30 Bore	Pilbara Tin Pty Ltd	W.R.121	265	24.7	
No.33 Bore	Pilbara Tin Pty Ltd	W.R.120	265	19.8	
Bernies No.1 Bore	Pilbara Tin Pty Ltd	W.R.108	865	51.2	Good
Bernies No.2 Bore	Pilbara Tin Pty Ltd	W.R.108	430	61.0	Good
Leonards Well	Pilbara Tin Pty Ltd	MC.658	108	n.a.	
Brockman River Store Bore	Jeffery	B.A.136	55	11.4	Good
Narry Spring No.1 Bore	Moolyella Tin Pty Ltd	D.C.818	575	30.8	Fresh
Narry Spring No.1A Bore	Moolyella Tin Pty Ltd	D.C.818	1 800	30.8	
Narry Spring No.1B Bore	Moolyella Tin Pty Ltd	D.C.818	575	36.9	Mainly fresh
Narry Spring No.3 Bore	Moolyella Tin Pty Ltd	D.C.789	72	53.3	Fresh

Pegmatites of two distinct ages can be recognized in the Moolyella tin field. The earlier form an integral part of the older granites and mainly follow the gneissic banding. Their contacts with the host rock are somewhat gradational, and they are composed mainly of microcline, quartz and biotite. No economic minerals have been found in them.

The younger pegmatites form swarms in which individual veins strike northerly and dip from 10 to 40 degrees easterly. They are best exposed in the hills at the head waters of Moolyella Creek, where, over an area of about 3 km^2, they make up about 15 to 20 per cent of the total rock. The veins cut cleanly across the banding of the gneissic granite host-rock, and are obviously younger than it (Figs 4A,B). They are of the layered aplite-pegmatite type (Fig. 4C,D) and contain accessory spessartine, green muscovite, cassiterite, zinnwaldite, lepidolite, fluorite, tantalite and magnetite. These pegmatites have not been shown individually on Plate 2, but the areas in which they are abundant are indicated by the eluvial tin workings. A map of the main swarm at the head of Moolyella Creek forms Plate 3.

Dolerite dykes of two ages can be recognized in the Moolyella tin field. The older dykes strike easterly, with many small offsets due to irregularities in their controlling fractures, and larger displacements due to later faults. The younger dolerites strike north-northeasterly or north-northwesterly, and displace the easterly trending dykes. They are wider, longer and straighter than the older dykes, but in places show en echelon off-sets, inherited from their controlling fractures, as well as displacements on younger faults and quartz veins. Both sets of dykes cut the Moolyella Adamellite.

North-striking quartz veins cross the tin field at intervals of from 0.5 to 2 km forming prominent ridges; the most conspicuous of these is The Sisters Hills, northwest of the tin workings. A northeasterly trending quartz vein crops out on a low ridge a few hundred metres north of the Bamboo Creek road. The quartz veins are the youngest crystalline rocks exposed

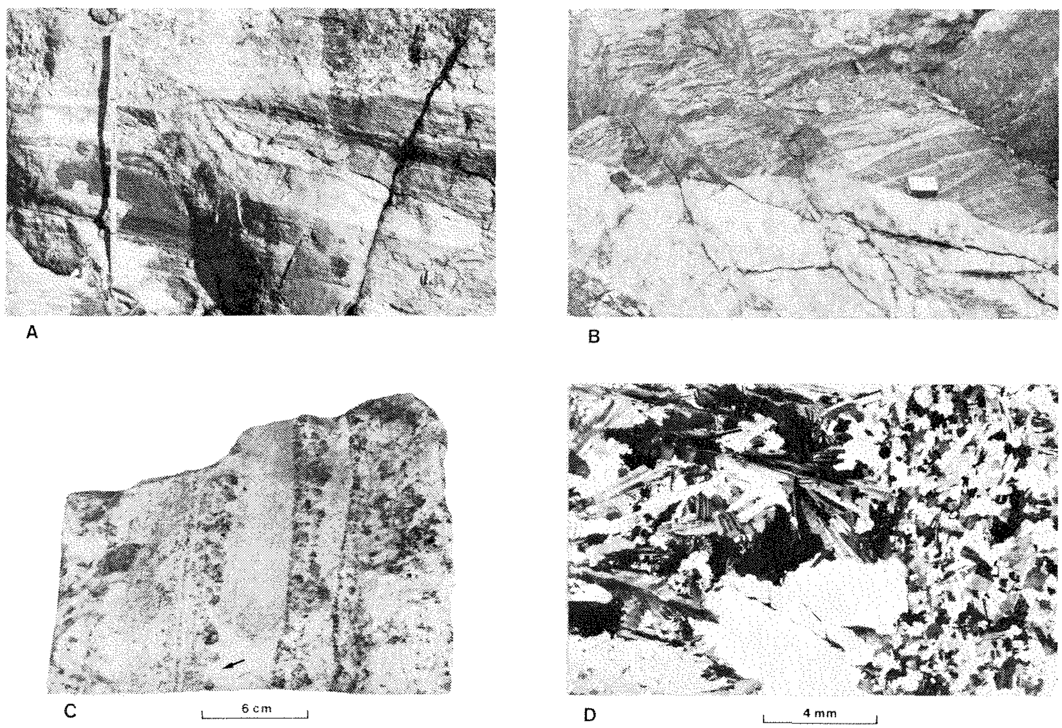
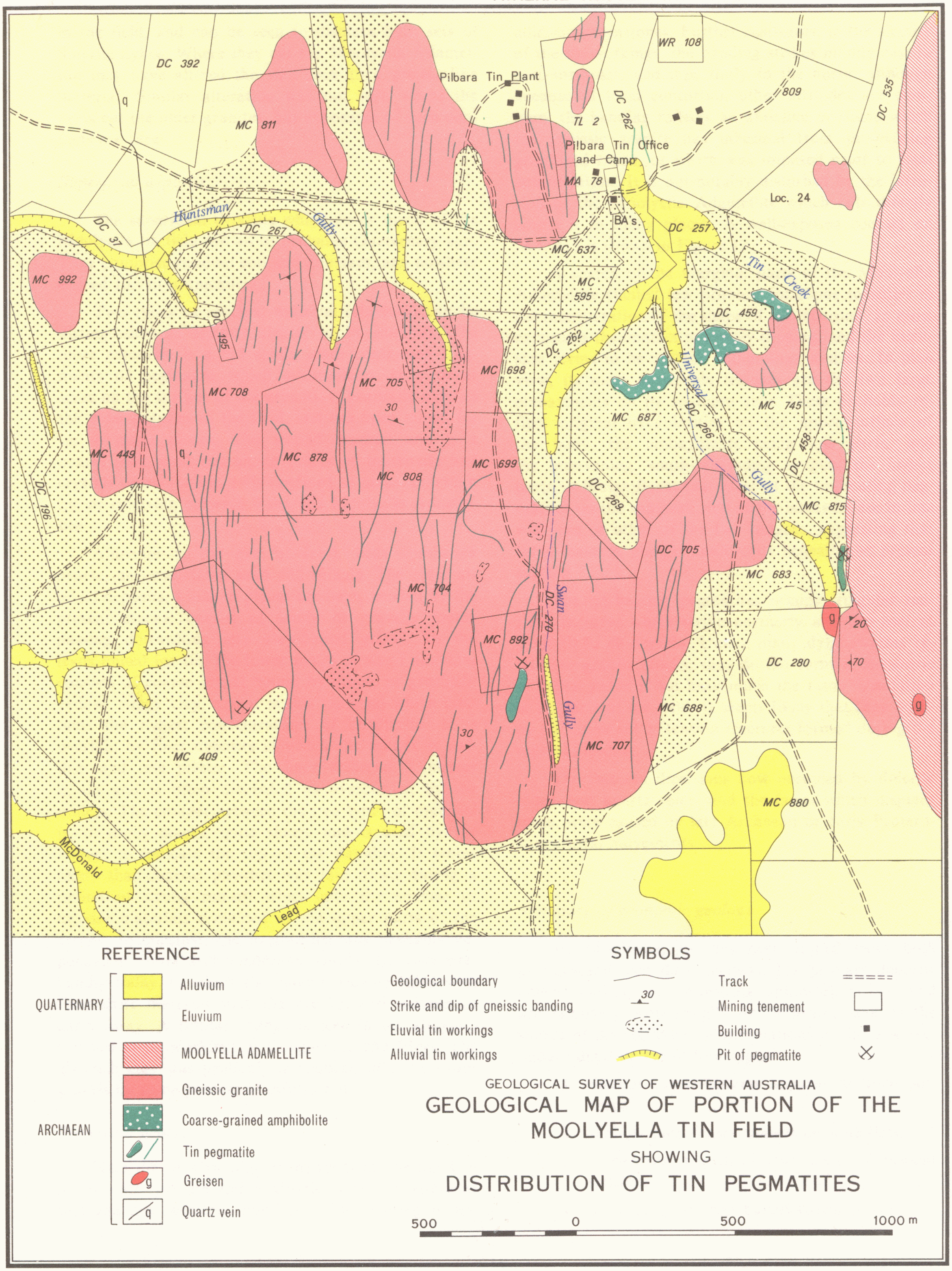


Figure 4. **Photographs of tin-bearing pegmatites at Moolyella.**

A. and B. Sharp cross-cutting contacts of tin-bearing pegmatites with gneissic granite; A. in Swan Gully by access road, and B. in a pit on M.C. 892.

C. Specimen (16496) of layered aplite-pegmatite from Swan Gully. Crystals of cassiterite occur on left-hand margin of the central fine-grained band.

D. Photomicrograph of specimen 16496 showing contact arrowed in C


DC 392
MC 811
Pilbara Tin Plant
TL 2
DC 262
WR 108
809
DC 535
Pilbara Tin Office and Camp
MA 78
BA's
Loc. 24
DC 257
Huntsman Gully
DC 267
DC 37
MC 637
MC 992
DC 195
MC 595
Tin Creek
DC 459
DC 262
MC 698
MC 705
MC 708
Universal
MC 687
DC 266
MC 745
MC 449
MC 878
MC 808
MC 699
DC 269
Gully
DC 458
MC 815
DC 196
DC 705
MC 683
MC 704
Swan
DC 270
MC 892
DC 280
Gully
MC 688
MC 409
MC 707
MC 880
McDonald
Lead
REFERENCE
QUATERNARY
Alluvium
Eluvium
ARCHAEAN
MOOLYELLA ADAMELLITE
Gneissic granite
Coarse-grained amphibolite
Tin pegmatite
Greisen
Quartz vein
SYMBOLS
Geological boundary
Strike and dip of gneissic banding
Eluvial tin workings
Alluvial tin workings
Track
Mining tenement
Building
Pit of pegmatite
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL MAP OF PORTION OF THE MOOLYELLA TIN FIELD
SHOWING
DISTRIBUTION OF TIN PEGMATITES
500 0 500 1000 m

in the field, and can be seen to displace both sets of dolerite dykes. Where they cut the Moolyella Adamellite they have altered the wall rock to a greisen-like material. Similar alteration was not seen where the veins cut the older granites, but exposures of such contacts are rare.

Superficial deposits

The superficial deposits which cover much of the Moolyella tin field are all of probable Quaternary age. They comprise residual soil and alluvium, and nowhere exceed 10.5 m in thickness.

Two types of residual material (eluvium) can be distinguished sufficiently clearly to be mapped. The more extensive is a red sandy loam containing fragments of pegmatite which accumulates as a dense scree on the surface of the ground. It normally overlies the older granites of the field, and has been mined for tin in many places. The second residual unit is a coarse pink sand containing flakes of muscovite and crystals of microcline. It is confined to areas underlain by, or receiving outwash from, the Moolyella Adamellite.

Alluvium in the present creek beds comprises coarse, unconsolidated sand and shingle. The older alluvial deposits, which in places are being eroded by the present creeks, consist of sandy or gravelly loams passing downwards into clay-bound gravel. In the leads mined for tin, the lower metre or so of alluvium consists of coarse gravel bound by green, or greenish-yellow, puggy clay, and it is this material which contains the richest concentrations of cassiterite. It is overlain by finer deposits in which the matrix is reddish and less plastic. The finer material is poorer in tin and is often discarded as overburden by the miners. The contact between the two types of material is, in many places, quite sharp, and is used by the miners to indicate the top of the pay-dirt. It seems likely that coarser pay-dirt was laid down during a period of strong run-off when only the coarser or heavier materials remained in the upper parts of the creeks. In contrast, the overburden was probably deposited in more arid conditions, similar to those prevailing today, in which the valleys became filled with finer drift material that the creeks were unable to carry away. A similar change is seen in the alluvium exposed in tin workings at Cooglegong and Eleys. The greenish clay was probably introduced into the lower gravels by some process of infiltration.

Structural geology

Near the western edge of the tin field, the banding in the older granite and migmatite strikes east-northeast and dips westerly, parallel to the layering of the adjacent greenstones. Further eastwards, in the vicinity of the tin workings, the banding strikes mainly east to east-northeast, and dips flatly to the north, although because of local contortion other attitudes are common. the banding reflects an anticline or dome which the gneissic granite has inherited from pre-existing granitized rocks, or which was imposed prior to final consolidation. It is not notably disturbed by the intrusion of the Moolyella Adamellite which cuts directly across it in many places. A well-exposed contact on M.C.815 is shown in Figure 17.

A search of the marginal parts of the Moolyella Adamellite elicited few primary foliations to assist in the interpretation of the shape of the intrusion. In most exposures the contact is steeply dipping, and the intrusion seems to be a stock rather than a sheet. In plan view, its most noticeable features are the two large embayments on its southern side. These probably reflect original irregularities on the upper surface of the body, the embayments being low parts, and the intervening, south-protruding tongues the higher parts. It is significant that most of the tin-bearing pegmatites on the southern side of the intrusion are in line with one or other of the two tongues, suggesting that these features plunge southwards beneath the present surface.

The tin-bearing pegmatites occupy irregular tension fractures which strike northerly and dip east at from 10 to 40 degrees. Unlike many dyke swarms related to granite stocks, they do not form a concentric or radial pattern, but have much the same orientation in all parts of the field. It seems likely that they occupy an earlier set of tension fractures formed during the regional folding.

The fracture directions now occupied by dolerite dykes and quartz veins, and the faults which displace these, were caused by late Archaean or early Proterozoic crustal movements.

Summary of economic geology

At Moolyella, tin has been mined from both primary and secondary deposits. The primary deposits consist entirely of tin-bearing aplite-pegmatites, and are relatively economically unimportant, save as the source of the secondary accumulations of tin. The secondary deposits are of four types:

1. detrital concentrations adjacent to lode outcrops;
2. shallow sheet-wash deposits on wide flats;
3. tin-bearing gravels in the beds of present streams;
4. deep leads, or older buried stream gravels.

The first and second types grade into one another, and, when disturbed by mining operations, cannot be distinguished. Similarly, in a worked-out creek bed, it is impossible to tell whether the deposit was of the third or fourth type. For these reasons, only two types of secondary deposits are distinguished in the following descriptions, namely alluvial and residual.

The largest and richest tin deposits at Moolyella are situated in the western part of the field. The source of the cassiterite is the extensive swarm of tin-bearing pegmatites which crop out on a range of low hills immeditely west of the Moolyella Adamellite (Plate 3). Drainage from the hills has formed three major deep leads—Moolyella Creek, Huntsman Gully and the MacDonalds lead. Numerous other small gullies contain tin ore, and extensive eluvial deposits were formed around the margins of the range.

Other deposits mined at Moolyella were derived from small scattered clusters of pegmatites cropping out to the south of the Moolyella Adamellite, and west of Brockman Creek. The more important of these are on Tin King Creek, Mud Springs Creek, Prospectors Creek, and Six Mile Creek. The distribution of the various workings is shown on Plates 2 and 3.

PRIMARY DEPOSITS

Although cassiterite-bearing granite was reported from the Moolyella tin field by Sullivan (1939) and McMath (1953), most of the specimens collected during the present investigation contained less than about 30 ppm of tin, and none contained accessory cassiterite. A chip sample of the largest outcrop of greisen was also found to contain negligible tin. The only rocks in the area of the field in which primary cassiterite has been identified are the layered aplite-pegmatites. This fact, together with the coarse grain-size of the alluvial cassiterite mined, suggests that the pegmatites were the only significant source of tin in the field.

The cassiterite content of the pegmatites varies considerably, and in only a few places is it high enough to have encouraged mining. No details of lode tin produced from the field prior to 1963 are available, although Montgomery (1907) described several veins which had been worked or tested for tin at that time. The production since 1963 is given in Table 6. Much of the material submitted as "lode" to the State Battery at Marble Bar seems to have been a mixture of weathered pegmatite, pegmatite scree and soil derived by scraping around the outcrop of the pegmatite veins.

During the examination of the tin deposits, it was found that many of the pits from which lode tin was recorded had been covered by subsequent alluvial diggings.

Mineral Claim 409

The workings on M.C.409 are in the vicinity of a deposit referred to as Eleys lode by Montgomery (1907). Two pegmatite veins about 15 m apart and dipping steeply southeast have been mined. The southeastern vein is about 30 cm wide with cassiterite studded through both quartz-albite and quartz-microcline matrices. It was mined over a distance of 20 m to a depth of about 2 m.

The western pegmatite vein was worked only on its southeastern edge by means of a shallow cut 10 m long. The lode material is similar to that in the eastern vein. Recorded production from the claim amounts to 30 tonnes averaging 0.25 per cent tin concentrate.

Mineral Claim 815

The largest production of lode tin in the Moolyella field came from M.C.815, amounting to 480 tonnes of ore averaging 0.3 per cent tin concentrate. The lode is a pegmatite dyke at the edge of the Moolyella Adamellite. Workings consist of a 40 m long bull-dozed cut which was partly filled by mud and detritus at the time of inspection. No details of the width of the vein could be seen, but it appears to be dipping easterly. There is a considerable amount of cassiterite-bearing pegmatite on the surrounding dumps.

Mineral Claim 892

Mineral Claim 892 is located near the head of Swan Gully in the central part of a low range of gneissic-granite hills. Two north-striking veins have been mined on the claim. The western vein is about 1 m thick and dips at 20° to the east. It cuts across the banding of the host rock and has a crude layering due to variations in the proportions of the constituent minerals. Cassiterite crystals up to one cm across are concentrated mainly along the edges of the vein, although a few occur towards the centre. They are restricted to those parts of the vein which are made up largely of albite, pink garnet and green muscovite. Zinnwaldite, magnetite and a little fluorite are also found in the lode. The only opening on the vein is a cut 1.5 m deep and 5 m long driven into the side of the hill.

The eastern vein is not exposed over its full width, but seems to be similar to the western vein. It was worked from two pits, and contains irregular patches of cassiterite.

Assays carried out on two samples from the veins gave results of 0.038 and 0.099 per cent SnO_2 for the eastern and western veins respectively (Table 10).

Mineral Claim 901

On Mineral Claim 901 a few shallow pits and some eluvial diggings follow a north-striking tin-bearing pegmatite over a distance of 20 or 30 m. The pits are on the same line as the eluvial workings on M.C.893.

Atkins lode

The prospect formerly known as Atkins lode was described by Montgomery (1907), who gave its position as 3.2 km south of Mud Springs. This corresponds approximately to the location of P.As 2675 and 2778, from which tin ore was mined in 1963 and 1966. The site is now occupied by alluvial and eluvial diggings which obscure the former surface. Montgomery noted that the lode was a large pegmatite vein trending west-northwesterly, and reaching 3.7 m in width. It consisted of quartz, feldspar and greenish mica, with some parts of the outcrop consisting of quartz, and others being nearly all feldspar. He reported that the ore was confined mainly to 'greisen' (probably fine-grained micaceous albite pegmatite), although he noted that some of the feldspar also carried cassiterite. An assay of picked ore from the lode yielded 13.31 per cent SnO_2.

Other reported deposits of lode tin

The records of the Marble Bar State Battery show that quantities of tin ore have been treated from M.Cs 654, 871 and 893, and D.Cs 354 and 546. On all of these tenements there are outcrops of tin-bearing pegmatite, around which a considerable amount of bulldozing has been done. No workings which could be specifically assigned to lode mining were noted.

Montgomery (1907) reported a tin-bearing pegmatite a short distance north of Atkins lode, and described another (Martin's lode) "found near the head of Berne's flat to the southeast of the township there". This vein trended north-northwest, was flat dipping, about 1.2 m thick, and contained "fair" tin ore. Its exact location is unknown, but Berne's flat was the name given to the extensive area of eluvial workings at the head of MacDonalds lead.

ALLUVIAL DEPOSITS

Moolyella Creek

Moolyella Creek is formed by the confluence of Swan Gully, Universal Gully and Tin Creek (Plates 2 and 3). It flows northerly until it is joined by an unnamed tributary on D.C.268, at which point it bends to a northwesterly course until it joins Brockman Creek. All of the above-mentioned tributary creeks have been mined out, while the main trunk creek has been stripped of alluvium from the confluence to a point about 500 m north of the Bamboo Creek road, that is, over a length of about 3.7 km. Information on the older, upstream workings is taken mainly from reports of Maitland (1904) and Montgomery (1907).

Swan Gully rises in the central part of the main source area and flows northerly to its junction with Moolyella Creek, running parallel to several prominent veins of tin-bearing pegmatite. It was worked intensively by hand methods in the early days of the field, and, more recently, by machinery, but it is still possible to gather pieces of cassiterite from its banks. Near its source, the original depth of alluvium was only 45 to 60 cm, which increased steadily when followed downstream, although it was never great. At present the creek bed is mainly bare rock. The width of the diggings ranges up to 90 m.

Universal Gully has its source at the tin-bearing pegmatite worked on M.C.815, and crosses several other pegmatites before flowing into Moolyella Creek. A pot-hole, at the foot of a small waterfall formed by one such vein crossing the stream, yielded nine tonnes of cassiterite in the early days of the field.

Tin Creek also rises at the western edge of the Moolyella Adamellite and flows north and then east to join the main water course. Although there are no

TABLE 10. SAMPLING RESULTS—MOOLYELLA TIN FIELD

Sample No.	Locality*	Description	Weight sample (kg)	Weight concentrate (g)	Assay concentrate (%)	Grams per tonne SnO_2
16468	D.C.728	Bottom wash	2.85	13.6	0.33	22.5
16469	M.C.655	Bottom wash in costean	2.22	85.1	1.42	780
16470	D.C.728	Bottom wash between 2 to 2.7 m depth in costean	2.20	66.1	0.90	3.85
16471	D.C.728	Wash between 1.7 and 2.0 m in costean	2.84	44.8	0.19	43
16472	D.C.754	Bottom wash in costean	2.84	67.1	0.35	118
16474	D.C.753	Sample from costean	2.32	23.5	1.94	280
16475	D.C.493	Lower 1.2 m of wash in costean	2.90	58.8	0.21	61
16476	D.C.19	Bottom wash from dump of cut	2.42	42.3	3.20	800
16477	D.C.753	Bottom wash in costean	3.10	12.8	2.04	120
16478	D.C.493	Lower 1.2 m wash in pit	2.84	12.1	1.03	63
16479	D.C.19	Lower 0.6 m of wash		30.7	0.15	
16491	M.C.892	Pegmatite (east vein)	13.6	124.1	2.17	385
16492	M.C.892	Pegmatite (west vein)	15.9	108.8	10.1	990

*Localities of most samples are shown on Plate 2 records of the old workings in this creek, an inspection of the mined-out area suggests that the alluvium was narrow and shallow.

The workings in Moolyella Creek, for 2 km from the confluence of the three tributaries to the junction with D.C.268, are almost completely obscured by tailings from the treatment plant of Pilbara Tin Pty Ltd. According to Maitland (1904), the alluvium in this section averaged about 2.4m deep, and was from 4.5 to 18.5m wide. Below the junction the creek traverses flat, eluviated country, and the tin-bearing alluvium is buried beneath almost barren overburden. Near the junction, the depth to bedrock was about 3.5m and the payable wash was 1.2m thick. A section exposed during 1969 in a large pit about 300m below the junction, consisted of 5m of overburden overlying up to 1.2m of wash. The richest tin gravels were restricted to two old channels incised into the weathered gneissic-granite bedrock. Open-cast mining of the lead reached a point about 500m north of the Bamboo Creek road (Plate 2) where it was discontinued because of the increasing cost of removing the deepening overburden. Older workings, visible on the ground and described by Montgomery (1907), extend downstream almost to Brockman Creek. They comprise shafts up to 7.5m deep sunk to bedrock with drives and cross cuts in the pay dirt. One channel exposed over a length of 60m in this fashion was reported to be 6 to 12m wide, and to contain more than 11.5kg of tin concentrate per tonne of dirt (Montgomery, 1907, p.78).

Huntsman Gully

The tin-bearing creek now known as Huntsman Gully, but called Meagher's Gully by Maitland (1904), rises on the northwestern side of the main swarm of tin-bearing pegmatites (Plate 3) and flows west-northwesterly into Brockman Creek. It has been mined-out from its source to Horseshoe Flat (Plate 2) where declining grade and increasing water intake stopped further operations. In its upper reaches, the tin-bearing wash ranged from a few centimetres to (exceptionally) one metre in thickness. Further downstream, the depth of the detritus increased to 2.5 to 3.0m and reached as much as 200m in width.

The face at the lower end of the present open cut shows 5.5m of alluvium. The uppermost gravels exposed in the face contain material from the Warrawoona Group, and were evidently laid down by flood waters of Brockman Creek. The width of the lead here is about 35m. In 1969 an attempt was made to test the extension of this lead by pitting with a back hoe, but many of the pits did not reach the bedrock, and little information on the course and tin content of the channel was gained.

MacDonalds lead

It is evident from Maitland's (1904) map that the stream that both he and Montgomery (1907) called Prospectors Creek is the one now referred to as MacDonalds lead. It rises on the southwestern side of the main pegmatite swarm, and flows first southwesterly and then northwesterly into Brockman Creek (Plate 2). Workings extend from its source to Horseshoe Flat, and embrace a number of tributary creeks.

The early diggers treated shallow alluvium in the bed of the creek, and nearby residual deposits, with the aid of dry blowers. By 1907, the deeper alluvium had been discovered by MacDonald and party, who, at the time of Montgomery's visit, had recovered about 475 tonnes of black tin. The lead at that time was about 4.5 m deep, and averaged 9 m wide, ranging in width from very narrow to 30 m. The cassiterite in the upper part of the lead was coarse and angular, but became finer grained downstream. The minimum payable grade of the ground worked was estimated by Montgomery to be 16 kg/m^3 although he states that the actual yield was much greater.

The face of a pit examined during 1969 exposed 4 m of alluvium although the bottom of the section was obscured. The uppermost part consisted of red clay, with a bed of coarse gravel near the base. The pit was 30 m wide at this point. About 450 m north of the face the probable extension of the lead was tested by a line of pits up to 5.5 m deep, and a bull-dozed cut over 4 m deep. In 1971, Pilbara Tin Pty Ltd reported encouraging results from drilling carried out in shallow alluvium on the flanks of the main lead.

Mud Springs Creek

Several tributaries of Mud Springs Creek were mined for tin although the main creek does not seem to have been worked or tested in recent times.

The largest reported production came from Tin King Creek on D.C. 198. This stream drains southwards from a small area of tin-bearing pegmatites near the southern edge of the Moolyella Adamellite. It is mined-out over its entire length of 1 000 m, the depth of alluvium ranging from almost nothing to 1.2 m and the width averaging about 15 m.

Shallow alluvial workings are also present on D.C. 305 and some nearby gullies on W.R. 19795.

Two south-flowing tributaries of Mud Springs Creek were mined for tin on D.Cs 201 and 279 about 2 km west of Mud Springs. Both tributaries drain south from the pegmatite swarm at the western edge of the Moolyella Adamellite. Each creek is about

1.5 km long and up to 15 m wide, and both have been mined-out over their full lengths to a depth of about 2 m.

A shallow westerly flowing branch of Mud Springs Creek traversing M.Cs 667 and 668 crosses the Great Northern Highway about 1.2 km southwest of Mud Springs. It was mined over a distance of 1 400 m to a maximum depth of about 2 m. The width of the cut is about 15 m.

Prospectors Creek

The watercourse shown as Prospectors Creek on current maps of the Moolyella tin field is about 5 km south of the creek called by that name in the earlier reports of Maitland (1904), Montgomery (1907), and Sullivan (1939). It follows a westerly course near the southern edge of the field, and has been mined for tin in two places where it is joined by small gullies draining tin-bearing pegmatites. The principal workings are located immediately south of Fisher's cairn, close to the Moolyella Tin Ltd treatment plant. The workings consist of cuts extending over a distance of 450 m on the main creek, and others on a south-flowing tributary.

The alluvium here is about 60 m wide and 3 m deep in the middle of the channel.

Six Mile Creek

Six Mile Creek, a north-flowing tributary of the Talga River, forms the approximate eastern boundary of the Moolyella tin field. Small deposits of alluvial tin have been worked near its source, and on several tributaries which join it along its length.

D.C. 684 covers a head-water tributary of Six Mile Creek. Here, the alluvium was mined over a length of 350 m, a width of 18 m, and to a depth of 1.5 m. The water course drains the tin-bearing pegmatite worked on M.C. 871. Other shallow diggings follow a small gully which meets the main creek at the northwestern end of D.C. 684.

D.Cs 354, 355 and 356 cover three easterly-draining tributaries which join Six Mile Creek in a large embayment in the Moolyella Adamellite (Plate 2). A few tin-bearing pegmatites near each claim have been the source of local concentrations of cassiterite in the creek beds. The deposits were narrow and only about 1 m deep. The lengths of the portions mined were about 150 m on D.C. 354, 200 m on D.C. 355, and 350 m on D.C. 356.

Shallow tin gravels were also mined from a small creek on M.C. 889.

Eight Mile Creek

The most easterly workings in the Moolyella tin field are on D.C. 809, located on a branch of Eight Mile Creek. The deposit is in an embayment in the Moolyella Adamellite, the country rocks being gneissic and foliated granite cut by a few tin-bearing pegmatites. Apart from some patches of dry-blower tailings, eluvial workings are scarce. The alluvium, dug from the creek over a distance of 275 m, was mostly less than 1 m thick. The operator, Mr M. Edwards, reported that the concentrates from this area contained an unusually large proportion of tantalite.

Dredging Claim 666

D.C. 666 crosses the Great Northern Highway 7.2 m north of the Marble Bar turnoff. Some scattered tin-bearing pegmatites cutting foliated granite and migmatite were the source of cassiterite mined over a 250 m length of the creek, and in one or two small tributaries. The deposits were both shallow and narrow.

ELUVIAL DEPOSITS

Eluvial cassiterite was mined in many parts of the Moolyella tin field, the soil about every outcrop of tin-bearing pegmatite having been treated at some time. By far the most extensive eluvial diggings are in and around the low hills of pegmatite-veined gneissic granite which forms the source of the principal alluvial deposits of the field (Plate 3). The hills themselves are largely made up of bare rock, but any hollows or gutters which permitted the accumulation of detritus have been thoroughly cleaned out, apparently several times. The slopes surrounding the hills were treated by dry-blowers in the early days of the field, and subsequently were scraped as bare as possible by earth-moving machinery. At present, parties of aborigines regularly cull over the workings, using the yandy dish. The residual material worked was usually less than 50 cm thick, and consisted of a mixture of soil and rock debris containing coarse, angular pieces of cassiterite.

Similar, but smaller, eluvial deposits were mined in the vicinity of most of the lode and alluvial diggings described in the previous sections. Others were worked on M.Cs 679, 888, and 893, D.Cs 707 and 801, and on open ground (probably former M.C. 148) about 800 m north of the Brockman River store. The positions of the eluvial deposits are shown on Plates 2 and 3.

RESERVES AND RESOURCES

Reserves

The last comprehensive assessment of ore reserves at Moolyella was carried out by Pilbara Tin Pty

Ltd (on its leases only) in 1968. It showed a total reserve of about 520 000 m^3 of ore containing 1 725 tonnes of tin oxide. Since that time the Company, and its successor Pilbara Concentrates Pty Ltd, has mined about 1 280 tonnes of tin concentrate, some of which was from ground outside the original ore reserve.

A review of various ore reserve assessments supplied to the Department in 1974 concluded that about 650 tonnes of tin concentrate remained in the ground having an average grade greater than the cut-off (0.9 kg/m^3) prevailing at that time. Of this amount, it was considered that about 430 tonnes had been assessed on inadequate data. Since 1974 the price of tin concentrate has risen from about $43 to $110 per metric tonne unit. Possibly marginal ground excluded from the 1974 review is now mineable.

In about 1970, Metramar Minerals Ltd published reserves of 1.76 million m^3 of ore averaging 1.67 kg/m^3 SnO_2. The figure was based on the sampling of regularly spaced back-hoe costeans along the creeks, but details are not available. Probably the grades were estimated by "dish assays". The ground involved was mainly along Prospectors Creek.

Resources

The high cut-off grades (0.9 to 1.2 kg/m^3) used on the Moolyella tin field necessarily mean that a large amount of tin-bearing material, of a grade which would be considered payable in a more favourable locality, has been left untreated. Such material constitutes a significant tin resource for the State and will probably be mined when improved technology, higher prices or national needs justify it.

The materials which make up the resources are the extensions of the known deep leads beneath presently uneconomic depths of overburden, lower grade alluvial deposits on the fringes of the tin field, overburden dumps on the sides of the open cuts, and the heaps of tailings produced by the treatment plants. Other less promising sources of future tin supplies are the pegmatite dykes.

The most promising extension of a known deep lead is that on Moolyella Creek which was worked from shafts for a distance of about 450 m beyond the limits of the present open cut. There is also the possibility of proving extensions to Huntsman Gully and MacDonalds lead beneath Horseshoe Flat.

The water courses which are likely to contain low-grade alluvial deposits are Prospectors Creek, Mud Springs Creek and Six Mile Creek. All of these have tributaries in which tin was mined, and none has cut down sufficiently to dissipate the older alluvium along its course. Prospectors Creek was tested in about 1968 by a number of bulldozed costeans and backhoe pits. Typical sections show 1.2 to 1.5 m of greenish-yellow clay-bound wash overlain by a similar thickness of overburden. Two samples of the lower 1.2 m of wash in one costean, when assayed, gave values of about 0.6 kg of SnO_2 per tonne.

On the northern side of the tin field, several north-flowing braided creeks occupy wide, infilled valleys that show some promise for low-grade tin deposits. Samples of bottom wash taken from costeans on these creeks contained from 0.02 to 0.78 kg of SnO_2 per tonne. The depths of the alluvium ranged from 1 to 2 m.

The largest body of unworked alluvium in the field is that along Brockman Creek, but no significant quantities of tin have been found in this stream. An attempt to use seismic geophysical methods to locate buried and possibly stanniferous channels of this creek (Nowak, 1971) are summarized on p. 25.

Figures provided by Pilbara Tin Pty Ltd indicate that about 2 000 000 m^3 of untreated overburden will remain in various dumps when the existing ore reserves are mined. The tin oxide content of this material should range from almost nothing to 0.9 kg/m^3. No systematic testing of these dumps has been carried out, but estimates of between 0.3 and 0.6 kg/m^3 of SnO_2 given to the writer in the field seem reasonable, especially for the dumps on the upper parts of the leads.

The relatively low extraction ratio (about 60 per cent) achieved by the cones has resulted in an appreciable quantity of cassiterite being left in the tailings of the treatment plants. Portions of four tailings dumps sampled by Ishihara Sangyo Kaisha Ltd contained from 0.8 to 1.25 kg/m^3 of SnO_2. Many of the tailings produced in the 1950s and early 1960s have been subsequently retreated with good results.

Several mining engineers have speculated upon the possibility of mining the swarm of tin-bearing pegmatites at the head of Moolyella Creek, together with the intervening gneissic granite, in a large-scale open cast operation. The economics of such a venture have yet to be tested by a suitable drilling programme, but available information suggests that it would not be feasible unless there was a marked increase in the price of tin. Production and assay data on the pegmatites presented in Tables 6 and 10 indicate that the average grade of the pegmatite veins is probably less than 0.2 per cent SnO_2. A traverse across a typical section of the swarm showed that pegmatite comprises only about 20 per cent of the hills, making the average grade of the pegmatite plus granite less than 0.04 per cent SnO_2. At current (1978) prices, the value of the contained tin would be less than $3.00 per tonne of rock mined.

GEOPHYSICAL SURVEY

Montgomery (1907) stated "Below McLaren's claim (on Moolyella Creek) a sluicing and dredging area has been applied for in Brockmans Creek, but bores have shown the ground in the creek to be shallower than the bottom of the lead in McLaren's claim, and there is therefore a likelihood that the old deep lead system had an outlet which is buried beneath the flat and does not correspond with the existing creek in position". Consideration of the geology shown on Plate 2 restricts the position of any such lead to beneath the alluvium flanking Brockman Creek, or possibly to the anabranch west of the main creek channel.

In 1971, as part of the present investigation, the Geological Survey undertook a seismic refraction survey over Brockman Creek in an attempt to define any buried channels that could contain commercial tin deposits. The work was carried out by a crew led by Mr I. R. Nowak, from whose report (Nowak, 1971) the following details are taken.

Four seismic lines totalling 3 660 m were shot over the prospective area. Good contrast was obtained between the alluvium and the underlying granitic rocks, and the method was able to trace the bedrock profile quite accurately. Surface to bedrock depths ranged from 90 cm to 10.5 m but rarely exceeded 7.6 m. The survey revealed no sign of a large concealed channel, although it did locate some small channels and shallow depressions which are thought to be worth testing further. Most of these are situated beneath the present creek beds, but one is offset to the west and probably represents an older, buried channel. Probable extensions of Huntsman Gully and MacDonalds lead were indicated by small depressions beneath the southernmost line.

Although the hoped-for old channel was not located by the survey, it did show that seismic refraction can trace bedrock profiles with some precision in the conditions met with in the Pilbara tin fields, and that the method should be useful in prospecting for deep leads.

SHAW RIVER TIN FIELD

GENERAL INFORMATION

A number of tin mining centres situated near the Shaw River and linked by their geological associations are grouped as the Shaw River tin field. This field covers an area of about 1 200 km² between south latitudes 21°26′ and 21°43′ and east longitudes 119°17′ and 110°37′. The two principal centres, Cooglegong and Eleys, are respectively 69 and 105 km by road from Marble Bar. The field is connected to Marble Bar, Nullagine and Wittenoom by graded roads maintained by local Shire Councils. Individual centres within the field are connected to these roads by graded tracks. Small airstrips at Cooglegong and Eleys are used by aircraft bringing in mail and light stores to the mining communities. Of the three pastoral leases within the tin field only Hillside now operates.

Simpson (1948) states that tin was discovered in the field by A. Eley in 1890. Following an initial period of mining from 1893 to 1894, during which 77 tonnes of tin concentrate were exported from the Eleys centre, the field remained dormant until further deposits were found at Cooglegong by Bligh in 1900. Between 1900 and 1914 about 1 670 tonnes of tin concentrate were produced in the field and up to 125 men found employment at the Cooglegong centre alone. During the Great War production averaged only about 30 tonnes per year and from 1920 to 1950 it was generally less than 10 tonnes per year. Sullivan (1939) reported that only one European and a few Aboriginals were dry-blowing for tin at the Cooglegong centre in 1938.

Early mining methods consisted mainly of dry-blowing the alluvial deposits and upper parts of the eluvium. In places pits were sunk to reach bedrock in the creeks and the lower 15 cm of richer gravel were mined, and treated by puddling. Sullivan saw evidence of old sluice tailings near Two Mile Creek. As was the case at Moolyella, rising tin prices in the early 1950s brought renewed interest in the field and a number of syndicates were formed to work the deposits on a larger scale than had previously been possible. Chief among these were the Johnston family (now J. A. Johnston and Sons), Northern Mineral Syndicate, Pilbara Exploration N.L., Shaw River Alluvials and Shaw River Tin. As the better grade deposits were exhausted the smaller operators either merged with, or sold out to, the larger concerns. At the time of this survey only two companies worked the field: Cooglegong Tin Pty Ltd (formerly Northern Mineral Syndicate) controlled most of the prospective ground within the Cooglegong and Hartigan centres and J. A. Johnston and Sons owned much of the Eley centre. The British Metal Corporation had substantial interests in both of these companies. S. H. Stubbs and Sons held a considerable amount of ground near Split Rock and Coomba Creek in the eastern part of the field and the Canning Tin Syndicate had a number of claims in the western part.

Plants operating, or on stand-by, at the start of the survey (1969) were those of Cooglegong Tin Pty Ltd at Spear Hill, J. A. Johnston and Sons at Hillside, S. H. Stubbs and Sons at Split Rock, Canning Tin Pty Ltd near Tambourah Creek, and Russell at

Five Mile Creek. From 1971-1974, the only plant operating was that of Cooglegong Tin Pty Ltd, and this was employed mainly in treating tailings. During 1975 this operation was transferred to J. A. Johnston and Sons, who at present are the sole producers from the field.

Production attributed to the Shaw River tin field from 1893 to 1975 amounts to 6 584.62 tonnes of tin concentrate. Details are given in Table 11. The field has also produced a recorded 548 tonnes of tantalite concentrates containing 20.2 tonnes of Ta_2O_5.

References

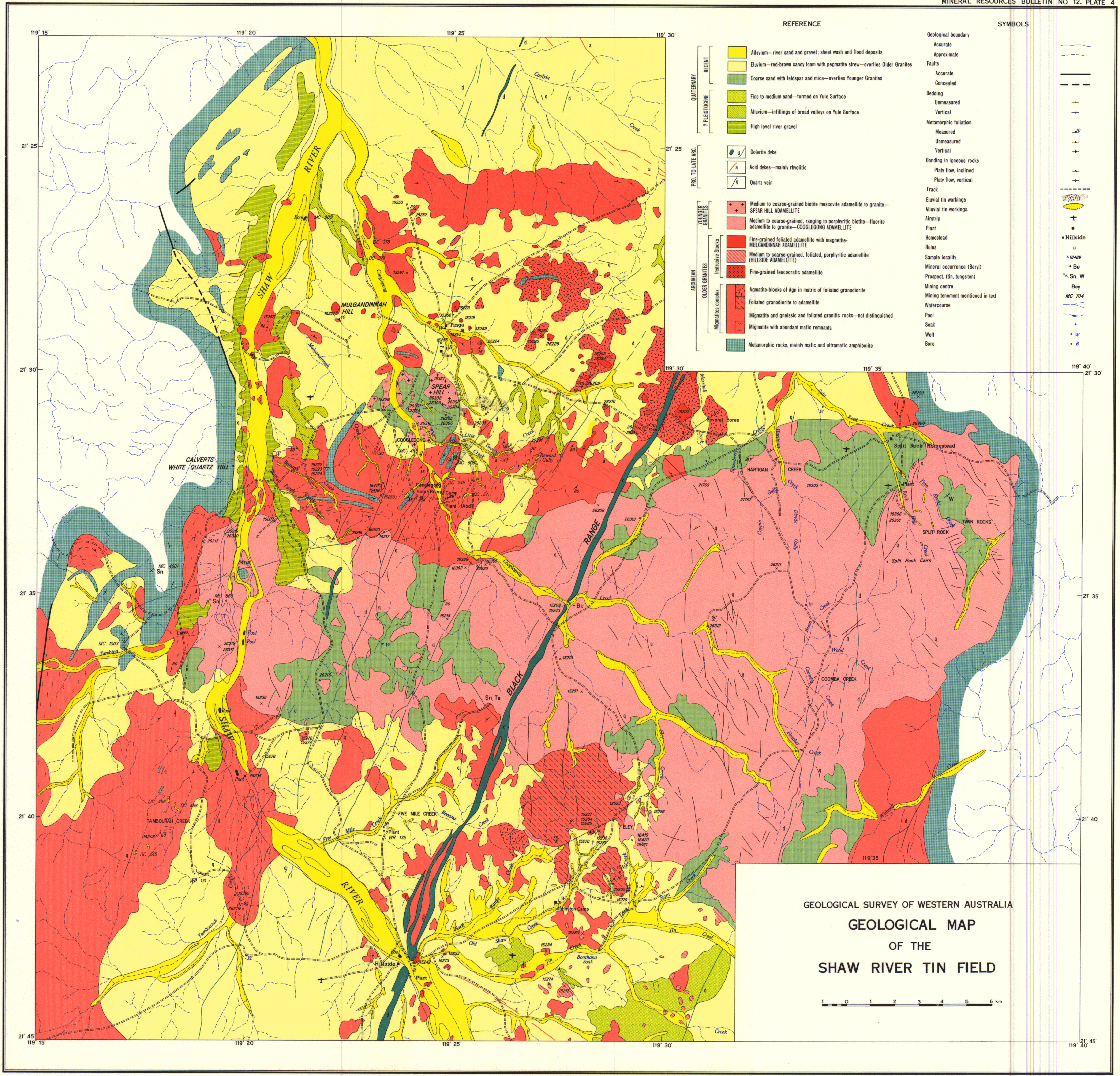
Maitland (1905) described the principal geological features of the Cooglegong centre and noted that the tinstone was derived from pegmatite veins. He described the granite as being generally uniform in composition, although he noted that it was gneissic in part. Descriptions of some of the eluvial deposits and mining methods in use at the Cooglegong centre were given by Montgomery (1907). He recommended that the larger river beds be prospected for tin with the hope of establishing a tin dredging operation. Cleland (1910) gave an account of prospecting activity at the Cooglegong centre, seen during his visit in 1909. The report of Simpson (1928) has the first description of the Eleys centre, as well as further notes on the geology and diggings at Cooglegong. He also lists the minerals present in the tin concentrate, noting the potential value of the monazite and gadolinite contents. The results of an examination of the Cooglegong and Shaw Patch workings by the Aerial, Geological and Geophysical Survey of North Australia are given by Sullivan (1939). The report contains a brief account of the geology and tin deposits and includes a map of portion of the field.

During 1965 and 1966, Westfield Minerals (W.A.) N.L. drilled lines of holes across the Shaw River near its junction with Cooglegong Creek and down-stream to the junction with Coolyia Creek.

In about 1967 Cooglegong Tin Pty Ltd carried out an extensive programme of drilling and consteaning throughout the northern part of the field. Their work was particularly concentrated on the upper parts of Hartigan and Cooglegong Creeks although they also tested areas near Shaw Patch, Canning Creek and the lower parts of Cooglegong Creek. Partly as a result of this work, Placer Development Pty Ltd became interested in the field and in 1969 acquired options over most of the existing mining tenements. This company continued the testing programme using a backhoe to dig pits in the prospective ground. The company checked some of the previous work and extended it northwards to the junction of Cooglegong

TABLE 11. PRODUCTION OF TIN CONCENTRATE FROM THE SHAW RIVER TIN FIELD 1893-1975

Centre	Tenement	Operator or lease holder	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)	Remarks
Cooglegong	D.C.25,26	Johnston, J. A.	1949-1954	185.14	125.56	204 221.02	
	D.C.25,26, etc.	Johnston & Sons	1957-1958	84.17	58.21	95 746.90	
	D.C.26,27,105	Shaw River Alluvials	1955-1957	86.31	59.18	101 698.26	D.C.27 & 105 at other centres
	D.C.49,50	Thompson, R. & Stutz, E.	1952-1953	4.92	3.49	6 414.18	
	D.C.48,49, etc.	Pilbara Exploration N.L.	1957-1962	169.70	113.71	208 024.00	
	D.C.53, etc.	Cooglegong Tin Pty Ltd	1955-1969	2 301.23	1 297.77	3 099 123.31	Formerly Northern Minerals Syndicate
	D.C.53, etc.	Marshall, W.	1971-1974	97.60	67.25	194 106.52	On tribute from Cooglegong Tin Pty Ltd
	D.C.60	Munn, W.	1954	.21	.15	227.60	
	M.C.383, etc.	J. A. Johnston & Sons Pty Ltd	1975	105.49	63.29	346 082.00	
	Sundry claims & Crown Land	Various	1900-1969	1 930.08	n.a.	485 596.85	
	Total: Cooglegong			4 964.85		4 741 240.64	
Eleys	M.C.39,40,41,42	Singapore Leases	1899-1900	6.86	n.a.	848.00	
	D.C.32	Johnston, J. A.	1959-1967	665.32	468.51	1 180 983.47	
	D.C.68	Shaw River Tin	1954-1955	57.89	38.88	60 841.98	Recorded as from Moolyella
	D.C.254 etc.	J. A. Johnston & Sons Pty Ltd	1967-1970	611.78	379.65	1 016 786.55	
	Sundry claims	Various	1893-1935	225.55	n.a.	30 764.00	Old Shaw
	Crown Land	Various	1961-1962	4.25	2.92	5 810.30	Eleys
	Total: Eleys			1 571.65		2 296 034.30	
Tambourah Creek	D.C.691, etc.	Canning Tin Pty Ltd	1966-1967	7.64	5.02	13 680.62	
Five Mile Creek	*M.C.1203, etc.*	*Coral Bay Minerals Pty Ltd.*	*1970*	3.67	2.49	6 982.38	
Coomba Creek-Split Rock	D.C.481, etc.	Stubbs, S. H.	1966-1968	34.95	23.46	61 716.45	
Field generally	Crown Land	Sundry persons	1966	1.86	1.34	3 549.00	Locality uncertain
	Total: Shaw River tin field			6 584.62		7 123 203.39	



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF THE SHAW RIVER TIN FIELD

Creek and the Shaw River (Murphy, 1970a). The company also tested ground in the Split Rock and Eleys areas (Murphy, 1970b,c).

Water supplies

Although a number of natural pools along the Shaw River and Cooglegong Creek have been used as a source of water for treating tin ore, they generally failed to provide an adequate supply for long periods. Better, although not always sufficient, quantities were obtained from bores at Spear Hill and Johnston's camp. Supplies of up to 1 080m^3/day have come from bores sunk along creeks into gneissic granite and migmatite in places where these rocks are cut by veins of quartz or pegmatite. Johnston's plant makes use of a bore sunk into alluvium in the Shaw River immediately upstream from a large dolerite dyke. Water obtained from bores in the field is generally suitable for domestic purposes, although it is hard and has, in some places, a high fluoride content. Table 12 summarizes available information on bores in the Shaw River tin field.

GEOLOGICAL INFORMATION

The Shaw River tin field is underlain mainly by granitic rocks of the Shaw Batholith (Hickman and Lipple, 1975) which, in this field, comprises large areas of migmatite and gneissic granite, many stocks of foliated granite, and two intrusions of tin granite with swarms of associated tin-bearing pegmatites. The batholith intrudes mafic and ultramafic rocks of the Warrawoona Group which are exposed at either edge of the field. It is intruded in turn by dykes of rhyolite, dacite, dolerite and quartz.

Granitic rocks

The distribution of the granitic rocks within the Shaw River tin field is shown on Plate 4. The petrography and chemistry of the rocks are described in Chapter 5. The older gneiss and migmatite complex can be divided into four types although boundaries are gradational. The most primitive type is made up of stromatic migmatite with numerous inclusions of amphibolite. It is best developed towards the western edge of the tin field where there are excellent exposures in the beds of the Shaw River and Tambourah Creek. A large area of amphibolite-rich migmatite surrounds Spear Hill and extends southward to the vicinity of Shaw Patch and the old Cooglegong store. It contains several large rafts of greenstone. Well-banded gneissic granites form bare rocky ridges to the west of Canning Creek and north of Split Rock. A leucocratic foliated granite with rare mafic schlieren forms a range of hills to the northwest of Eleys. Agmatites made up of brecciated gneissic granite invaded by foliated granite crops out at the northern edge of the field, roughly from Mulgandinnah Hill to Hartigan Creek. At the southern edge of the field, agmatite, comprising gneissic granite blocks in a matrix of medium-grained to porphyritic granite, crops out south of Ram Creek.

The intrusive foliated granites are best developed at the northern and southern edges of the field. At the northern edge, stocks of fine-grained foliated granite form prominent tors such as Mulgandinnah Hill. South of Ram Creek there are a number of tors of foliated porphyritic to medium-grained granite. These types are named respectively the Mulgandinnah Adamellite and the Eley Adamellite. In each of these areas the granite comprising the stocks is similar to that forming the neosome of the agmatitic migmatite intruded by the stock. The larger of the two bodies of tin granite is named the Cooglegong Adamellite. It crops out over a roughly arcuate area in the central and eastern part of the tin field. It is a medium to coarse-grained granite varying from even-grained in its northern part to porphyritic in its southern portion.

TABLE 12. INFORMATION ON WATER BORES AND WELLS IN THE SHAW RIVER TIN FIELD

	Location	Water level (m)	Depth (m)	Yield (m^3/day)	Salinity (ppm)
E1	Johnston's camp	9.7	10.8	75	domestic
E2	Johnston's camp	7.1	11.3	55	1 250
E3	0.7 km southwest Johnston's camp	?	13.7	325	560
E4	0.7 km southwest Johnston's camp	7.0	16.8	655	?
E5	Johnston's plant		6.7	435	495
Five Mile Well	Five Mile Creek		12.2	Fair	good
Canning Well	Lat 21°40'S, 119°18'E		12.2	Fair	good
S.H. 1	W.R. 99, Spear Hill		53.4	108	
S.H. 2	W.R. 99, Spear Hill		30.5	Nil	
S.H. 3	W.R. 99, Spear Hill	12.8	73.8	?	fresh
S.H. 4	W.R. 99, Spear Hill	11.0	52.4	2 160	fresh
No. 7	W.R. 136, Hartigan	13.6	36.6	108-165	
No. 8	W.R. 136, Hartigan	12.8	36.6	165	
No. 9	W.R. 136, Hartigan	10.4	42.8	108	
No. 10	W.R. 136, Hartigan	9.0	45.8	1 416	
No. 11	W.R. 136, Hartigan	8.4	45.8	435	
No. 12	W.R. 136, Hartigan		10.7	Nil	

The smaller body of tin granite, which is probably connected to the Cooglegong Adamellite at depth is named the Spear Hill Adamellite after its most prominent outcrop. It is more fractionated than the Cooglegong adamellite (p. 141), and, area for area, has yielded more tin.

Acid dykes

Acid dykes of rhyolitic composition cut the granitic rocks in several places within the Shaw River tin field. The dykes have two trends; west-northwest and west-southwest. Some contain fluorite but no direct association of the dykes with tin mineralization was noted. At the north end of the Black Range, 10-15 km northeast of Cooglegong, a prominent swarm of dacite dykes is exposed close to the main road to Marble Bar. Both types of acid dykes are cut by the dolerite.

Dolerite dykes

The Shaw River tin field is traversed by a swarm of north-northeast striking dolerite dykes. The most prominent dyke forms a razor-backed ridge known locally as the Black Range. It can be traced for about 80 km. At its northern end the dyke stops abruptly but the continuation of its course is marked by a belt of agglomerate which grades into the lowermost unit of the Fortescue Group lavas. It seems likely that these dykes were feeders for the Fortescue Group.

Quartz veins

At least two generations of quartz veins are present in the Shaw River tin field. The older veins mostly strike northwesterly and are most abundant in or close to the Cooglegong Adamellite, to which they are probably related. The granite near the veins is altered to a greenish greisen-like rock. These older veins are cut by dolerite and the acid dykes. The younger quartz veins are thicker than the older ones and crop out more boldly. They strike northerly following obvious fault lines, and in places appear to cut dolerite dykes. They are most common near the edge of the Shaw Batholith and in places, such as the prominent White Quartz Hill, follow faulted contacts between the granite and the Warrawoona Group.

Superficial deposits

The crystalline rocks of the Shaw River tin field are overlain in many places by shallow residual and alluvial deposits of Pleistocene to Recent age. They include calcrete, high level river gravels, sandplain, sheet wash, eluvium and alluvium.

The calcrete is probably the oldest Cainozoic unit in the field. It comprises lime-cemented river gravels cropping out close to the course of the Shaw River. It is about 5 m thick, rests on weathered granite, and is overlain by unconsolidated high level alluvium. The pebbles and cobbles in the calcrete consist of chert, basalt and amphibolite derived from the Warrawoona and Fortescue Groups. In one spot (M.C. 868) the calcrete has been mined on a small scale for tin.

Deposits of unconsolidated, high level river gravels 2 to 5 m thick, stretch in discontinuous belts along either side of the Shaw River. They are about 10 m higher than the present river bed and lie above the level of present floods. They consist mainly of pebbles and cobbles of rocks derived from the Warrawoona and Fortescue Groups, loosely held together by silt and clay. These deposits have been dissected by the present drainage and contain only small quantities of tin.

Sandplain deposits, remnants of the Yule Surface of Kriewaldt and Ryan (1967), appear as low plateaux throughout the tin field. They comprise sandy loam and sand derived from the granitic rocks of the area and redistributed by wind action and sheet flooding. Kriewaldt and Ryan record thicknesses of up to 6 m for these sandplain deposits but in the Shaw River area they are mostly thinner than this.

Broad shallow valleys which lack defined stream channels contain deposits of sand, loam and fine gravel deposited largely by the action of sheet flooding. Some of the valleys form part of the Yule Surface but others are evidently younger, although still older than the present drainage.

Eluvium, made up of sand and sandy loam derived directly from the underlying granitic rocks, and transported only by downslope movement, covers much of the Shaw River tin field. Those deposits overlying the older granite have a veneer of quartz and pegmatite fragments while those derived from the younger granite contain feldspar crystals and mica flakes.

The alluvium in the beds of the present rivers and larger creeks consists of loose sand and shingle resting on bedrock and has only a low tin content. In the smaller creeks, which have not yet cut down to bedrock during the present cycle of erosion, the loose deposits overlie older consolidated alluvium. Typically this consists of an upper layer of loosely-bound silt and clay with gravel beds and a lower layer of puggy clay-bound gravel. The boundary between the two layers is mostly quite sharp. The significance of this layering has been discussed in the section on the Moolyella tin field, and, as at Moolyella, the richest tin ore is found in the lower clay-bound layer. The greatest thickness of alluvium recorded in the Shaw River tin field is 4.5 m, although greater depths exist near the junction of Cooglegong Creek and the Shaw

River, some distance north of the tin diggings. In most creeks mined for tin the alluvium has been no more than 1.5 to 3 m thick.

Summary of economic geology

All of the tin mined from the Shaw River tin field was derived originally from pegmatite. The most productive pegmatites form swarms cutting the older granite complex, mostly near the margins of the younger granites, although some are found as far as 2 km from these contacts. Typically they are layered bodies with alternating coarse microcline-rich and fine albite-rich bands, and contain spessartine and green muscovite in addition to cassiterite. Individual veins strike northerly or northeasterly and dip at low angles to the east. These pegmatites are similar in all respects to those at Moolyella, specimens of which are described on pages 18 and 136. Good exposures of layered pegmatites of this type are present at the headwaters of Mulgandinnah Creek, at Shaw Patch, east of Spear Hill, in the hills near the old plant at Cooglegong, and at the head of Old Shaw Creek. Individual pegmatites are not shown on Plate 4 but the outcrop areas of the pegmatite swarms correspond to the eluvial workings shown on this plan.

Small quantities of finer grained cassiterite were derived from thin (10 to 45 cm) pegmatites cutting the tin granites. They mainly follow flat joints and are made up principally of quartz, microcline and biotite, but contain small patches or narrow selvedges of a fine-grained, sugary-textured assemblage of quartz, albite, spessartine and green muscovite. Pegmatites of this type are found at Split Rock, Coomba Creek and Gunpowder Creek near Spear Hill.

Despite the widespread occurrence of cassiterite-bearing pegmatites, lode tin has been mined in only one locality in the Shaw River tin field. This was at Stutz's P.A., 1.8 km southeast of Spear Hill, where three narrow pegmatite veins were pitted to produce about 2 tonnes of ore averaging 1 per cent SnO_2 (Simpson, 1928). These veins cut a large amphibolite remnant in migmatite.

By far the greatest amount of tin won from the field came from the alluvial deposits, particularly from the clay-bound consolidated gravels found in the less dissected creeks. Most of these deposits were immediately below the present stream beds, although concealed leads were found in the downstream part of Old Shaw Creek, and on M.C. 989 between Cooglegong Creek and the Shaw River. In general, the residual deposits are too shallow to contain concealed leads and the deepest ground worked on the field was only 6.5 m.

Eluvial deposits are located below and between outcrops of tin-bearing pegmatites and consist of from 15 to 50 cm of soil and scree. Although rich in grade their contribution to the tin mined from the field in recent years has been small. Cassiterite has also been found on M.C. 868, in a dissected calcrete deposit alongside the Shaw River. One sample taken from the unconsolidated high level gravel just west of the Cooglegong airstrip also contained a small quantity of tin.

Apart from cassiterite the concentrates obtained from the Shaw River tin field contain yttrotantalite, tanteuxenite, mangano-columbite, gadolinite and monazite. Small quantities of beryl have been mined from the field and at least one small lead vein is known.

COOGLEGONG CENTRE

The Cooglegong centre extends from near the Shaw River at latitude 21°32′S, eastwards for 11 km to the head of Two Mile Creek and northerly to the north side of Spear Hill. It includes the diggings at Two Mile Creek, Shaw Patch, Spear Hill, and along Cooglegong Creek. The primary mineralization is more or less spread over the entire extent of the field, the various diggings being separated by rocky areas in which it was not possible for cassiterite to accumulate, rather than by large gaps in the distribution of the tin-bearing pegmatites. The total production recorded from the centre is 4 964.50 tonnes. Owing to the large proportion of the production attributed to sundry claims, and to the practice of carting ore from many parts of the centre to a central treatment plant, it is not possible to nominate the tin produced from the various groups of diggings in the centre.

Most of the prospective ground at Cooglegong has been treated and it is now difficult to estimate the original widths or depths of the tin-bearing wash.

The Two Mile Creek diggings are the largest in the centre. They extend for 5.5 km along Two Mile Creek and include a number of tributary streams. The main creek bed was mined out over widths of between 20 and 60 m and to depths of 1.5 to 2.5 m. The thickness of the pay dirt is stated to have been about 1 m. Contributions of cassiterite to the creek were made primarily by pegmatites cropping out near Reward Gully, Little Two Mile Creek and on M.C. 605. The bedrock here is mainly stromatic migmatite with many large remnants of amphibolite, although the lower part of the creek overlies Spear Hill Adamellite.

The main workings at Spear Hill cover three small north-flowing creeks named Spear Hill Gully, Two Mile Creek and Four Mile Creek. All flow over migmatite to the east of the Spear Hill tor. The creeks were mined out over lengths of 2.5, 0.9 and 2.8 km respectively, the usual width of the creek beds being 10 to 20 m and the depth 1 to 2 m. The source of the cassiterite mined from these creeks was a swarm of aplite-pegmatites cutting migmatite near the eastern side of the Spear Hill Adamellite. The downstream portions of the creeks were not worked owing to a fall-off in the grade of tin ore. Gunpowder Creek, which flows westerly into Cooglegong Creek on the south side of Spear Hill, derived cassiterite from narrow aplitic pegmatites cutting the Spear Hill Adamellite. The wash in this creek was quite shallow.

The Cooglegong Creek diggings follow a number of small tributaries flowing into Cooglegong Creek in the vicinity of the old hotel. Those on the western side of Cooglegong Creek lie in M.Cs 454 and 455 and two on the eastern side are within D.Cs 57 and 245. All of these creeks are shallow and narrow, their alluvium rarely exceeding 1 m in depth or 10 m in width. They flow through hills of migmatite and gneissic granite and there is little prospect of further alluvium being found along their courses.

The bed of Cooglegong Creek was mined in two places where it is joined by two of the larger tin-bearing tributaries. In general the creek has cut down to bedrock in this part of its course and does not contain significant quantities of payable gravel.

The water shed between Cooglegong Creek and the Shaw River is formed by a prominent ridge of dolerite to the west of which are the diggings referred to as Shaw Patch. Here a swarm of aplite-pegmatites cutting migmatite and rafts of amphibolite have shed cassiterite into Shaw Patch, Banana, and Mulgandinnah Creeks. Shaw Patch and Banana Creeks flow westerly into the Shaw River. They were worked over their entire length, although the principal diggings are restricted to the central sections where the better accumulations of alluvium formerly existed. The upper part of the streams are too narrow and rocky to be mined by machinery and the lower parts have been cut down to bedrock by headward erosion from the Shaw River. The widths of the creeks average about 15 m.

Mulgandinnah Creek flows northwesterly, following a course nearly parallel to that of Cooglegong Creek. It was mined out downstream from its origin for a distance of 2.5 km over widths ranging from 5 to 20 m. Other diggings at Shaw Patch comprise several small gullies, some draining southerly from the source area, and a number of large patches of eluvium.

Two pits were opened up by Cooglegong Tin Pty Ltd on D.Cs 377 and 378 on Cooglegong Creek (east of Mulgandinnah Hill). They were reported to average about 1.2 kg/m^3 of tin concentrate, although they are several kilometres downstream from the main source pegmatites. At the time of the writer's inspection the pits were partly filled by later stream deposits. The pits are located on patches of alluvium trapped on the upstream side of an outcrop of gneissic granite which constricts and divides the creek at this point. Some further work was done on a shallow gully draining one or two tin-bearing pegmatites near the southwest corner of D.C. 378.

ELEYS CENTRE

The Eleys, Old Shaw or Hillside centre is about 7 km northeast of the water gap where the Shaw River passes through the Black Range. The greater part of the 1 571.65 tonnes of tin concentrate mined from the centre was derived from a comparatively small swarm of pegmatite veins straddling the watershed between Cooglegong Creek and Old Shaw Creek. These veins cut gneissic and foliated granite of the older complex and lie in a broad embayment in the southern side of the younger Cooglegong Adamellite. Several stocks of younger granite cut the older gneisses within this source area. In at least one spot tin was shed from pegmatites cutting the younger granite.

The principal diggings in the centre follow Old Shaw Creek from its source downstream for about 6.5 km. Where work ceased the alluvium was about 300 m wide and the overburden was 2 m thick. The cassiterite is reported to have become finer and more rounded as the creek was followed down, although in places there were admixtures of coarser, more angular cassiterite, evidently derived from local sources. In the lower part of the workings, tin-bearing leads were encountered some distance north of the present position of the stream bed.

Long Tin Creek drains the easternmost part of the source area. It was mined over a length of about 1.2 km to depths of 1 to 2 m.

The headwaters of Black Range Creek drain the western fringe of the source area. A cut being worked in 1969 showed a width of 15 m of alluvium with 60 cm of stanniferous clay-bound grit and gravel overlain by 1.2 m of overburden.

On the northern side of the watershed the principal workings follow Eleys Creek, a headwater tributary of the south branch of Cooglegong Creek. Two small tributaries of Eleys Creek have also been mined. All three creeks are narrow and rocky and the amount of ore mined was quite small, despite a total length of workings of about 2 km.

The average recovered grade of ground worked at Eleys from 1966 to February 1969 was 1.26 kg/m^3 of tin concentrate.

FIVE MILE CREEK

Between 1967 and early 1969, three small gullies draining into Five Mile Creek were mined for tin. The ground was treated at a plant on W.R.135 (Russell's plant) but there is no official record of the amount of tin produced. Mr D. Coppin, who was involved in the operation, told the writer that about 6 000 m^3 of ore containing from 0.6 to 1.2 kg/m^3 of tin concentrate had been treated. A further 3.67 tonnes of tin concentrate were reported from this area in 1970.

The workings range from 10 to 15 m in width and are about 1 to 1.3 m deep. The same syndicate also worked the gully at the head of Five Mile Creek near the spot where lode tantalite was mined from a pegmatite vein (see Plate 4).

TAMBOURAH CREEK

In 1966 to 1967 a total of 7.64 tonnes of tin concentrate was mined from a number of localities on the western side of the Shaw River. The work was done by Canning Tin Pty Ltd which erected a plant on W.R.131 close to Tambourah Creek. Most of the diggings are scattered along Canning Creek, a tributary of the Shaw, lying between Tambourah Creek and Tambina Creek. They comprise shallow cuts or scrapings in the vicinity of outcropping tin-bearing pegmatite. The larger cuts are on D.Cs 466, 468 and 545. Some further ore was taken from M.C. 1003, 6.5 km north of D.C. 466. Here the source is a prominent pegmatite dyke cutting a raft of ultramafic rock in the older granite. Cassiterite was mined from the soil around the dyke and from small gullies draining it.

About 3 km north of M.C. 1003, another tin-bearing pegmatite has been tested near the north end of D.C. 608. The vein strikes north, dips vertically and is about 200 m long and 3 to 5 m wide. It intrudes amphibolite near the margin of the Shaw Batholith.

SPLIT ROCK

Split Rock is an abandoned station homestead situated 20 km east of Spear Hill. Cassiterite was first reported in its vicinity in 1903, at which time a small amount was mined. Samples from the same locality were submitted to the Government Chemical Laboratories in 1936. Further mining was carried out between 1966 and 1968, although the production at this time was included with that from Coomba Creek.

The workings are entirely within the Cooglegong Adamellite which in this area is very coarse grained and carries an appreciable amount of fluorite. It is cut by a number of flat-dipping, narrow (5 to 40 cm) pegmatite veins made up mainly of quartz, microcline and biotite with selvedges of fine, sugary-textured quartz, albite, green mica and spessartine. The granite is also cut by felsite dykes and north-striking swarms of narrow quartz veins. The only primary cassiterite seen at Split Rock was obtained by crushing and panning samples of pegmatite, particularly those which contained albite and spessartine. Samples of weathered granite and of quartz yielded no tin when similarly treated. The tin workings follow narrow gullies traversing rocky terrain at the head of Split Rock Creek and are distributed sporadically over an area of about 2 km by 1 km, wherever there was an accumulation of detrital material in the creeks. The ore was treated at a plant located 1.2 km southeast of the old homestead.

COOMBA CREEK

Coomba Creek is a small tributary of the Cooglegong, crossing the old Eleys Road 10 km south of Split Rock. It was mined for cassiterite between 1966 and 1968, although many years earlier the mineral was known to occur in this locality. The recorded production of 34.95 tonnes includes tin concentrate won from Split Rock. The ore was treated at Split Rock after its bulk had been reduced by screening at the mine site. The principal diggings follow Coomba Creek for 400 m downstream from the point where it cuts through a prominent quartz ridge. The creek was mined to a width of 30 m and depth of 1 to 2 m. Upstream from the quartz ridge are small diggings scattered on various tributary gullies, as well as some patches of eluvial workings.

The tin at Coomba Creek is derived from small pegmatites in the Cooglegong Adamellite. Small quantities of cassiterite were detected in costeans dug on Breen Creek and Wood Creek, to the north of Coomba Creek.

HARTIGAN CREEK

Although early Pilbara prospectors knew of tin in Hartigan Creek, no production of the metal has been recorded. The area is on the north edge of the Cooglegong Adamellite, 15 km east of Split Rock. Test pits dug by Cooglegong Tin Pty Ltd showed tin to be present over a wide area in Hartigan Creek, Strawberry Creek and Marshall Creek, but in insufficient quantities or grades to warrant the construction of a plant.

SAMPLING RESULTS

Assay results from 23 samples of alluvium, overburden and pegmatite collected during the survey are listed in Table 13. Of particular interest are the comparatively high tin-oxide contents of the overburden dumps on Long Tin Creek.

TABLE 13. SAMPLING RESULTS—SHAW RIVER TIN FIELD

Sample No.	Details*	Weight sample (kg)	Weight concentrate (g or %)	Sn in concentrate (%)	SnO_2 content (g/tonne)
16402	Overburden dump, Long Tin Creek (D.C.295)	3.0	11.6 g	11.1	610
16403	Overburden dump, Eleys (D.C.295)	3.0	10.4 g	10.8	535
16404	Dump of costean near Mulgandinnah Hill	3.0	29.3 g	.35	50
16405	Recent alluvium in tributary of Long Tin Creek (near D.C.295)	3.0	17.8 g	35.6	3 000
16406	Pegmatite on upper part of Mulgandinnah Creek (near D.C.215)	1.0	50.8 g	.04	30
16407	Pegmatite on upper part of Mulgandinnah Creek (near D.C.215)	.8	15.4 g	0.06	15
16408	Pegmatite near Long Tin Creek (near samples 16419-21)	.9	3.0 g	.80	40
16432	Bottom wash, Five Mile Creek area (400m east of plant)	6.0	12.2 g	13.5	390
16433	Bottom wash, Five Mile Creek area (D.C.696)	6.0	8.0 g	6.7	130
16417	Pegmatite, Mulgandinnah Creek (D.C.215)		.3%	.03	1.3
16418	Pegmatite, Mulgandinnah Creek (D.C.215)		.6%	.05	4.3
16480	Bottom wash in costean near D.C.203, 4km ESE of Spear Hill	3.0	28.1 g	.24	30
16481	From costean near D.C.202, 5.5km ESE of Spear Hill	3.0	14.1 g	2.32	155
16482	Pegmatite, M.C.714, Split Rock area	2.7	7.1 g	.82	30
16484	Pegmatite, near M.C.714, Split Rock area	2.0	3.8 g	.68	20
16485	Dump of costean on Hartigan Creek, D.C.386	3.0	40.5 g	2.00	385
16486	Bottom wash of costean on D.C.717, Cooglegong Creek	2.7	11.5 g	1.95	120
16488	Lower 450mm of wash in costean on D.C.544, 2.5km north of Canning Tin plant	1.97	14.1 g	.70	70
16489	Lower 300mm of alluvium in costean on D.C.526, 4km west of Canning Tin plant	2.15	19.6 g	.15	20
16490	Kankar-cemented gravels, M.C.952	±3	12.9 g	19.3	1180
16493	Costean on deep lead near junction of Shaw River and Cooglegong Creek (M.C.989)	1.97	6.3 g	.59	30
16494	High level gravels, about 1.5km north Cooglegong air strip	±5	6.6 g	2.63	±50

*Locations of most samples are shown on Plate 4

RESERVES AND RESOURCES

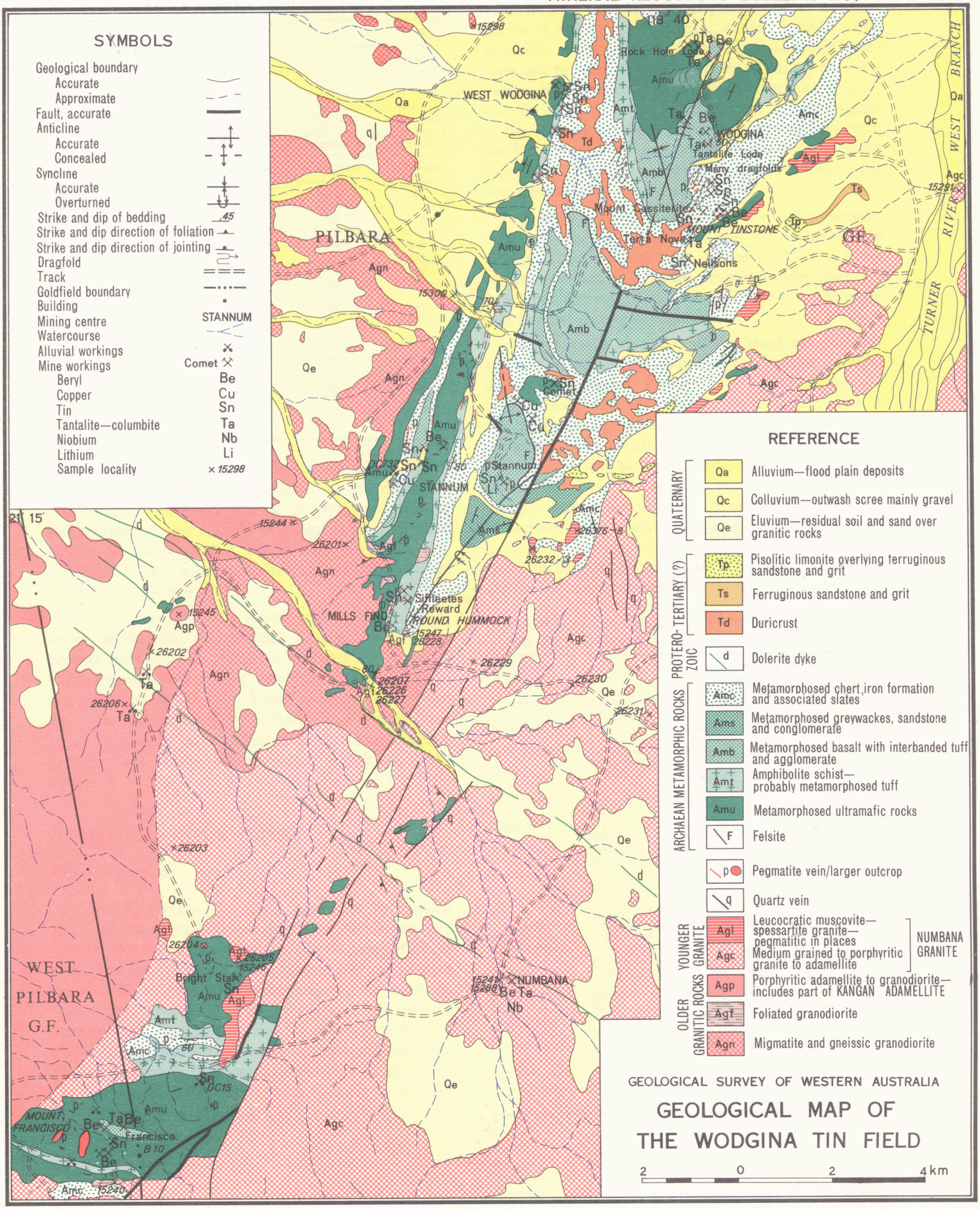
Reserves

Some earlier estimates of ore reserves on the Shaw River tin field were based on dish sampling of widely spaced costeans. The results were poorly documented, dish 'assays' were not checked by chemical methods, and the conclusions must be treated with caution. One such programme in the Hartigan Creek area resulted in ore reserves of 1 150 000 m³ averaging 1.8 kg/m³. When rechecked by drilling with better controlled sampling and assaying, the ore reserves were reduced to only 14 500 m³ of ground with grades better than 1.5 kg/m³.

Reports held by the Mines Department include three on sampling programmes considered to have been carried out in a satisfactory manner. In 1965 Geotechnics (Aust.) Pty Ltd (Ward, 1965) assessed the results of a pitting programme carried out at Shaw Patch on M.C.616 and D.Cs 25 and 26. They concluded that there were 180 500 m³ of eluvium averaging 0.72kg/m³ indicated on M.C.616, and 700 000m³ of material averaging 1.1 kg/m³ inferred on D.Cs 25 and 26. A further total of 414 000m³ of ground of unknown grade was inferred on M.C.615 and to the south of Shaw Patch. Most of the ground sampled was shallow, and has subsequently been mined.

During 1967, Geotechnics (Aust.) Pty Ltd investigated the lower part of Mulgandinnah Creek, the Hartigan Creek area, and the tailings dump at Spear Hill (Ward, 1967). The lower part of Mulgandinnah Creek (approximately 3km north of the Spear Hill airstrip) proved mainly to have tin contents well below economic grades, and only a few hundred tonnes of sub-marginal ore were located. In the Hartigan Creek area, the higher tin grades were found in coarse sand and gravel in the creek beds; alluvial plains between the creek returned only poor assays. The work indicated about 14 500 m³ of ore averaging 1.5 kg/m³ or better of tin oxide and 9 900 m³ of sub-marginal ore with between 0.9 and 1.5 kg/m³ of tin oxide. Sampling of the dump at Spear Hill showed most cassiterite to be concentrated near the outlet flume from the plant. Reserves were put at 1 070 m³ of ore averaging more than 1.5 kg/m³ and 4 500 m³ of sub-marginal ore grading between 0.9 and 1.5 kg/m³.

The most comprehensive testing programme on the Shaw River tin field was carried out by Placer Prospecting (Australia) Pty Ltd in 1969 and 1970 (Murphy 1970a, b, c). The company carried out systematic pitting of most of the unworked alluvium and deeper eluvium in the field. Results are held by the Department as colour-coded assay plans in which values are represented in dollars per cubic yard, based on the prices of tin, tantalum, niobium and rare earth oxides at the time. No depths are recorded, so no calculation of reserves is possible. Placer concluded that higher tin assays were erratically distributed, and although small concentrations of cassiterite exist here and there, no large payable accumulations of tin ore remain. In particular, the programme showed that hoped-for economic deposits in the lower part of Cooglegong Creek, in the Shaw River near the junction of Cooglegong Creek, and in old channels between these streams, did not exist.


SYMBOLS
Geological boundary
Accurate
Approximate
Fault, accurate
Anticline
Accurate
Concealed
Syncline
Accurate
Overturned
Strike and dip of bedding
Strike and dip direction of foliation
Strike and dip direction of jointing
Dragfold
Track
Goldfield boundary
Building
Mining centre STANNUM
Watercourse
Alluvial workings
Mine workings Comet
Beryl Be
Copper Cu
Tin Sn
Tantalite—columbite Ta
Niobium Nb
Lithium Li
Sample locality × 15298
REFERENCE
QUATERNARY
Qa Alluvium—flood plain deposits
Qc Colluvium—outwash scree mainly gravel
Qe Eluvium—residual soil and sand over granitic rocks
TERTIARY (?)
Tp Pisolitic limonite overlying ferruginous sandstone and grit
Ts Ferruginous sandstone and grit
Td Duricrust
PROTERO-ZOIC
d Dolerite dyke
ARCHAEAN METAMORPHIC ROCKS
Amc Metamorphosed chert, iron formation and associated slates
Ams Metamorphosed greywackes, sandstone and conglomerate
Amb Metamorphosed basalt with interbanded tuff and agglomerate
Amt Amphibolite schist—probably metamorphosed tuff
Amu Metamorphosed ultramafic rocks
F Felsite
p Pegmatite vein/larger outcrop
q Quartz vein
YOUNGER GRANITE
Agl Leucocratic muscovite—spessartite granite—pegmatitic in places
Agc Medium grained to porphyritic granite to adamellite
NUMBANA GRANITE
OLDER GRANITIC ROCKS
Agp Porphyritic adamellite to granodiorite—includes part of KANGAN ADAMELLITE
Agf Foliated granodiorite
Agn Migmatite and gneissic granodiorite
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL MAP OF THE WODGINA TIN FIELD
2 0 2 4 km
PILBARA
WEST PILBARA G.F.
WEST WODGINA
WODGINA
Tantalite Lode
Many dragfolds
Rock Hole Lode
Mount Cassiterite
MOUNT TINSTONE
Terra Nova
Neilsons
STANNUM
Comet
Stannum
MILLS FIND
Siffleetes Reward
ROUND HUMMOCK
NUMBANA
Bright Star
MOUNT FRANCISCO
Francisco
TURNER RIVER WEST BRANCH
118 40
21 15
G.F.

A report, not held by the Department, but shown to the writer in 1972 by the Manager of J. A. Johnston and Sons, gives some credible reserves in the Eleys area. A drilled length of Old Shaw Creek, below the present diggings, is estimated to contain 30 600m³ of alluvium averaging about 1.2kg/m³ of tin oxide under an average overburden thickness of 1.8m. The tailings dump at Johnston's plant was calculated to contain 53 500m³ of material with about 0.9kg/m³ tin oxide.

Resources

The principal resources of tin in the Shaw River tin field are the overburden and tailings dumps, areas of alluvium and eluvium around the edges of present diggings, and possibly older calcreted alluvium preserved in places along the Shaw River. Owing to the shallow nature of most of the superficial deposits, there are unlikely to be any undetected deep leads in the vicinity of the known deposits.

Drilling carried out by Westfield Minerals (WA) N.L. (Jones, 1966) indicated that downstream from its junction with Cooglegong Creek, the Shaw River carries negligible quantities of cassiterite.

WODGINA TIN FIELD

GENERAL INFORMATION

The Wodgina tin field (Plate 5) lies about 130 km south of Port Hedland, between the Turner and Yule Rivers. It embraces the mining groups of Wodgina, West Wodgina, Stannum, Mills Find, Numbana and Mount Francisco, covering a tract of country between latitudes 21°10′S and 21°30′S, and longitudes 118°30′E and 118°40′E. The field includes two prominent greenstone ranges which rise to heights of about 180 m above the surrounding granitic plains.

Access to Wodgina, the principal centre, is by a graded track branching from the Port Hedland to Wittenoom road about 90 km south of Port Hedland. Other parts of the field are reached by two-wheel tracks radiating from Wodgina. The greater part of the field is in the Yandeearra Aboriginal Reserve and non-aboriginals require a permit for entry.

In the past, water was obtained from wells sunk close to the various mines. Supplies were usually inadequate and future operators will probably have to locate water in the alluvium and jointed granite along the Turner River. For example, a well near the Mount Cassiterite mine provided only 5.5 m³ per day.

Tin ore was discovered at Wodgina in 1902, since when the field has yielded 478 t of tin concentrate, most of which has come from the Mount Cassiterite mine. Details of production are shown in Table 14. At

TABLE 14. PRODUCTION OF TIN CONCENTRATE FROM THE WODGINA TIN FIELD, 1902-1975.

Group	Tenement No.	Name of lease or operator	Period	Concentrate produced				Value ($ Aust)	Remarks
				Lode (t)	Stream (t)	Total (t)	Metal content (t)		
Wodgina	M.L.84	Mount Cassiterite	1904-1908	135.66	14.07	149.73	n.a.	28 368.00	Partly same ground
	M.L.84,93,148	Mount Cassiterite leases	1908-1918	198.63	1.63	200.26	n.a.	33 826.00	
	M.L.93	Mount Cassiterite North	1906-1907	9.82		9.82	n.a.	1 942.00	
	M.L.89	Tinstone	1906-1909	14.94		14.94	n.a.	2 780.00	Same ground
	M.L.255	Mount Tinstone	1913-1914	2.49		2.49	n.a.	560.00	
	M.C.109	McLeod, D.W.	1965-1967		4.00	4.00	2.15	5 757.13	Includes all above leases
	M.L.86,87,95	H.M.—Anchorite leases	1917		5.08	5.08	n.a.	1 000.00	
	M.L.195	Cassiterite No. 1	1912	0.36		0.36	n.a.	98.00	= M.L.94 Hazlewood
	M.L.85	Commonwealth	1906	3.00		3.00	n.a.	696.00	
	M.L.88	Chamberlain	1906	0.36		0.36	n.a.	120.00	
	Sundry claims		1903-1951	5.87	51.76	57.63	n.a.	11 633.84	May include production from other groups
West Wodgina	M.L.203	Wodgina Queen	1912-1913	1.63		1.63	n.a.	380.00	
	M.L.213	Referenda	1912	1.07		1.07	n.a.	294.00	
Stannum	M.L.77	Stannum	1902-1906	6.20		6.20	n.a.	922.00	Same ground
	M.L.198	Stannum	1912	0.91		0.91	n.a.	252.00	
	D.C.732	McLeod, D.W.	1968		3.99	3.99	2.46	5 955.31	
Mills Find	M.L.178	Siffleetes Reward	1910-1913	3.56		3.56	n.a.	712.00	
	Sundry claims	? Mills	1906		0.86	0.86	n.a.	138.00	
Mount Francisco	M.L.192	Comet	1912	0.30		0.30	n.a.	72.00	=Bright Star
	M.C.390	McPherson, N.E. & Fetwadjieffa	1957		0.13	0.13	n.a.	144.80	Probably Bright Star
	P.A.2751	McLeod, D. W.	1965		0.25	0.25	0.18	604.80	
	M.C.910	Crow, Yergarla	1967		5.76	5.76	3.08	7 874.00	Probably Francisco leases
	D.C.15 WP	McLeod, D. W.	1967		1.56	1.56	0.99	2 654.13	
	P.A.312,313 WP	Nomads Pty Ltd	1965		2.52	2.52	1.76	6 004.80	Near Francisco leases
	Crown Land	Sundry persons	1963-1964		1.60	1.60	0.84	1 828.20	
Total Wodgina Field				384.80	93.21	478.01		114 617.01	

n.a. not available
WP West Pilbara G.F. (all other tenements are in Pilbara G.F.)

one time the field was the World's main source of tantalite, total production being about 200 t of Ta-Nb concentrates. It also yielded 1 200 t of beryl, some of which was the caesium-bearing variety rosterite.

References

Maitland (1906) mapped the Wodgina and Stannum centres and described the mines operating at that time. Further descriptions of tin and tantalite deposits in the field were given by Mitchell (1905), Montgomery (1907), Cleland (1910a, b), Woodward (1910a), and Blatchford (1913). Finucane and Telford (1939) remapped the Wodgina centre in connection with a survey of the tantalite deposits. Further accounts of the tantalite occurrences are given by Miles and others (1945) and Ellis (1950). Simpson (1912, 1919, 1928) described the rare minerals found in the pegmatites of the field. Blockley (1971) presented a geological map of the field showing the positions of the various tin, tantalum and beryllium deposits (some of which had not previously been located accurately) and reported briefly on the geology and mineral resources of the district.

GEOLOGICAL INFORMATION

The rock assemblage making up the Wodgina and Mount Francisco ranges includes basalt, ferruginous chert, clastic sediments and acid and ultramafic sills metamorphosed to lower amphibolite facies (Blockley, 1971). These rocks are preserved as roof pendants along a synclinal keel within granitic rocks of the Yule Batholith (Hickman and Lipple, 1975). Those members of the Yule Batholith exposed near the tin field are an older migmatite and gneissic complex, a pluton of 'older' homogeneous porphyritic granite—the Kangan Adamellite, and an even-grained to porphyritic 'younger' granite — the Numbana Granite. Near its contact with the layered rocks, the Numbana Granite grades into marginal leucocratic phases which are either foliated or pegmatitic in texture. Prominent pegmatite veins, in most places closely associated with the marginal granite, cut the layered rocks and provide the source of the tin, tantalum and beryllium minerals mined in the field.

The main structural feature of the Wodgina field is a syncline trending north-northeast which passes through the middle of the Wodgina range and extends, with interruptions by granite intrusion, to Mount Francisco. A major north-northeasterly fault can be traced from Mount Francisco to Wodgina. The unusual outcrop pattern of the west limb of the syncline keel has not been resolved. It would be best explained by a large north-northeast fault between the straight throughgoing ridge of chert and the thinner cherts which appear to branch from it. However, no sign of such a fault was seen during the mapping. Hickman (1975b) interprets the outcrop pattern as being due to the refolding of D2 folds about a D3 syncline axis. Hillsides in the vicinity of Stannum, Mills Find and Mount Francisco show cross-sectional views of the granite/greenstone contacts. In several places, the roof pendants of greenstone can be seen sitting in granite which forms the lower part of the hill while the greenstone forms the crest. The leucocratic marginal phase of the Numbana Granite appears to form more or less flat sheets between the main phase and the intruded greenstones.

Younger rock units exposed in the field are duricrust, pisolitic limonite and ferruginous sandstone of Tertiary age, and Quaternary to Recent deposits of residual soil, outwash and alluvium. The residual soil and alluvium are thin throughout the field, and no large placer tin deposits have formed.

Granitic rocks

Migmatite and gneissic granite crop out on the western and southern sides of the Wodgina Range, and underlie much of the sand plain between Wodgina and the Yule River. The rocks range from well-banded migmatite to foliated granite. In many places they contain concordant bands of porphyritic granite with phenocrysts set parallel to the banding, and are cut by dykes of massive, even-grained granite. Concordant pegmatites are common in the more migmatitic parts.

The porphyritic Kangan Adamellite intrudes the migmatite complex with much interfingering at the contact. It occupies the southwestern part of the Wodgina tin field and extends considerably beyond it (Hickman and Lipple, 1975, Fig. 3). Its composition ranges from adamellite to granodiorite, and it is considered to be a member of the suite of granitic rocks intruded into, or mobilized from, the migmatite complex about 2 900 m.y. ago.

The present name has been modified from Kangan Granite (Hickman and Lipple, 1975, 1979) on the basis of additional petrography and chemistry.

The Numbana Granite crops out east of the Wodgina range, and extends south to enclose the eastern part of the Mount Francisco greenstone inlier, and continues southward to the Yule River. Its outcrop area as shown on Plates 1 and 5 differs from that figured by Hickman and Lipple (1975, Fig. 3). It is now considered, on the basis of petrography and chemistry, that the area of porphyritic adamellite distinguished by Hickman and Lipple, immediately east of the Wodgina range, is part of the Numbana Granite.

Texturally, the greater part of the Numbana Granite is even-grained or porphyritic, but adjacent to the greenstones leucocratic, foliated, and pegmatitic phases are developed. At its contact with the Kangan Adamellite, the Numbana Granite is typically finer grained.

Further details on the petrography and chemistry of the various granites are given in Chapter 5.

Pegmatites

The rare-metal pegmatites form clearly intrusive veins within the greenstones, or rarely, as at Numbana, in the granite. Most veins have a north-northeasterly strike, and a low dip angle, and cut the bedding of their host rocks. The greater number of pegmatites have irregular shapes and were probably intruded into tension gashes. However, some, like the Tantalite lode at Wodgina, follow well-defined faults.

The pegmatites consist mainly of inter-grown quartz and albite, but lenses or veins of blue quartz, pure albite, or quartz-albite-muscovite are common. Microcline, green muscovite, blue-green tourmaline, lepidolite and spessartine are other common constituents of the pegmatites. Some pegmatite veins have a more-or-less zonal arrangement of the mineral assemblages, but in others this is not so. Pegmatites made up of only one mineral phase also occur, consisting usually of either quartz-albite or blue quartz. Some of the tin-bearing pegmatites at Wodgina have a late-stage phase of blue tourmaline and mica which may occur along the edge of the veins, or as detached veins on parallel shears. Wall-rock alteration about pegmatites cutting basic and ultramafic rocks has produced selvedges of biotite which may also contain cassiterite.

WODGINA CENTRE

The Wodgina group of tin mines (Fig. 5) is centred 1.5 km south of the present settlement in the northern part of the field. It straddles a high ridge of chert and iron formation on the western limb of the main syncline, the topographic expression of which forms a natural amphitheatre.

The sedimentary rocks underlie amygdaloidal basalt to the west, and overlie a sill of ultramafic rock to the east. Granite intruding to the level of the ultramafic sill has given rise to a network of pegmatite veins which carry cassiterite, beryl, tantalite and lithium minerals. The tin ore is confined almost completely to those pegmatites intruding the chert and iron formation. The richest tin lodes are developed on steeply dipping pegmatite veins following east-striking faults and the better grade tin ore came from seams of tourmaline-mica lode formed on the walls of the pegmatites, or on parallel shears.

Most of the underground workings within the Wodgina group are now inaccessible, and with the exceptions noted, information on these is from Mitchell (1905), Maitland (1906), Montgomery (1907), Woodward (1910a), Blatchford (1913) and Cleland (1910a).

Geological maps of the area of the group accompany the reports of Maitland (1906) and Finucane and Telford (1939). Plans and sections of the Mount Cassiterite main lode appear in Woodward (1910a) and Blatchford (1913). Later details of the main lode as well as information on the middle lode are shown on Mines Department plans 1-3/296.

Mount Cassiterite mine

The largest underground tin mine worked in Western Australia is that on the former Mount Cassiterite lease (M.L.84). Tin was mined from four areas on the lease, known respectively as Phippards lode (or the main lode), the middle lode, the south lode, and the southeastern lode. The western part of the Phippards lode lies on former M.L.117 under which heading it was described by Maitland (1906). The lease was later repegged as M.L.148, and operated in conjunction with M.L.84.

Phippards lode crops out at the crest of the ridge and at intervals down the western side. The few exposures that remain are of blue-grey quartz or albite pegmatite, but formerly it contained segregations of mica, and was associated with cassiterite-rich veins of tourmaline-mica rock. A cross-section presented by Woodward (1910a) and reproduced in Figure 6 shows the lode material to follow, with some local divergence, the footwall side of a 'quartz-pegmatite' vein.

Blatchford (1913) saw the underground workings at a time when the mine had reached an advanced stage of development. He described the lode as: "a true fissure lode of the acid dyke variety. In appearance it varies from almost pure quartz to a mixture of feldspar and mica to nearly pure feldspar or mica. Tin oxide is found through the lode in varying proportions, and occurs both in the coarse and angular, and also, not uncommonly, in a very fine form throughout the rock mass. Taken as a whole, most of the mineral occurs, however, in the walls of the lode, and is rarely found evenly distributed right across a face".

He also noted: "Tin ore also occurs in bunches along either side of the lode preferably on the footwall. Some very large blocks of the pure oxide have been won from this source, reaching a weight, at times, of several hundredweight." Simpson (1948) recorded the presence of spodumene on the mine dumps, and notes that the tourmaline-mica rock contains pyrrhotite.

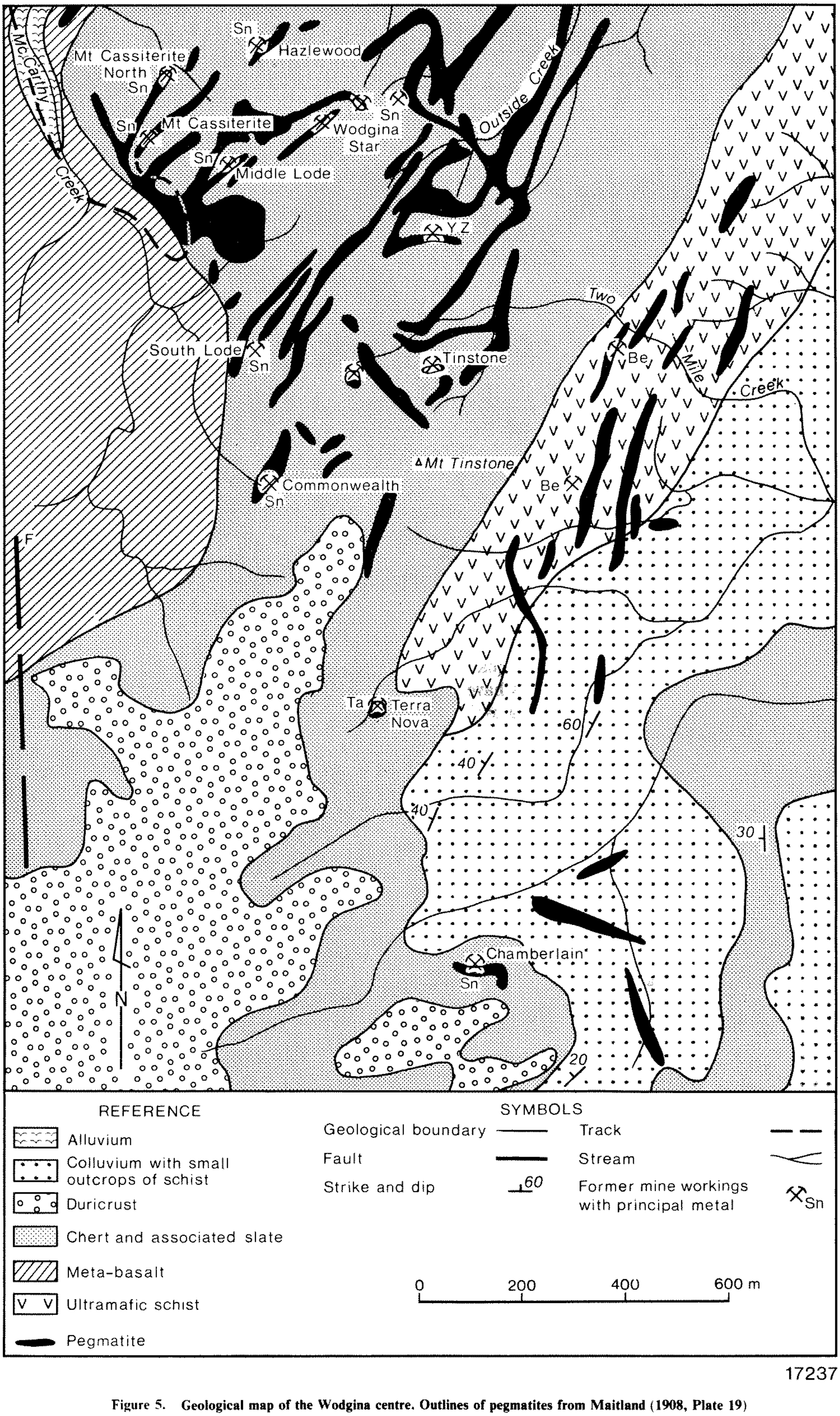


Figure 5. Geological map of the Wodgina centre. Outlines of pegmatites from Maitland (1908, Plate 19)

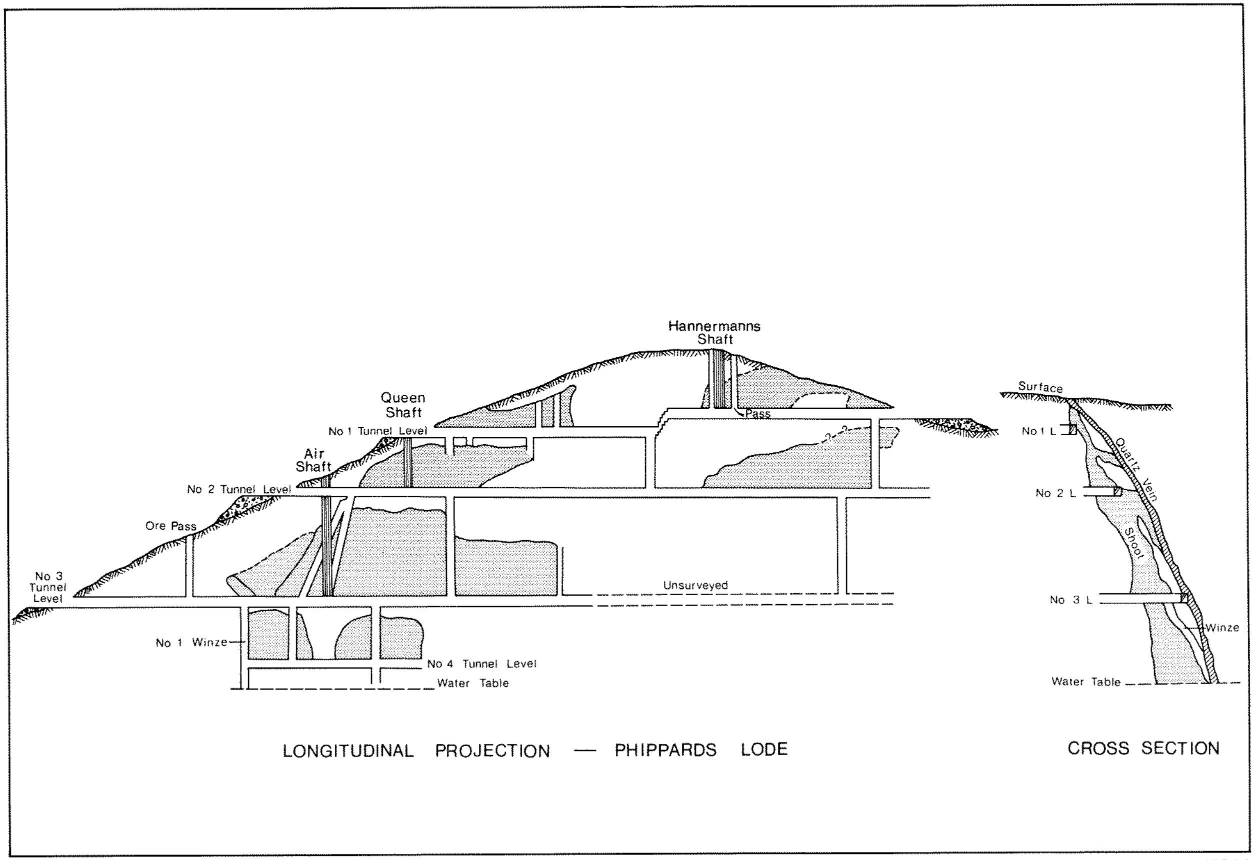


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Figure 6. Longitudinal projection and cross section of Phippards lode, Mount Cassiterite tin mine, Wodgina centre. Compiled from plans held by the Department of Mines

Mining was restricted to two irregular shoots (see Fig. 6). The first to be worked cropped out on the eastern slope of the ridge. It was stoped over lengths of up to 40 m down to the number 2 level, and was about 1.2 m wide. At the time of Woodward's inspection, a rich, west-pitching shoot no more than 12 m long had been mined from its outcrop on the western side of the ridge down to the No. 4 level. It was formed mainly on a branch vein, but good tin values extended into the principal lode near the junction. At some later time, the stopes were extended eastwards along Phippards lode for distances of up to 70 m. The lode in these stopes averaged 1.5 m in width, but reached 4.2 m on the No. 4 level.

Early mining of Phippards lode was from shallow open cuts and a main shaft (probably Hannermanns Shaft) 15 m deep sunk on the eastern shoot. Later mining was carried out more systematically from three tunnels driven into the western slope of the ridge at depths of 15 m, 32 m, and 55 m respectively below the collar of Hannermanns shaft, and from a drive (the No. 4 level) established from winzes sunk below the No. 3 tunnel (Fig. 6). It should be noted that while the No. 1 and No. 2 tunnels were driven into the outcrop of the lode, the No. 3 tunnel was put in through slate and chert until it intersected the lode at about 57 m from its portal. At present only the No. 3 tunnel is accessible, and this only as far as the air shaft in the main tunnel, and the first winze in the northern branch.

The middle lode workings are 150 m south of Hannermanns shaft. They follow two lodes which strike at about 090 degrees, and dip steeply south. They are similar in composition to the main lode.

The No. 1 middle lode is the more southerly of the two. It was mined from a tunnel and a drive 15 m below the tunnel. Between 15 and 60 m from the tunnel portal, the vein split into a cymoid loop, the northern branch of which was referred to as the north lode. The longitudinal projection on Mines Department plan 3/296 shows stopes extending over a distance of 40 m, but does not indicate which of the two branches was mined. Only part of the lode above the bottom level is shown as stoped.

The No. 2 middle lode was mined to a depth of 23 m from two tunnels and two shafts. The lower tunnel was connected to the treatment plant by a tramway and was apparently used as a haulage way. The shoot was stoped out over a maximum length of 30 m and to a depth of 23 m.

Near the southern edge of the former Mount Cassiterite lease, two open cuts and a shaft were put in on the south lode or manganese lode. In the more easterly cut, the pegmatite is about 1 m wide and has a vein of tourmaline on either wall. The other cut, about 30 m west of the first, is on a small, stepfaulted quartz vein about 60 cm wide. The tin occurs in a seam of mica-tourmaline lode along the hanging wall of the vein.

From the north end of the cut, a vertical shaft was sunk to a depth of 15 m, cutting at 10 m an irregular body of quartz with a seam of tin ore on its hanging wall. A drive 5 m long from the bottom of the shaft exposed no further ore.

About four tonnes of cassiterite are said to have been mined from the western open cut, and a further 100 kg from the lode exposed in the shaft (Mitchell, 1905).

The southeastern lode is about 150 m east-southeast of the middle lode. A tunnel driven into the ridge on a bearing of 025 degrees intersects an east-striking lode which is stoped either way from the tunnel. This lode is not mentioned in the earlier reports, and there is no information on its composition or grade.

An officer of the Bewick Moreing Co. sampled the main lode in 1905. The assay results are not now applicable to the evaluation of ore reserves, but do give an indication of the extreme variation of tin content found in the veins. For that reason, they are reproduced in Table 15.

Mount Cassiterite North

The workings on the Mount Cassiterite North lease (former M.L.93) were described by Maitland (1906) and Montgomery (1907) but were wrongly referred to as M.L.110. The two lodes worked are about 100 m north of Hannermanns shaft, cropping out near the head of May Gully.

The lodes strike east, dip southerly, and carry ore mainly in soft tourmaline-mica rock, although cassiterite is also present in quartz. The deepest opening is at Mays shaft, 18 m deep, sunk from a small knoll on top of the spur. A cross-cut from the shaft cut the more northerly of the two lodes. Short tunnels driven into the lodes from the northern and southern sides of the ridge are shown on Mines plan 1/296 but no further details are available.

Official returns show a production of only 9.78 tonnes from this mine, although Montgomery (1907) reported that about 20 tonnes had been obtained by hand picking. The ore was sent down to McCarthy Creek by means of a flying fox, and there puddled and washed. Between 1908 and 1918 the lease was worked in conjunction with the Mount Cassiterite mine, and any further production is included in the combined figures.

Hazlewood mine

The lode worked on the former Hazlewood lease (M.L.94) is on strike with the main lode of the Mount

TABLE 15. SAMPLING RESULTS FROM THE MOUNT CASSITERITE LEASE

Sample No.	Details	Width (cm)	Sn (%)
1	From open cut at east end of main lode 30 m east of Hannermanns shaft	71	Trace
2	From open cut at east end of main lode 30 m east of Hannermanns shaft	84	12.6
3	From open cut at east end of main lode 30 m east of Hannermanns shaft	61	Nil
4	From open cut at east end of main lode 30 m east of Hannermanns shaft	30	16.2
5	From open cut at east end of main lode 30 m east of Hannermanns shaft	91.5	17.2
6	From open cut at east end of main lode 30 m east of Hannermanns shaft	61	Nil
7	From open cut at east end of main lode 30 m east of Hannermanns shaft	86.5	Nil
8	From open cut at east end of main lode 30 m east of Hannermanns shaft	91.5	Trace
9	From open cut at east end of main lode 30 m east of Hannermanns shaft	91.5	16.1
10	From open cut at east end of main lode 30 m east of Hannermanns shaft	76	Nil
11	From open cut at east end of main lode 30 m east of Hannermanns shaft	79	Nil
12	From open cut at east end of main lode 30 m east of Hannermanns shaft	43	Nil
13	From open cut at east end of main lode 30 m east of Hannermanns shaft	51	Trace
14	From open cut at east end of main lode 30 m east of Hannermanns shaft	61	Nil
15	From vein in cross cut north from 15 m level of Hannermanns shaft	104	Nil
16	From vein in cross cut north from 15 m level of Hannermanns shaft	104	Nil
17	From vein in cross cut north from 15 m level of Hannermanns shaft	122	Trace
18	From vein in cross cut north from 15 m level of Hannermanns shaft	153	Nil
19	Quartz vein in open cut adjoining Hannermanns shaft	91.5	Trace
20	Quartz vein in open cut adjoining Hannermanns shaft	153	Nil
21	Schist band in above cut	122	Nil
22	Schist band in above cut	122	Nil
23	Schist band in above cut	122	Nil
24	Schist band in above cut	122	Nil
25	Outcrop between Hannermanns shaft and eastern cut	153	Nil
26	Outcrop between Hannermanns shaft and eastern cut	122	Nil
27	Pegmatite and tourmaline from more easterly cut on western ore shoot, main lode	152	Nil
28	Pegmatite and tourmaline from more easterly cut on western ore shoot, main lode	152	Nil
29	Pegmatite and tourmaline from more easterly cut on western ore shoot, main lode	122	Nil
30	Pegmatite and tourmaline from more easterly cut on western ore shoot, main lode	152	Nil
31	Pegmatite and tourmaline from more easterly cut on western ore shoot, main lode	147	Nil
32	Pegmatite in more westerly cut on western shoot main lode, said to have yielded several hundred kg of tin ore	61	Nil
33	Pegmatite in more westerly cut on western shoot main lode, said to have yielded several hundred kg of tin ore	71	Trace
34	Pegmatite in more westerly cut on western shoot main lode, said to have yielded several hundred kg of tin ore	61	Nil
35	Tourmaline vein—east cut on south lode	15	Nil
36	Tourmaline vein—east cut on south lode	10	6.0
37	Tourmaline vein—east cut on south lode	7.5	5.8
38	Pegmatite—east cut on south lode	91.5	Nil
39	Tourmaline vein—east cut on south lode	15	2.9
40	Ironstone, said to contain tin	—	Nil
41	Quartz vein—west cut on south lode	61	1.8
42	Quartz vein—west cut on south lode	27	Trace
43	Quartz vein—west cut on south lode	76	Nil
44	Quartz vein—west cut on south lode	61	Trace
45	Quartz vein—west cut on south lode	61	3.2
46	Quartz vein—west cut on south lode	61	8.6

Sampled by Bewick, Moreing & Co., 1905.

Cassiterite mine, and about 250 m west of Hannermanns shaft.

The principal opening is a tunnel driven on a well-defined lode which dips steeply north, is at least 1 m wide, and was described by Maitland (1906) as micaceous and kaolinitic. The footwall of the lode is a slickensided fault plane.

Production from the Hazlewood lease is not recorded.

Tinstone mine

About 500 m southeast of the Mount Cassiterite mine, a pegmatite cropping out on a spur near the head of Two Mile Creek was taken up as the Tinstone lease and worked between 1906 and 1909 to yield 14.9 tonnes of tin concentrate. The surrounding country is rugged, and access is by foot only.

In the main group of workings, two intersecting veins were mined. The principal vein strikes at 220 degrees and dips at 60 degrees southeast, ranging from 30 to 60 cm wide. It consists of pegmatite bordered by tourmaline-mica rock. It was stoped over a length of 20 m to a vertical depth of 15 m from a tunnel driven into its outcrop. The second vein strikes at 140 degrees and dips 40 degrees south. A tunnel driven along it intersects the stope on the first vein, but the only other mining done on it was a little stoping, one surface rise and a winze.

A further 50 m southwest a small open cut exposes a pegmatite 60 cm thick, with cassiterite in a vein of tourmaline-mica rock on the footwall side. The vein dips at 40° northwest.

About 180 m west-northwest of the mine, another line of pits follows a pegmatite down a steep gully leading into Two Mile Creek.

Lepidolite is present in the dumps and face of the main tunnel on the lease and in at least one other vein.

Wodgina Star mine

On strike with, and about 300 m east of, the middle lode on the former Mount Cassiterite lease, a thin, weathered pegmatite was worked from a 6 m deep shaft and one or two pits. These were the workings described on the Wodgina Star lease by Maitland (1906). A further 120 m southeast, at the head of a neighbouring gully, a short tunnel has been driven on another vein.

Commonwealth mine

When examined by Maitland (1906) the only opening on the Commonwealth lease was a cut 7.5 m long on a pegmatite vein 1.8 m thick. The best tin ore came from a vein of tourmaline-mica lode 30 to 60 cm wide on the footwall of the vein.

Since that time, a tunnel has been driven into the hill beneath the outcrop of the vein, but no other details are known.

Y.Z. prospect

On the former Wodgina Y.Z. lease, (M.C. 90), cassiterite occurs throughout a 60 cm wide kaolinized pegmatite. The vein strikes northwest and dips at 5 to 10 degrees southwest, cropping out on a spur overlooking Outside Creek.

The vein was worked from a number of pits and one tunnel 10 m long, but no production is recorded.

Chamberlain mine

The mine called "Nielson" by Maitland (1906) and "Chamberlain" by the original claimant, is 1.8 km south of Mount Cassiterite and is reached by a track leading southwards along the eastern edge of the Wodgina range. It is about 60 m above plain level, a little below the duricrust cap of a steep spur.

The lode approximately follows the contour of the spur for a distance of 55 m. It dips at about 5 degrees east, where worked, but steepens to the south, and is displaced by small faults. It consists of a narrow (15-30 cm) band of yellow clay and tourmaline formed on a fracture more or less parallel to, and 1.2 to 3 m below, a flat-lying quartz vein.

The lode was mined from several tunnels driven into the hillside. The longest tunnel which is still accessible extends for 32 m directly into the hill on a bearing of 175°. Within that distance, the lode is cut by two faults, and towards the end of the tunnel, reverses in dip and rises above the back of the tunnel.

A second tunnel, driven from a point a few metres west of the first, extends for 24 m on a bearing of 235 degrees, running at an acute angle to the face of the hill. It connects to another short tunnel driven in from a point about 25 m further west along the outcrop, and leads to a small stope.

A further 30 m westerly along the outcrop there are the remains of another tunnel leading to collapsed stopes. On the northern slope of the spur, about 30 m below the level of the workings, there is another collapsed tunnel. No pegmatite was noted in its dumps and its purpose is obscure. It may represent an unsuccessful, and geologically unsound, attempt to intersect the lode at depth.

Assay results from samples of lode material are included in Table 16.

Alluvial diggings

The beds of all the narrow gullies draining the Wodgina group were worked by hand methods for alluvial cassiterite.

Alluvial deposits referred to in earlier reports occur in Ogilvies Gully, May Gully, Two Mile Creek, and Outside Creek. McCarthy Creek has been worked for tin and tantalite near the point where it crosses the Tantalite lode. The distribution of alluvial deposits is shown on Figure 5.

Some of the cassiterite obtained from the alluvium was very coarse. Simpson (1948) recorded pieces weighing 12.7, 19.5, 30.0 and 36.3 kg obtained from Ogilvies Gully.

H.M.-Anchorite leases

The well-known tantalite-bearing pegmatite worked on the H.M. and Anchorite leases contains no recorded cassiterite. However, a nearby parallel vein, striking 360 degrees and dipping 50 degrees east, was

TABLE 16. SAMPLING RESULTS FROM THE WODGINA TIN FIELD

Sample No.	Location	Description	Sample interval (cm)	Assayed concentrate as percentage of sample	% Sn in conc.	% SnO_2 in sample
16411	Chamberlain, 9 m up No. 1 tunnel	Tourmaline lode		100	(a)	(a)
16412	Chamberlain, 24 m up No. 1 tunnel	Tourmaline lode	30	100	(a)	(a)
16413	Chamberlain, 29 m up No. 1 tunnel	Tourmaline lode		100	(a)	(a)
16414	Chamberlain, 15 m along No. 2 tunnel	Tourmaline lode	45	100	(a)	(a)
16415	Chamberlain, 26 m along No. 2 tunnel	Tourmaline lode	23	100	0.03	0.03
16416	Chamberlain, above portal No. 3 tunnel	Tourmaline lode	30	100	0.03	0.03
16441	Costean in Eastern Creek, 800 m north of Stannum mine	Alluvium	100	2(b)	0.04	(a)
16459	Bright Star, dump of central shaft	Pegmatite	Grab	2.47	69.3	2.17
16460	Bright Star, chip sample, central shaft	Pegmatite	60	.84	55.4	.58
16461	Bright Star, chip sample, south shaft	Pegmatite	53	1.34	57.4	.98
16462	Siffleetes Reward, chip sample	Pegmatite	60	1.64	.78	.003
16463	Siffleetes Reward, dump of small trench	Pegmatite	Grab	1.48	33.8	.64
16464	Siffleetes Reward, large pegmatite below workings	Pegmatite	Random chip	.43	.51	.003
16465*	Stannum mine, 100m south of main shaft	Lithium pegmatite	120	.23	36.4	.106
16473				2.3(b)	.02	(a)

(a) Less than 0.001%
(b) Approximate only
* Also 1.62% Li_2O

reported to contain tin oxide. The vein was trenched over a distance of 35 m, and is 1.4 m wide in the northern face. It also contains zinnwaldite.

WEST WODGINA GROUP

Seven small tin deposits at West Wodgina on the western side of the Wodgina range were located and examined during this survey. Only three, the Referenda, Wodgina Queen and Wodgina Prince could be related with any certainty to their former unsurveyed mineral leases. The others have been numbered 1 to 4 for convenience of description (see Plate 5). Production recorded from the group amounts to only 2.7 tonnes of tin concentrate but some production mentioned by Blatchford is not listed in the official figures. The only previous description of the West Wodgina group is given by Blatchford (1913).

Access to the group was formerly by a bridle track from Wodgina through a steep-sided gorge. This track is unsuitable for motor vehicles and the best present route to the mines is across country from the track leading to Stannum.

The tin lodes of the West Wodgina group are simple or zoned pegmatites containing cassiterite, lepidolite, garnet and some tourmaline. Five of the deposits lie in a band of amphibole schist, another occurs west of this band in massive ultramafic rock, and the last is in siliceous sediments east of the schist band.

Wodgina Queen mine

The Wodgina Queen (former M.L.203) mine was described by Blatchford (1913) as "Wilson, Houston, and Oswalds lease". A pegmatite consisting largely of blue-grey quartz with cassiterite and lepidolite was worked. Cassiterite is distributed throughout the vein but is most abundant on the footwall side. The principal opening on the vein is a shaft at least 3 m deep and a partly filled stope or open cut. The vein is 1 m wide at the surface but bulges to 8 m in the cut. About 15 m south of the shaft is a trench 6 m long and about 2.5 m deep on a similar pegmatite. The mine has a recorded production of 1.63 tonnes of tin concentrate. One crushing of 20.3 tonnes averaged 4.5 per cent tin oxide.

Wodgina Prince mine

The mine, believed to be Blatchford's "Raney and Halls Lease" and called by those operators the Wodgina Prince (former.M.L. 222), is about 600 m south of the No. 4 prospect. The lode crops out about one third of the way up the west side of a duricrust-capped chert ridge and may be a southern continuation of the vein worked in the No. 1 prospect. No official production figures are available, although Blatchford records that 20.3 tonnes of ore gave a return of 1.5 per cent tin oxide.

Where mined, the vein is 1.5 to 1.8 m thick, dipping flatly to the west. It consists of albite and blue quartz with sticks of lepidolite and crystals of cassiterite. The wall rock is amphibole schist. The principal opening in the vein is a cut 3 m deep.

Referenda mine

The Referenda mine (former M.L. 213) is the most southerly of the West Wodgina group. Official records show its production as 1.07 tonnes of tin concentrate although Blatchford (1913) noted that at least eight tonnes had been produced up to the time of his inspection. Early production on the lease was from a small south-westerly flowing gully worked along its course for 200 or 300 m. Later the source of the cassiterite was traced to a pegmatite vein striking north-west and dipping easterly in amphibole schist. The vein was trenched over a distance of 45 m and in one place an underlay shaft was sunk to a depth of 5 m. The vein averages 60 to 90 cm in width but reaches 1.8 m at the northern end of the workings. The dip varies from 75 to 45 degrees east. The distribution of cassiterite in the lode is erratic. At the north end it is in the footwall, but elsewhere appears to be within the pegmatite. A vein of tourmaline rock occurs immediately west of the lode.

No. 1 prospect

The most northerly prospect of the group is located on the west side of the main chert ridge. It is probably the deposit that Blatchford referred to as Jenning and Childs lease, but identification is uncertain. Workings on the lease comprise two cuts 45 m apart in a pegmatite vein striking at 025 degrees and dipping east. This vein can be traced for about 900 m southerly, and in the vicinity of the prospect intrudes ultramafic schists, although in general it cuts metasediments. In the northernmost cut the vein is 1.8 m thick and dips 40 degrees east. It has a quartz core with micaceous margins. Some sections have a liberal sprinkling of cassiterite associated with tourmaline. Where exposed in the southern cut the pegmatite dips at 75 degrees east and is only 40 cm wide.

No. 2 prospect

The No. 2 prospect lies about 300 m west of the main line of workings. It comprises one pit 1.5 m deep and other shallow trenches on west-dipping lenses of pegmatite cutting ultramafic schists. The veins are made up of albite, blue quartz, muscovite and scattered cassiterite.

No. 3 prospect

About 260 m south of the Wodgina Queen on the same line are two shallow pits on a flat-lying pegmatite. The vein here consists mainly of blue quartz and intrudes basic schist with thin chert beds. The No. 3 prospect may be identical to the Carbine Extended No. 1 lease (M.L.202) described by Blatchford.

No. 4 prospect

A further 160 m south along the main line of workings are four shallow pits spread over 30 m in a narrow pegmatite. The vein contains lepidolite as well as cassiterite.

Carbine lease

The lode worked on the Carbine lease (former M.L.190) was not identified during this survey. Blatchford (1913, p.70) described it as follows: "The lode opened out on this lease is probably a parallel lode to that on the Carbine Extended or possibly the same faulted to the westward. As in the Carbine Extended sufficient work has not been done to even ascertain the true dip, strike, or width, of the lode. Some rather nice ore, however, has been raised, three tons of the same being on the surface ready for treatment."

STANNUM GROUP

The Stannum or Eastern Creek group of tin mines is centred about 8 km southwest of Wodgina within the greenstone range although some maps show it farther southwest in the granite. The mines are reached by a motor track running parallel to the west side of the range with a branch leading to the Stannum mine. The group consists of the Stannum, Stannum North, Comet and some unnamed workings in or near M.C.213 and D.C.732.

Previous reports on one or more of the three principal mines appear in Maitland (1906), Montgomery (1907), and Blatchford (1913). Maitland included a geological map in his report.

Total production recorded from the group amounts to 11.1 tonnes of tin concentrate, but the actual amount was probably greater, much of it being concealed in the returns from Wodgina.

Stannum mine

The Stannum mine (former M.L.77) pegged originally by McCarthy and Ogilvie in 1902 appears to have been the first tin deposit found in the Wodgina field. It is situated near the head of a small watercourse (Eastern Creek) which emerges from the range 6.5 km south-southwest of West Wodgina and is reached by following an indistinct track upstream along the creek. The mine is located near the axis of the main syncline in an area of well-exposed metabasalt. A felsite sill intruded along the contact of the metabasalt and overlying chert thickens locally near the mine.

The tin-bearing pegmatite worked in the mine can be traced for about 1 km. The workings are located about midway along it at a point where its strike changes from north to northeast. Two branch veins developed at this point carry the best tin ore. Cassiterite forms up to 5 per cent of many specimens on the dumps and is accompanied by columbite, lepidolite, blue tourmaline and topaz. Work done since Maitland's inspection consists mainly of picking over the dump. As a result the old diggings are partly obscured and the following description is taken mainly from Maitland (1906).

The northern branch vein was followed down its 35 degree southerly dip for a distance of from 4.5 to 6 m in which it averaged about 60 cm in width. It extends around the hillside to a point about 5 m from the main shaft (now inaccessible), in which it was reputedly intersected at a depth of 5.5 m.

The southern branch vein was trenched to about 1.5 m depth along its outcrop. It dips about 6 degrees south and is 30 cm wide. Some work has also been done on the main vein close to the two branches and in other places along its strike. It carries lepidolite (in places finely disseminated in quartz) over a considerable distance. One sample collected 300 m south of the mine assayed 1.62 per cent LiO_2 over 1.2 m horizontal width. The vein here dips 50 degrees east. The alluvial flat north of the pegmatite was stripped to a depth of 1 to 1.2 m and several tonnes of coarse angular cassiterite obtained.

Stannum North prospect

The small prospect known as the Stannum North (former M.L. 79) is about 500 m northwest of the Stannum mine, near the head of a steep gully draining from the prominent chert ridge that is one of the main features of the Wodgina range. Cassiterite and lepidolite occur in a pegmatite vein which strikes easterly, dips 15 degrees south and can be traced for about 160 m around the contour of the hill. The vein cuts metabasalt, the margin being marked by a narrow selvedge of biotite. It was worked from a few shallow cuts and a tunnel which followed the vein down dip for 10 m. In the tunnel the vein is 1.2 m thick near the portal, narrowing to 30 cm at the face. The narrow gully draining the prospect was also worked for alluvial cassiterite.

Comet mine

The most northerly and least accessible prospect of the Stannum Group was called the Comet. It lies near the head of the next large creek north of Eastern Creek and is separated from the other mines of the group by a high ridge of chert. The mine is located on the northern slope of a steep valley which connects to the open country west of the range only through a narrow rocky gorge. The floor and lower slopes of the valley are underlain by schistose ultramafic rock and the ridges on either side of the valley by chert and iron formation. A number of faults cut through the valley, one of them being followed by the gorge outlet.

Tin ore was mined mainly from a tunnel on a lepidolite-bearing pegmatite vein 60 to 90 cm wide. The tunnel is now inaccessible but was described by Maitland (1906) as being 15 m long and driven on a bearing of 045 degrees. At about 7.5 m from its portal it entered vertically dipping chert beds and the pegmatite vein cut out. Maitland interpreted the contact as a fault. About 50 m northwest of the tunnel is a pit and a shallow shaft with some cassiterite-bearing pegmatite on the dump.

Mineral Claim 213

About 3.5 km west of the Stannum mine on the western side of the principal ridge, several shallow gullies on M.C. 213 were worked for tin and tantalum minerals. The gullies drain a number of pegmatite veins intruded near the contact of metasediments and ultramafic schist. Apart from one vein worked for beryl near the southeastern corner of the claim, no primary deposits were mined on the tenement. Production of tin concentrate from the claim is not recorded, but is probably small.

Dredging Claim 732

The small gullies worked for tin and tantalite on M.C.213 coalesce to form a larger creek which, immediately southwest of that claim, is covered by D.C.732. This watercourse was mined by hand methods over a distance of about 400m to produce 4 tonnes of tin concentrate and 2.8 tonnes of tantalite.

Other deposits

The ultramafic sill immediately east of M.C.213 is intruded in several places by irregularly shaped pegmatite veins. At one locality 250m northeast of M.C.213 a flat-lying pegmatite was worked in two places about 150m apart for cassiterite and tantalite. The vein also contained zinnwaldite and a radioactive mineral of the thorogummite type. Alluvium in small gullies draining this vein was treated to recover tin and tantalite concentrates, but no record of production exists.

MILLS FIND DEPOSITS

The area referred to as Mills Find* by Simpson (1948) is located about 3km southwest of the Stannum mine on the western side of a dome-shaped hill called Round Hummock (Plate 5). The area is underlain by amphibole schist which is intruded by foliated granite and many pegmatites. The production shown on Table 14 is probably understated; Blatchford (1913) recorded that 11 tonnes of tin concentrate had been produced prior to 1912 from Siffleetes Reward. Previous reports on the centre were made by Blatchford (1913) and Simpson (1928).

Siffleetes Reward

The diggings on former M.L. 178 (Siffleetes Reward) are located 400m north-northwest of the cairn on Round Hummock. They comprise shallow pits and trenches on five parallel northeast-striking pegmatite veins spaced over a lateral distance of 30m and in places connected by cross veins. The greatest distance over which any single vein was mined was about 20m and no openings deeper than 1.5m were seen. Cassiterite is abundant in some parts of the pegmatite, being concentrated particularly where veins terminate in horse-tail structures or where they contain inclusions of mafic country rock.

The grade of these concentrations is quite high. One parcel of 20 tonnes of ore treated at the Mount Cassiterite battery yielded about 0.7 tonnes of tin concentrate, a grade of about 3.5 per cent tin oxide. Results for other samples are shown in Table 16. A large flat-lying pegmatite below the lode workings was sampled but contains only traces of cassiterite.

The shallow soil scree and alluvium on the lease has also been treated for cassiterite and probably most of the discrepancy between the 11 tonnes reported by Blatchford and the 4.4 tonnes in Table 14 consists of secondary tin ore won by Siffleete. More recently, Aboriginals under the direction of Mr D. MacLeod have reworked the ground.

Other deposits

About 250m north of Siffleetes Reward another pegmatite vein containing cassiterite was tested by shallow pits over a distance of 15m and a creek bed downslope from the outcrop has been worked for alluvial ore. A beryl-bearing pegmatite 600m south of Siffleetes Reward appears to contain no cassiterite.

*Note however that Simpson and Gibson (1907) place Mills Find in the vicinity of the Bright Star mine near Mount Francisco.

MOUNT FRANCISCO GROUP

Mount Francisco is the highest part of a range of greenstone hills extending from 19 to 25 km south-southwest of Wodgina. The range can be reached from Wodgina by rough tracks along either side of the Wodgina range (Plate 5) or by an old track from Yandeearra Station homestead. Water is available in two wells sunk near the southwestern end of the range.

The Mount Francisco range is made up largely of ultramafic rock, which, together with lesser amounts of metasediment, metabasalt, and amphibolite schist, forms a roof pendant in the Numbana Granite. The metamorphic rocks are intruded by many pegmatites carrying minerals of beryllium, tantalum, niobium and tin.

Tenement locations

None of the few leases surveyed at Mount Francisco feature in the production tables, and in general it is difficult to relate the workings seen on the ground to their former tenements. The Bright Star mine can be identified from Blatchford's (1913) description, although it is about 1 km from the plotted position of the original mineral lease. Another mine which falls within M.L.299 is assumed to be the Francisco. Dredging Claim 15WP was found several kilometres from its reported position by the chance discovery of its datum peg. The Edie Emma mine described by Blatchford was not identified in the present survey. Several of the unsurveyed tenements which yielded tin ore during the 1960s probably correspond to former surveyed M.L.s but precise identification is uncertain.

Bright Star mine

The tin deposit originally pegged as the Bright Star (M.L.125) and later as the Comet (ML.188,192), the Southern Cross (M.L.265) and the Valieare (M.L. 306) is probably the same ground subsequently worked as P.A.2751 and M.C.390. It is situated near the northern end of the Mount Francisco range, about 4.1 km on a bearing of 030 degrees from Trigonometrical Station B10.

Cassiterite was mined from three shoots forming part of a network of pegmatite veins cutting ultramafic schist. The principal pegmatites were intruded along the cleavage direction of the schist, striking at 065 degrees and dipping 60 degrees northwest. Granite crops out a short distance east of the mine and appears as small stocks within the schist. It probably forms a floor to the schist a short distance below the present surface.

Three shallow shafts were sunk on the deposit, two on parts of a pegmatite stockwork and a third on a separate lens. The pegmatite in the most northerly shaft is low grade and pinches out 1.2 m below the surface. The central shaft, 15 m southwest of the first, is sunk on a vein 1.2 m wide at the surface, but which splits into two branches below the surface. Rich tin ore is present on the inner part of each branch below the split, being disseminated over 60 cm in the west wall of the east branch and 25-30 cm in the east side of the western branch. Beneath the junction of the veins the shaft follows the western, more flatly dipping, branch. At present the lower part of the shaft is filled, but Blatchford (1913) described it as 6 m deep with a cross cut from the bottom drive a few feet into the main dyke.

The third shaft is 30 m southwest of the central shaft. It follows a northeasterly-striking vein for about 7.5 m down dip at an angle of 45 degrees. At the surface, the vein consists of two branches which join at depth. According to Blatchford, a short drive extends northwards from the bottom of the shaft. The collar of the shaft is at the foot of a low scarp formed by the outcrop of yet another branch of the same vein. This was tested by a short tunnel driven through into the schist on the northwest side. Cassiterite is liberally disseminated in all parts of the vein, being richest in the branch followed in the shaft. Assays of three samples from the Bright Star mine given in Table 16 represent some of the richer material in the deposit. Much of the pegmatite between the ore shoots is almost barren of tin.

Francisco leases

Surveyed M.Ls 299 and 309 respectively named Francisco and Francisco South are located on the highest ridge of the Mount Francisco range about 500 m west of Trig. B10. The ground is now in M.C.910 which covers a number of pegmatite outcrops mined for beryl, tantalite and, in one place, cassiterite. Small steep gullies draining the ridge were also mined for secondary tantalite and cassiterite and probably yielded most of the production of these minerals recorded from the vicinity of the Francisco prospect. The principal beryl and tantalite workings are on thick, flat-lying veins which extend for a considerable distance around the contours of the hill and reappear in other nearby gullies. The only significant concentration of tin ore seen was in a narrow vein striking northeast and dipping 50 degrees southeast. Cassiterite in the vein is associated with abundant black tourmaline. Further northeast along the lode the pegmatite is rich in lepidolite. Workings on the vein comprise shallow shafts and a few pits.

Edie Emma lease

The Edie Emma lease (former M.L.174) was not relocated during this survey. Blatchford (1913) described it as 3 miles (5 km) west of the Bright Star at the end of the range. However, this direction should probably be southwest to allow the deposit to fall within the range. Blatchford described limited mining operations on a group of three pegmatite dykes. The main pegmatite strikes northeast and is intersected near the workings by another striking north 15 degrees east. About 45 m from this intersection a cross vein connects the two to form the letter A. Of these the most important tin-bearer is the first. It has a thickness of about 2.4 m where exposed and dips at a low angle to the east. Coarse tin is found on the footwall side of the lode over a width of 30-45 cm. The lode is a pegmatite dyke containing coarse feldspar and quartz with a fair percentage of lepidolite. The second dyke is a large pegmatite traceable on the surface for some distance. At the time of Blatchford's inspection it had not been tested. Coarse cassiterite was also noted in the cross dyke but the vein was a "few inches" wide and had no great length.

Dredging Claim 15WP

D.C.15WP covers a north-flowing gully 2 km northeast of Trig. B10. It yielded 1.56 tonnes of tin concentrate from scattered alluvial diggings along the main creek and an east-flowing tributary. The source of the tin ore was apparently a pegmatite cropping out on a spur between the two tin-bearing branches.

Hooley's find

Simpson (1928) described a deposit of detrital cassiterite found by G. J. Hooley, 8 km south of Mount Francisco Well. Later (Simpson, 1948) he modified the location to 6.4 km south-southeast of the well. A search was made of this general area during the present survey, but Hooley's find was not located. Possibly it corresponds to M.C. 307, 3.3 km southeast of Trig. B10.

According to Simpson (1928) the tin ore followed the barely discernible outcrop of two east-striking pegmatite veins cropping out in flat granitic terrain. It consisted of gravelly and clayey soil in which good prospects (30-90 g from 4.5 kg) were obtained at intervals along "several chains length (40-80 m) of each outcrop."

COONDINA DEPOSITS

GENERAL INFORMATION

The date and circumstance of the first discovery of tin ore at Coondina are not recorded. The first mining tenements approved in the area were pegged in 1964, although field notes made by Mines Department geologists engaged in a regional survey in the late 1950's refer to "old" tin workings attributed to Aboriginals. The early tenements were allowed to lapse but the same ground was later re-pegged as D.Cs 281 to 285 and mined by J. A. Johnston and Sons from 1965 to 1968 to produce 51.86 tonnes of tin concentrate from a plant erected on M.C. 768. These deposits, which consisted of shallow alluvium in the beds of small present-day creeks, were soon exhausted, and early in 1968 the field was abandoned except for a few Aboriginals. Towards the end of 1968 one of the Aboriginals Mr S. Moonding discovered a new deposit of cassiterite while hunting kangaroos. He opened up an extremely rich lead in cemented alluvium within a largely concealed Tertiary drainage channel and started a minor rush to peg ground in the area. The most successful claim stakers were J. A. Johnston and Sons Pty Ltd who secured the greater part of the extension of the deposit outside the four small Prospecting Areas taken up by Aboriginals. This company recommenced production from Coondina in 1971, treating the ore at its old plant on M.C. 768. To the end of 1975 total production from the Coondina field amounted to 613.36 tonnes of tin concentrate (Table 17).

Coondina is situated about 18 km south of Hillside Station homestead on the east bank of the Shaw River. It is most easily reached by way of a graded track branching southwards 10 km from Hillside on the Nullagine Road.

TABLE 17. PRODUCTION OF TIN CONCENTRATE FROM COONDINA, 1965-1975

Tenement	Operator	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)	Remarks
D.C.281 etc.	J. A. Johnston & Sons Pty Ltd	1965-1967	51.86	35.30	105 107.68	From Recent alluvium
D.C.281 etc.	J. A. Johnston & Sons Pty Ltd	1971-1972	232.51	167.06	485 410.00	From cemented alluvium
M.C.1457	McLeod, D. W.	1970-1972	34.54	24.90	72 066.22	
M.C.5433	McLeod, D. W.	1973	2.68	1.88	5 681.00	
MC.2158	Westos Minerals Pty Ltd	1970-1971	25.34	18.54	54 052.00	
M.C.1348, 1349	J. A. Johnston & Sons Pty Ltd	'1973-1975	226.60	155.73	656 434.77	
P.A.2893	Moonding, S.	1970	15.89	11.19	33 738.48	
Crown Lands	Various	1970-1971	23.94	17.51	59 147.55	
Total			613.36	432.11	1 471 637.70	

Water for treating the ore is obtained from bores sunk in alluvium and weathered gneissic granite on the flood plain of the Shaw River; supplies so far have proved adequate. There are no published reports on the Coondina tin field. Some unpublished data taken from a report by J. Linden for J. A. Johnston and Sons Pty Ltd are used in the following description.

GEOLOGICAL INFORMATION

The Coondina centre lies within the Shaw Batholith. The greater part of it is underlain by gneissic granite and migmatite of the older granite complex, but a small stock of younger granite (the Coondina Adamellite) crops out 2.5 km southeast of the deposits. Similar granite also occurs 3 km southwest of the workings (Figure 7).

The cassiterite has its source in a number of flatly dipping veins of aplite-pegmatite of similar type to those found at Moolyella and Shaw River. These veins are most abundant and richest in tin in the vicinity of M.C. 768.

Superficial deposits comprise shallow eluvium, loose and clay-bound Recent alluvium in the beds of small creeks, more extensive deposits of alluvium on the Shaw River flood plain, dissected low mesas of unconsolidated Pleistocene river gravel and remnants of cemented Tertiary alluvium following old, now partly eroded, stream channels. Most tin production has come from the second and last of the above-mentioned deposits.

RECENT DEPOSITS

Practically all of the tin concentrate produced from 1965 to 1968 came from shallow alluvial deposits on D.Cs 281, 282 and 285, each following small, first or second order tributaries of the Shaw River. Tin-bearing gravels are restricted to the upper parts of the streams which flow over remnants of the Yule Surface. Rejuvenation of the drainage has stripped any deposits formerly laid down in the lower parts of the creeks.

Dredging Claims 281 and 282

These D.Cs cover two branches of a creek flowing north-northwesterly from the area of tin-bearing pegmatites near M.C. 768. They were mined with the aid of machinery to widths of 20 to 30 m and depths of 1.0 to 1.5 m, over distances of about 1 km and 1.2 km respectively.

Dredging Claim 285

The shallow gully on D.C. 285 is a branch of a north-flowing creek which meets the Shaw River near Coondina Pool. It was mined by machinery over a distance of 1.2 km to widths ranging from 5 m near its head to 60 m at its junction. The workings continue along the main creek for a further 300 m. Unmined sections of alluvium near the head of the creek consist of coarse clay-bound gravel. Concentrations of magnetite and cassiterite are common in the mined-out bed of the creek.

TERTIARY DEPOSITS

Johnston's mine

The more recent operations at Coondina were concentrated on tin-bearing deposits of clay and carbonate-cemented alluvium following a now abandoned stream channel running approximately parallel to the Shaw River. The northern end of the deposit is on M.Cs 2158 and 3453 (formerly 1457) from where it extends southwards through M.Cs 3457, 5433, 1348, 1349 to M.Cs 3501 and 5186. The total length of the deposit is 2 km and its width normally ranges from 45 to 75 m. It has a maximum thickness of 4.3 m. A typical section is shown in Figure 8A.

The richest tin ore occurs in the lowermost few centimetres of the deposit which usually consist of well-cemented (or even silicified) grit and gravel containing in places up to 20 or 30 per cent by volume of cassiterite (Figure 8B). This is overlain by more poorly cemented although still well-lithified tin-bearing alluvium made up of pebbles and cobbles of quartz, granite and pegmatite, set in a matrix of white clay and cemented by varying amounts of carbonate. All clasts of granite and pegmatite are completely kaolinized. The quartz pebbles are generally angular to partly rounded in shape. Cassiterite grains range from about 0.5 to 5 mm in diameter, the average being about 2 mm. Most pieces are angular with well-preserved crystal faces, but some well-rounded grains were noted. Outcrops of the Tertiary alluvium are rare. In places it is incised, and overlain by up to 1.2 m of sandy cassiterite-bearing Recent alluvium. Other parts of the deposit are obscured by high level Pleistocene river gravels or by Recent flood plain deposits. All pebbles and cobbles in the Tertiary alluvium are of local origin and, in this, it contrasts with the overlying Pleistocene alluvium which is made up largely of material derived from the Fortescue Group and carried at least 20 km to Coondina.

The average cassiterite content of ore being treated in 1972 was reported to be 1.8 kg/m^3 of tin concentrate. Ore reserves assessed by J. Linden in June 1971 amounted to 260 tonnes of tin concentrate in 275 000 m^3 of ore, an average grade of 0.95 kg/m^3.

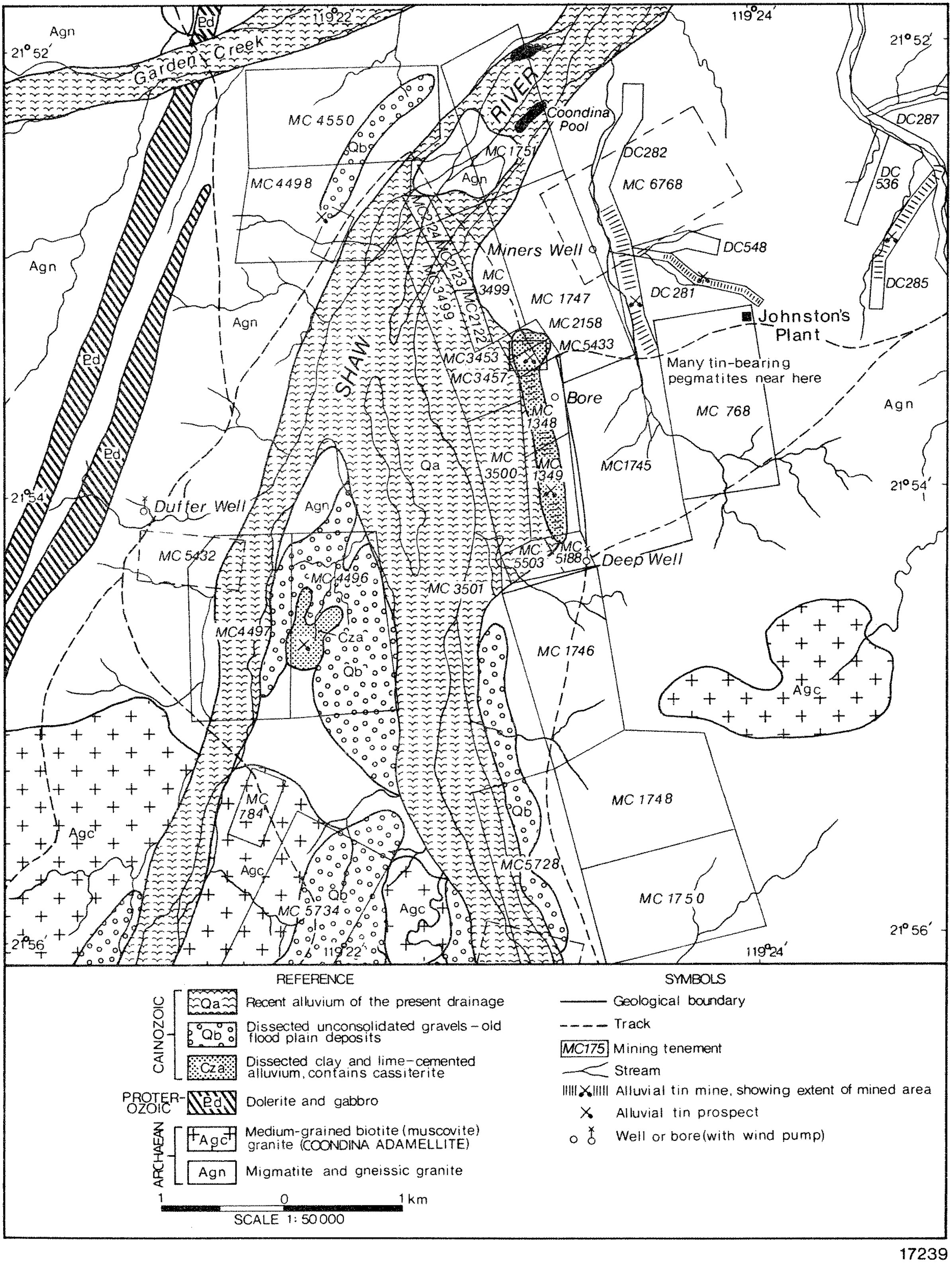


Figure 7. Geological map of the Coondina centre

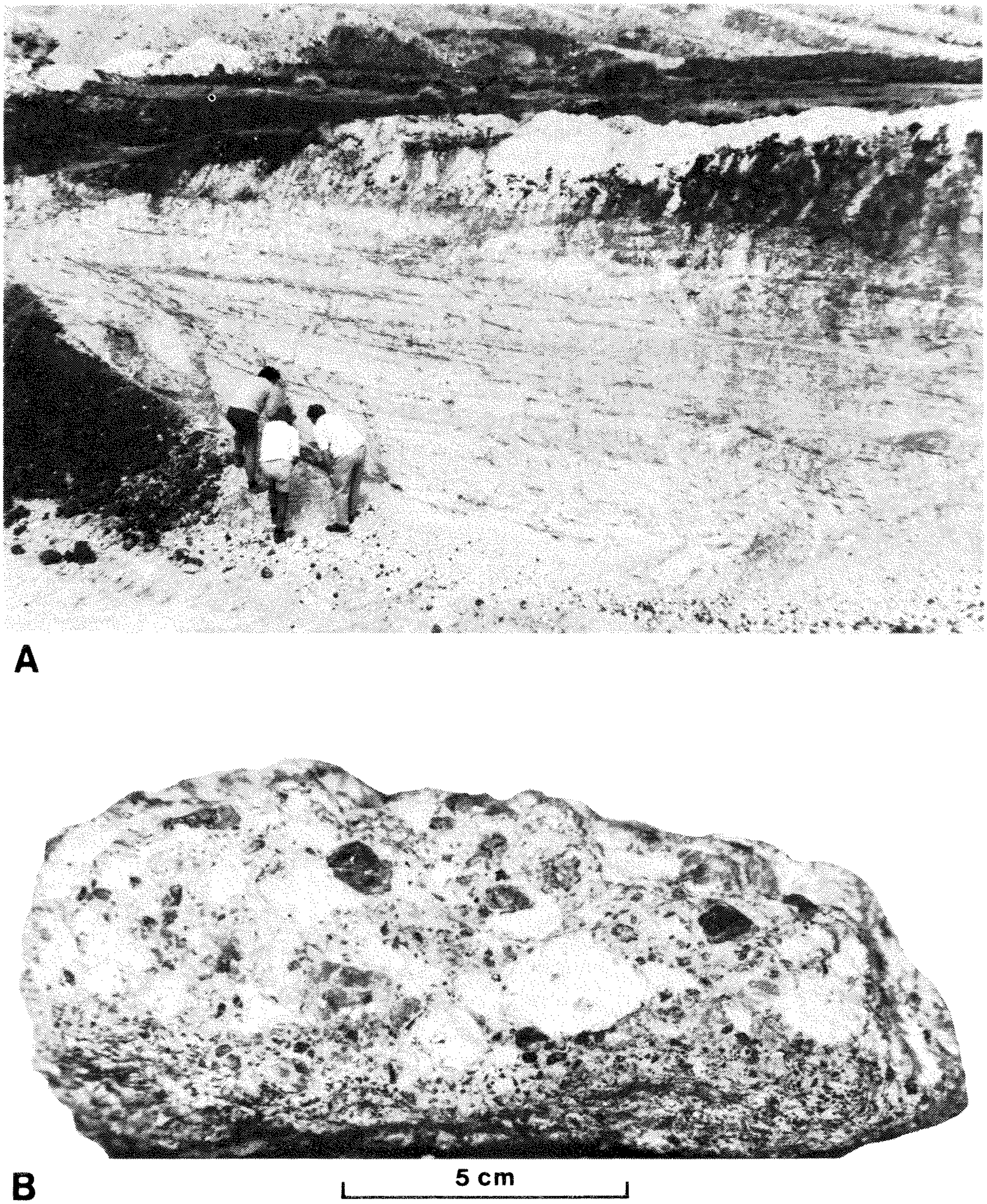


Figure 8. Photographs of Tertiary alluvium from Coondina.

A. Face of cemented alluvium exposed in a costean on M.C. 1349.

B. Specimen (21790) from base of alluvium showing kaolinized pegmatite and granite fragments (white), quartz (grey), and cassiterite (black). Cassiterite is concentrated mainly in lowermost 30 mm of specimen.

Mineral Claims 4496 and 4497

Cemented alluvium similar to that worked in Johnston's mine crops out on M.Cs 4496 and 4497 between and near the junction of the Shaw and Western Shaw Rivers. One pit sunk near the southern edge of the claims exposed 1.8 m of alluvium of which the lowermost 30 cm is tin-bearing gravel containing about 0.2 per cent SnO_2. Four hundred metres northeast of the shaft, further cassiterite is present in what appears to be the same lead. Much of the area of the claims is covered by Pleistocene gravels which conceal the greater part of the Tertiary alluvium.

Mineral Claim 4498

M.C. 4498 (formerly 2125) on the western bank of the Shaw River includes shallow workings about 1 m deep in cemented alluvium, underlying unconsolidated Pleistocene gravels. The ore is quite rich in places, the contents of some samples were estimated to be as high as 18 kg/m^3 of tin concentrate.

PROSPECTING RECOMMENDATIONS

The extensive deposits of high level Pleistocene gravels along the Shaw and Western Shaw Rivers may conceal further old channels containing cemented tin-bearing alluvium, and are worth investigating.

Unless there have been major changes in drainage and land slope since the early Pleistocene, the cassiterite on M.Cs 4496, 4497 and 4498 could not have come from the only known source area—on and about M.C. 768. Other tin-bearing pegmatites may exist to the south of Coondina, probably near the contact of the younger granite mapped in that area.

FRIENDLY CREEK DEPOSITS

GENERAL INFORMATION

The Friendly Creek, or Yule River, tin deposits are located 3.5 km east of the former gold mining camp of Pilbara at lat. 21°15′S, long. 118°20′E. They are about 160 km by road from Port Hedland, being reached by a graded track through Wodgina. Another track connects the centre to Whim Creek, about 80 km distant to the west.

Cassiterite was first reported in the area in 1909, although it was probably recognized by gold prospectors 30 years earlier. The tin concentrate produced during the 1900s was sold through Wodgina, and was attributed to that centre. The first tin production to be reported from the Friendly Creek centre was between 1951 and 1953. In 1969 the Yule River Tin Syndicate (Sack and Adamson) took over the main deposits in the field, erected a small plant in the southeast corner of M.C. 305, and produced 14.65 tonnes of cassiterite in 1970. The syndicate sold the mine to Bamboo Creek Gold Mines N.L. in 1970, and a new company, Yule River Mining Pty Ltd was incorporated. Total recorded production from the field to the end of 1975 is 119.82 tonnes of tin concentrate (Table 18) and 5.52 kg of associated gold.

Between 1970 and 1975 attempts to treat the deposits at the modest rate of 30 m^3 per hour were hindered by a shortage of water. Several bores sunk near the deposit appeared promising when first tested, but supplies did not withstand constant pumping during a dry period. Earth dams constructed across Friendly Creek were washed out by cyclonic rain. The most promising source of water for future operations appears to be the alluvial flats along the Yule River.

References

Brief mentions of tin deposits at Friendly Creek were made by Maitland (1909) and Woodward (1910b). Unpublished information prepared by Bamboo Creek Gold Mines (N.L.) and Whim Creek Consolidated N.L. is held by the Geological Survey of W.A.

GEOLOGICAL INFORMATION

The Friendly Creek centre (Fig. 9) is close to the western edge of the large tract of granitic rock which encloses the Wodgina tin field; that is the Yule Batholith of Hickman and Lipple (1975, 1979). The immediate bedrocks of the tin deposits are foliated granite, gneissic granite, and migmatite with numerous relicts of amphibolite; all are cut, firstly by pegmatite veins and then by dolerite dykes. Seven hundred metres northwest of the deposits the granite intrudes amphibolite and chert of the Warrawoona Group. Banding and foliation in the granitic rocks strike mainly northeasterly, parallel to this contact, and dip steeply northwest.

TABLE 18. PRODUCTION OF TIN CONCENTRATE FROM FRIENDLY CREEK, 1969-1975

Tenement	Operator	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)
D.C.9 WP	Sack, F. & R., Adamson, D.	1969-1970	14.65	10.26	28 270.25
M.C.305 WP	Yule River Mining Pty Ltd	1971-1975	102.01	71.61	282 950.93
Sundry claims		1951-75	3.16	n.a.	5 488.55
Total			119.82		316 709.73

WP West Pilbara Goldfield

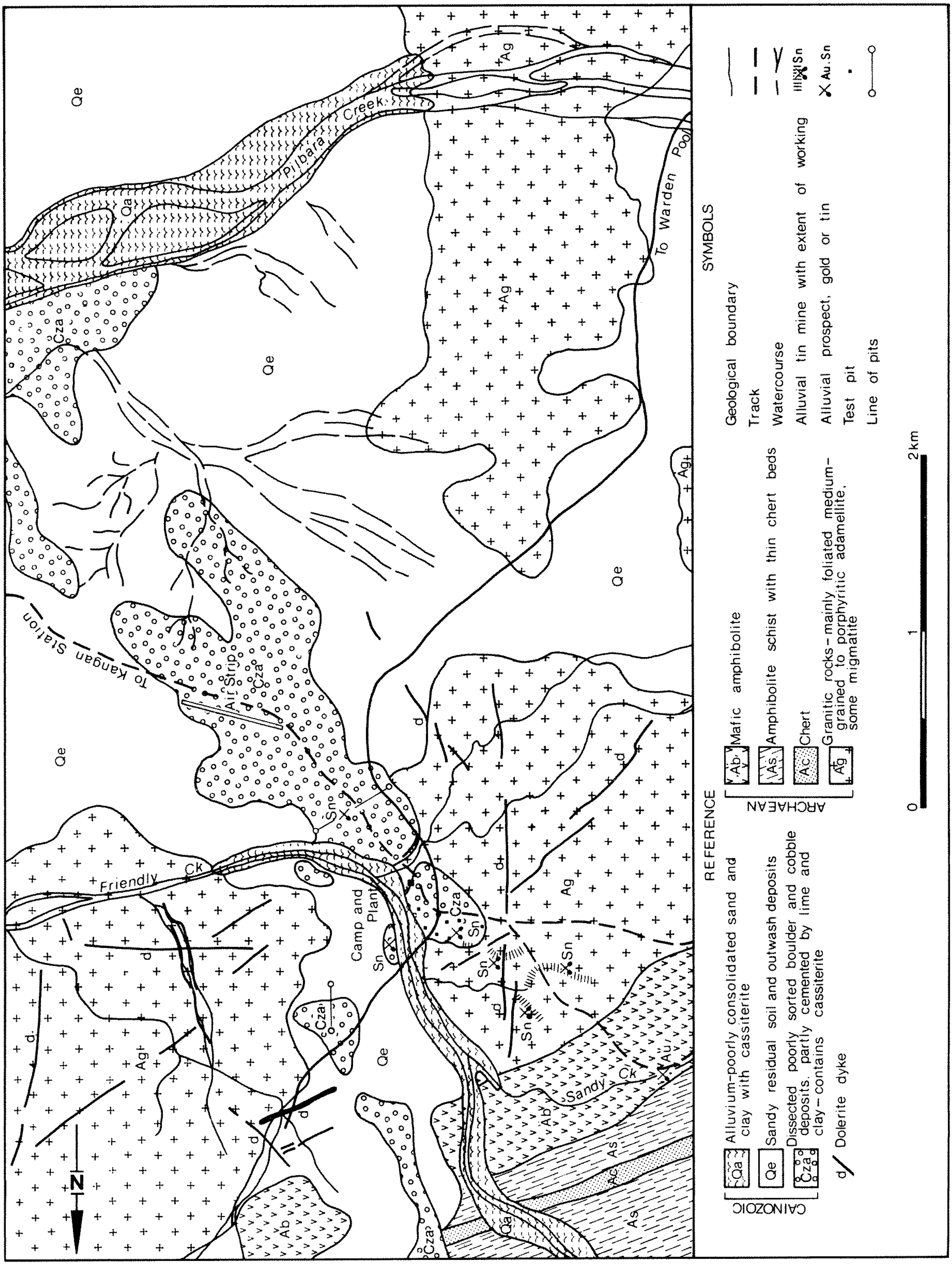


Figure 9. Geological map of the Friendly Creek tin deposits.

The source of cassiterite is a set of layered aplite-pegmatites of similar type to those found at Moolyella and Shaw River. The veins strike southwest and dip flatly northwest. The tin-bearing pegmatites are probably related to a stock of massive granite exposed south of the centre, or to fractionated foliated granite cropping out northwest of the mine (p. 125). Quartz veins cutting amphibolite of the Warrawoona Group were the source of alluvial gold mined at Pilbara in the 19th century, and undoubtedly yielded the small amounts of gold recovered in the present tin mining operation.

The bedrock is overlain by soil and shallow alluvium in present creeks, and a striking deposit of cemented high-level boulder beds of probable late Tertiary age. In places the older deposit is capped by up to 2 m of kankar. It can be traced for about 5 km in a southwesterly direction and ranges from 200 m to 1 km wide. The northeastern end of the deposit runs parallel to the upper part of Friendly Creek, but the lower part extends across the watershed between Friendly Creek and Pilbara Creek. The boulder beds were evidently laid down along a former southwesterly flowing tributary of Pilbara Creek which has since been captured by Friendly Creek. The elbow of capture is a well-marked feature located immediately downstream from the present tin workings (Fig. 9). Drilling by Westfield Minerals (W.A.) N.L. shows the deposit to have a maximum thickness of 30 m.

RECENT ALLUVIAL DEPOSITS

Most production prior to 1971 came from Recent alluvium in the bed of Middle Creek, an east-flowing tributary of Friendly Creek. The alluvium was contained partly in D.Cs 9 and 10, and partly in M.C.305.

The diggings have a total length of 1.7 km and include the greater part of the trunk creek as well as a northern branch. The diggings range in width from 5 m in the upper stretches of the creeks to 30 m in the lower part. The ground worked was quite shallow, ranging generally between one and two metres.

Elsewhere in the Friendly Creek area, Recent tin-bearing wash is known to occur along a 2 km-length of Sandy Creek, in the bed of Friendly Creek, and along another small tributary known as East Creek.

TERTIARY ALLUVIAL DEPOSITS

Mineral Claim 305

Tertiary alluvium within, or near, M.C.305, has been tested by costeaning and drilling. The deposit is a remnant of the old drainage system described above, preserved on the west bank of Friendly Creek. It has an area of about 10 ha and an average depth of 3 or 4 m where seen in costeans, but may be appreciably thicker.

The greater part of the exposed alluvium consists of weathered, angular, poorly-sorted boulders and cobbles of granite, chert, basalt, shale and quartz set in a matrix of red clay and loam and cemented to varying degrees with carbonate. The proportion of carbonate increases upwards to form kankar at the surface. In some exposures, the boulder and cobble beds overlie white, gritty clay with occasional quartz pebbles. In the bank of Friendly Creek, the boulder beds rest on dense white kaolin which may be weathered amphibolite, or else a sedimentary horizon in the deposit.

Cassiterite is concentrated mainly near the base of the boulder deposit, but forms irregular streaks and pockets at higher levels.

Mineral Claim 3036

In 1968, Kathleen Investments Pty Ltd sank a line of pits about 500 m southeast of M.C.305 to test the full width of the Tertiary alluvium where it traverses M.C.3036. The deposit is about 370 m wide in this section. The pits average 6.7 m deep with a range of 1 to 9.2 m, but later drilling by Whim Creek Consolidated N.L. suggests that the average thickness of the deposit here is about 15 m. The upper part of the alluvium is cemented by an irregular sheet of kankar up to 2 m thick. The lower part consists of clay and carbonate-bound gravels and boulders.

No results of the Kathleen Investments Pty Ltd test work could be obtained. According to a former manager of Pilbara Tin Pty Ltd, the only significant concentrations of cassiterite were at the base of the deposit but they were overlain by too much overburden to be mined profitably. Holes drilled by Whim Creek Consolidated N.L. also intersected only low tin grades.

RESERVES AND RESOURCES

In November 1974, Yule River Mining Pty Ltd estimated its reserves to be an inferred 230 000 m^3 of material treatable with the existing plant, i.e. mainly Recent alluvium. More recent drilling by Whim Creek Consolidated N.L. outlined two areas of Tertiary alluvium on the east side of Friendly Creek with total indicated reserves of 343 000 m^3 averaging 1.6 kg/m^3 of tin concentrate (Roberts, pers. comm, 1979).

The remnant of Tertiary alluvium on M.C.305 was estimated by the writer to contain an inferred 350 000 m^3 of cemented boulder beds containing 0.1 to 0.15 kg/m^3 of tin oxide.

TABBA TABBA DEPOSITS

GENERAL INFORMATION

The old tin and tantalum mining locality of Tabba Tabba is about 50km southeast of Port Hedland at lat. 20°40′S, long.118°51′E. It is best reached by a track branching southwards from the Great Northern Highway near the crossing of Tabba Tabba Creek, 56 km from Port Hedland. The deposits are about 13 km from the highway, covering part of a low range of hills rising about 30 m above a broad plain. A few minor tributaries of Tabba Tabba Creek drain from the range.

During past mining operations, water for crushing and concentrating the ore was obtained from three wells near the old Tabba Tabba Station homestead, 0.5km southeast of the mines. Further supplies could be obtained from the alluvium and weathered granite along Tabba Tabba Creek, where there are at present several station wells equipped with wind pumps. Production of pegmatite minerals from Tabba Tabba amounts to 131.92 tonnes of tin concentrate (Table 19), 18 tonnes of tantalum/niobium concentrates and 52 tonnes of beryl. The main tantalite lode is noted for being the principal source of the rare mineral simpsonite (calcium aluminium tantalate).

Although the greater part of the centre's tin production is officially attributed to "sundry claims" between 1916 and 1928, the distribution of the workings and the evidence provided by Simpson (1928) suggests that most came from M.Ls 313 and 362.

The Tabba Tabba deposits have previously been described by Simpson (1928), Finucane and Telford (1939) and Ellis (1950). The two later reports contain maps of the deposits, and Ellis gives a detailed description of the main tantalite-bearing pegmatite.

GEOLOGICAL INFORMATION

The Tabba Tabba tin and tantalum deposits occur in, or were derived from, several large pegmatite dykes cutting a narrow tongue of amphibolite and metasedimentary rocks between two masses of granite. The amphibolite includes varieties derived from basalt, gabbro and basic tuffs. The meta-sediments contain garnet-zoisite schist and banded iron-formation.

The granite on the eastern side of the greenstone tongue is poorly exposed, but seems to be part of the older complex. Its contact with the greenstones is marked by prominent migmatites. About 1km west of the deposits is the eastern edge of a large, boldly outcropping intrusion of foliated granite which cuts amphibolite and the migmatite phase of the older granite. Although no direct evidence of the age of this body is available, partial chemical analyses (Table 51) show it to have features common to younger granites. More recently, Hickman (1977) has identified a large pluton of probable younger granite in the area, and it seems likely that the analysed samples came from a cataclastically deformed phase of this body, which is probably responsible for the mineralization at Tabba Tabba.

Superficial deposits in the vicinity of the diggings comprise only shallow eluvium and a little alluvium in east-flowing tributaries of Tabba Tabba Creek.

PRIMARY DEPOSITS

Tabba Tabba tin mine

The main production of tin ore at Tabba Tabba came from two albite pegmatites which strike through M.L. 313 and join in an open V-shape in M.L. 362. The western vein strikes at 340 degrees near the intersection, but further north swings northeasterly. The eastern vein strikes east, then northeastwards away from the join. The two veins dip towards each other at angles of 20 to 35 degrees. Where exposed in workings the veins are about 30 cm to 2 m thick although some of the more flatly dipping portions reach 30 m in outcrop width. The total outcrop length of the veins is about 450 m.

The veins are composed of albite with quartz, microcline, muscovite, lepidolite and spessartine. Cassiterite is present throughout, but is more abundant in the eastern vein. Simpson (1928) estimated material in a dump on the eastern vein to contain from 5 to 25 per cent SnO_2. Two samples collected by Ellis (1950) from the northern part of the west vein each contained about 6 kg/m^3 of concentrate, which in one sample was almost pure cassiterite, and in the other, consisted of 68 per cent SnO_2.

Apart from one inclined shaft about 6 m deep, workings on the vein comprise pits and trenches generally less than 2 m deep.

TABLE 19. PRODUCTION OF TIN CONCENTRATE FROM TABBA TABBA, 1916-1975

Tenement	Operator	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)
M.L.313, 362	Tabba Tabba Consolidated	1935-1956	11.37	n.a.	4 564.30
P.A.2611	McLeod, D. W.	1960	.56	.38	648.80
Sundry claims?	Various	1916-1928	119.69	n.a.	26 556.00
Crown land?	Sundry persons	1960	.30	n.a.	334.60
Total			131.92		32 103.70

Main tantalite lode

A large, northwesterly striking pegmatite on M.C. 116, immediately north of the Tabba Tabba tin mine was the principal source of tantalum minerals at Tabba Tabba. It crops out over a length of 600 m, is from 15 to 55 m wide, and dips northeasterly.

Mineralization is restricted to narrow zones of aplitic albite pegmatite bordering large masses of sheeted quartz. The aplitic zones are finely layered with minerals such as tantalite and beryl occurring in a regular depositional sequence away from the quartz (Ellis, 1950). Tantalite, microlite and simpsonite were mined mainly from shallow shafts and cuts in the central part of the vein, where cassiterite formed only a small part (1 to 10 per cent) of the heavy minerals recovered. However, in a group of shallow diggings located about 200 m northwest from the main workings, samples taken by Ellis had SnO_2 contents of from 0.003 to 0.1 per cent (Table 20).

SECONDARY DEPOSITS

Secondary cassiterite at Tabba Tabba is restricted to small patches of shallow eluvium and alluvium adjacent to the pegmatite dykes.

Two areas east of the main tantalite dyke were estimated by Ellis (1950) to contain a total of 7 750 m^3 of material containing 1.8 kg/m^3 of concentrate with an average of 13.5 per cent SnO_2. Another area tested by Ellis on the west side of the tin lode had 2 000 to 3 000 m^3 of eluvium with from 0.5 to 6 kg/m^3 of cassiterite.

These deposits were worked by groups of Aboriginals after Ellis' inspection, and although reported production was low, the deposits are now considered to be worked out. There is little chance of finding large commercial placer deposits at Tabba Tabba.

PROSPECTING RECOMMENDATION

The two inwardly dipping branches of the V-shaped pegmatite on M.L.362 form an attractive prospect which could be cheaply tested by vertical holes sited between the arms.

TABLE 20. SAMPLING RESULTS FROM NORTHERN WORKINGS, TABBA TABBA*

Details	Concentrate from sample		% of original sample	
	kg/m^3	Weight %	SnO_2	Ta_2O_5
Dump of pit	1.53	0.061	0.003	0.058
Lode 75 cm wide	1.47	0.058	0.026	0.032
Lode 65 cm wide	8.39	0.335	0.100	0.235
Lode 38 cm wide	28.41	1.135	0.057	1.078
Lode 38 cm wide	4.54	0.181	0.054	0.127

*From Ellis (1950)

PILGANGOORA DEPOSITS

GENERAL INFORMATION

Pilgangoora is located near Mount York on the western side of the McPhee Range at latitude 21°03′S, longitude 118°54′E. It is best reached by a graded track 13km long branching from the Port Hedland to Wittenoom road 95km south of Port Hedland.

The ridges of the McPhee Range rise about 150m above the level of a wide plain which lies immediately west of the centre. Several well-defined creeks flow from the range out onto the plain and eventually join the Turner River drainage.

The only permanent water near the deposits is Coffin bore, on W.R.115. This is equipped with a wind pump and yields sufficient water to sustain small parties of miners or prospectors.

A total of 13.71 tonnes of tin concentrate was produced from Pilgangoora (Table 21) mainly as a by-product of mining about 50 tonnes of mixed tantalum-niobium concentrates from secondary deposits. Small quantities of beryl were also mined, and the pegmatites were evaluated as a source of spodumene in the late 1960s.

The first brief description of the tantalite deposits at Pilgangoora by Maitland (1906) was based on an unpublished report by an Inspector of Mines. Finucane and Telford (1939) and Ellis (1950) published maps of the centre together with descriptions of the salient geological features. Ellis' report gives details of results of a sampling programme covering alluvial and eluvial deposits in the area. Further sampling results are recorded in an unpublished report by Ishihara Sangyo Kaisha Ltd (1969).

TABLE 21. PRODUCTION OF TIN CONCENTRATE FROM PILGANGOORA, 1947-1975

Tenement	Operator	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)
M.C.174, 175	Griffiths, W. E.	1956	1.47	.91	1 470.42
M.C.291, 381	Perron Bros Pty Ltd	1956	.83	.61	812.94
M.C.381, 385	Northern Territory Prospecting and Development Co.	1957	.20	.12	210.00
M.C.291, 425	Northern Territory Prospecting and Development Co.	1956-1957	10.19	6.75	11 807.80
Sundry claims		1947-1955	1.02	n.a.	800.64
Total			13.71		15 101.80

GEOLOGICAL INFORMATION

The Pilgangoora deposits are within rocks of the Warrawoona Group close to the contact of a large mass of granite forming the Turner Batholith of Hickman and Lipple (1975). The Warrawoona Group rocks comprise steeply dipping metamorphosed mafic lavas, chert, pyroclastics and ultramafic rocks striking at about 020°. The granitic rocks are mainly concealed by outwash and kankar, but appear to be part of the older granite complex.

PRIMARY DEPOSITS

Near the granite contact a swarm of pegmatite dykes has intruded north-striking, east-dipping faults cutting the layered rocks. The swarm can be traced for about 5km. Individual dykes range up to 600m long and 300m wide.

Despite the impressively large size of the pegmatites, mineralization within them is sparse and patchy. It is restricted to parts of the veins where the normally barren quartz-microcline-biotite pegmatite is altered to quartz, albite, muscovite and spessartine with varying amounts of lepidolite, spodumene, tantalite, cassiterite and, rarely, beryl. Mineralization is restricted mainly to the margins of the veins.

Of the five groups of shallow pits sunk on the veins, four were principally for tantalite minerals, although they also contained varying, but economically less important, quantities of cassiterite. In the fifth locality, 1.3 km east-northeast of Coffin bore, tin ore was mined from narrow zones within a pegmatite cropping out on the north end of a spur of ultramafic rocks. Although high grade in places, the small sizes of the enrichments, and their distance from a treatment plant, makes further development unlikely.

SECONDARY DEPOSITS

Small scale mining of secondary tin-tantalite concentrations in shallow creeks and eluvial patches has been the only recorded source of these minerals in the Pilgangoora centre.

Coffin Creek

The richest tin-bearing gravels were mined along Coffin Creek and its tributaries, in the vicinity of the richer pegmatite deposits described above. The production, which was recorded against former M.C.291, came from areas now included in D.C.s 788, 756, 769, and M.C.921. The main creek bed was mined out to within 450 m of Coffin bore over a width of 40 to 50 m. Two south-flowing tributaries, on D.C.s 788 and M.C.921, were each worked over distances of 200 m and widths of 40 or 50m. The greatest depth of alluvium seen was about 2 m. In a number of costeans west of the worked-out section of the main creek, the alluvium comprises 1 to 1.5 m of poorly sorted floodwash and valley fill, overlying, in places, 40 to 60 cm of clay-bound gravel. Results of assays of six samples from these costeans are given in Table 22.

Pilgangoora Creek

The alluvial workings on Pilgangoora Creek are mainly on M.C.920 and D.C.755. They follow the creek for about 1.4 km and average about 50 m wide. The ground was quite shallow. Samples reported by Ellis (1950) range in depth from 15 to 90 cm and contain between 0.27 and 0.003 kg/m^3 of tin oxide.

Higher tin values were obtained from samples taken from Websters Gully, a southern tributary of Pilgangoora Creek. Here the average grade of the samples was 5.6 kg/m^3 of concentrate, of which about 10 per cent was SnO_2.

Houston Creek

About 2.4 km north of Pilgangoora Creek tantalite was mined along Houston Creek, and at a nearby eluvial deposit called by Ellis (1950) the Waggon Wheel Patch. The pegmatites in the vicinity were worked in two places for tantalite and contain scattered crystals of spodumene.

Diggings on Houston Creek extend for about 800 m in alluvium no more than 90 cm deep. The cassiterite content was low, samples tested by Ellis ranging from trace amounts to 0.18 kg/m^3 SnO_2. Slightly better grades were obtained from the Waggon Wheel Patch where Ellis estimated that there were 8 500 m^3 of material averaging 1.2 kg/m^3 of concentrate containing 8 per cent SnO_2. The area was subsequently mined by

TABLE 22. SAMPLING RESULTS FROM PILGANGOORA

Sample No.	Details(1)	Weight conc. (g)	% SnO_2 in conc.	g/tonne SnO_2 approx.
16392	D.C.756, 75 cm floodwash alongside alluvial workings	16.5	0.47	25
16393	MC.939, alluvium from creek draining pegmatite	2.8	1.10	10
16394	D.C.756, No. 1 costean(2), upper 1.4 m alluvium	26.4	0.41	35
16395	D.C.756, No. 1 costean. lower 45 cm alluvium (gravel)	21.6	0.72	50
16396	D. C.756 No. 2 costean, flood-wash material	36.7	1.47	180
16397	D.C.756, No. 3 costean	30.8	0.63	65
16398	D.C.756, No. 4 costean, flood-wash	18.0	0.65	40
16399	D.C.756, No. 5 costean	24.8	0.63	50
16400	D.C.756, No. 6 costean	13.9	0.82	40

(1) All samples were panned concentrates from two dishes (approx 3 kg) of material.

(2) Costeans numbered from west to east are 195 m, 305 m, 395 m, 435 m, 455 m and 515 m respectively from western boundary of D.C.756

Perron Brothers using a mobile dry concentrator mounted on a World War II military tank, and is now largely worked out.

Mineral Claim 425

The tin production recorded from M.C.425 (Table 21) apparently came from a small, hand-worked gully draining a large pegmatite on M.C.958 and flowing westwards through D.C.776. These claims are about 2.5 km north of Houston Creek, and cover the most northerly diggings in the Pilgangoora centre.

The worked area is confined to the bed of the gully, following it for about 500 m, and ranging from 1.5 to 3 m wide. No larger areas of alluvium suitable for machine mining exist along the creek.

PINGA CREEK (ABYDOS) DEPOSITS

GENERAL INFORMATION

Since 1951, 37.15 tonnes of tin concentrate have been mined, mainly by J. M. Henderson and Sons, from Pinga Creek, a tributary of the Yule River (Table 23). The mine, which has also been called Leeds Find or Abydos, is located at latitude 21°30′S, longitude 118°45′E, about 18 km southwest of Abydos homestead. It is reached by graded track branching from the Port Hedland to Wittenoom Road near the homestead.

In 1969, Mr Henderson was obtaining sufficient water for mining purposes from a bore sunk 11 m into alluvium and migmatite in the bed of Pinga Creek. Earlier attempts to bore for water in the area had produced only small supplies.

The deposit was recorded by Simpson (1928) who saw samples of concentrate from the area, but did not visit it. In addition to cassiterite, he noted monazite, gadolinite, tantaliferous polycrase and manganocolumbite. An unpublished report for Kathleen Investments Ltd is held by the Geological Survey of Western Australia (Neale, 1966).

GEOLOGICAL INFORMATION

The Pinga Creek deposit is within a large tract of migmatite and granite gneiss which locally contains small irregular intrusions of foliated granite (16380), believed, from its low content of lithium, rubidium and tin, to be an anatectic segregation within the older migmatite complex (Table 45).

The granitic rocks are cut by tin-bearing aplite-pegmatite of the type usually associated with younger granite. They may be related to the Numbana Granite which crops out a few kilometres to the north, or to a subjacent stock. Acid dykes, similar to those at Shaw River, strike at 100 degrees, cutting the other granitic rocks. Dolerite dykes are intruded along east-south-easterly fractures.

The crystalline rocks are overlain by shallow accumulations of eluvium and Recent sandy or clay-bound alluvium.

ELUVIAL DEPOSITS

Eluvium, together with shallow alluvium, was mined on D.Cs 496, 497 and 700, south of Henderson's plant. The largest area worked, on D.Cs 496 and 497, measured about 700 m by 100 m, covering residual deposits over, and downslope from, a swarm of pegmatite veins.

Smaller areas of eluvium were mined in the southern end of D.C. 700, and a broad deposit of colluvium, in the northern part of the same claim, was tested by pitting.

ALLUVIAL DEPOSITS

Alluvial cassiterite occurs in Pinga Creek and a number of small tributaries joining it in the vicinity of Henderson's plant. At the time of inspection mining was concentrated on the principal deposit, which follows the main trunk of Pinga Creek for about 4.8 km. The ore comprises a basal bed of puggy claybound gravel ranging from 15 to 45 cm thick, and averaging about 45 m wide. The average grade is stated to be about 1.2 kg/m^3 of tin concentrate.

TABLE 23. PRODUCTION OF TIN CONCENTRATE FROM PINGA CREEK (ABYDOS) 1951-1975

Tenement	Operator	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)
D.C.497 etc.	Henderson, J. M. & Sons	1965-1975	36.97	25.67	78 240.21
Sundry claims	Various	1951-1965	0.18	0.12	352.60
Total			37.15		78 592.81

Deposits in the tributary creeks are shorter and narrower than in the main creek, but grades are higher; some gullies tested by Kathleen Investments contained from 3.5 to 4.7 kg/m³ of tin concentrate.

RESERVES

Neale (1966) estimated total ore reserves to be about 110 000 m³ of ground containing about 200 tonnes of tin concentrate. The reserves were inferred from sampling of pits and costeans.

MINOR DEPOSITS

Cassiterite has been reported or produced in small quantities from a number of less important localities in the Pilbara Block. Centres from which some production is reported (Table 24) are Strelley, Corunna Downs, Daylight Creek, Upper Five Mile Creek, and Mount Hall. Localities at which the mineral has been reported but not worked commercially are Abydos, Haystack Well, Mount Florance, Nullagine, and White Springs. Tantalite mining on Pastoral Creek may have yielded some cassiterite as a by-product, but records are not clear on this point.

Geochemically anomalous tin values were recorded near Mount Edgar Station during a stream sediment survey.

STRELLEY

Official records (Table 24) show the Strelley tantalite mining centre to have yielded only 0.1 t of tin concentrate. However, when the deposits were first discovered in 1916 they appear to have been worked for tin rather than tantalum, for Simpson (1948) records that about 35 t of cassiterite were recovered in that year.

The Strelley centre (lat. 20°32'S, long. 119°01'E) is about 65 km by road from Port Hedland, immediately north of the Great Northern Highway on the east bank of Tabba Tabba Creek.

Finucane and Telford (1939), Miles and others (1945) and Ellis (1950) reported on the centre as a tantalite source, although all three contributions contain some reference to cassiterite.

The principal deposit, on M.C.106, comprises a pegmatite dyke about 600 m long, ranging in outcrop width from about 25 m to 180 m. It forms a low ridge trending at 030°, capped in places by white quartz. Northwards from the ridge the presumed extension of the dyke beneath flat sandy country is marked by a number of quartz outcrops. Ellis considered a well-defined barren quartz reef about 18 m wide, cropping out further north again, to be part of the same body. The pegmatite consists mainly of microcline and quartz with small amounts of muscovite. Lenses of massive white quartz occurring in irregular lenses throughout the dyke do not seem to be confined to any one particular zone. A notable feature of the dyke is the marked vertical schistosity parallel to the regional strike of the enclosing amphibolite and banded iron-formation. Such schistosity is unusual in the Pilbara rare-metal pegmatites, although it is common at Greenbushes.

Economic minerals, mainly tantalite with associated cassiterite, microlite, lithiophyllite, lepidolite and beryl are restricted to greisen lenses within the dyke or to zones where fine-grained albite has replaced the microcline pegmatite as stockworks. Ellis noted that coarse greisen with up to 9 kg/m³ of cassiterite forms several lenses along the eastern side of the vein.

The early unrecorded production of tin concentrate came mainly from shallow eluvial deposits flanking the pegmatite. The most recent operation appears to have been an attempt to re-treat old tailings using a small riffle box.

Cotton's prospect, on former M.L.346, is located about 3 km north of M.C.106. Cassiterite, and associated tantalite, microlite and beryl, occur in two en echelon pegmatite veins, each about 90 m long. Both veins dip at about 45° west, across the regional cleavage. The richest tin concentrations occur in an assemblage of sheet-jointed glassy quartz, weathered granu-

TABLE 24. PRODUCTION OF TIN CONCENTRATE FROM MINOR DEPOSITS, CROWN LAND AND SUNDRY UNLOCATED CLAIMS, PILBARA BLOCK, UP TO 1975

Centre	Tenement	Operator	Period	Tin conc. (tonnes)	Metal content (tonnes)	Value ($ Aust)
Strelley	M.C.106	Haselby, H. A. & H. B.	1963	.06	.02	42.10
	Crown Land	Sundry persons	1963	.04	.03	51.70
Corunna Downs	Crown Land	Sundry persons	1965	.85	.59	1 830.70
Daylight Creek	P.A.841	Weatherall, A.	1963	.09	.06	117.00
Upper Five Mile Creek	M.C.92, 93	Dorrington & Party	1955	.34	.19	280.80
Mount Hall	M.C.241 etc.	Nomads Pty Ltd	1963	1.10	n.a.	1 287.80
Unassigned production (Marble Bar and Nullagine Districts)	Crown Land & sundry claims	Sundry persons	To 1975	146.19	n.a.	266 384.96
Total				148.67		269 995.06

lar albite, muscovite and granular quartz; or in garnet-bearing albite aplite. Ellis recorded grades of up to 8 kg/m^3 in two deposits and noted that one exposure of aplite contained 5 per cent free cassiterite.

CORUNNA DOWNS

Although Mines Department statistics (Table 24) show a small production of tin concentrate from Crown Land on Corunna Downs Station no local information on the occurrence could be obtained. A granite of the younger type (the Mondana Adamellite) occurs in the southern part of Corunna Downs Station and it is possible that there is some tin mineralization associated with it. Another possibility is that the cassiterite came from Split Rock which is located only a few kilometres west of Corunna Downs Station on the other side of the Coongan Syncline. Campana (1963) reported the results of tin determinations on samples taken from the dumps of wells on Corunna Downs Station. The best tin values obtained were 150 ppm at Northern Cross well, 67 ppm at Dot well, 60 ppm at Star well and 52 ppm at No. 9 well. The locations of most of these wells are shown on the Marble Bar 1:250 000 geological sheet.

DAYLIGHT CREEK

In 1963, 0.09 t of concentrate were taken from P.A.841L recorded as being at Daylight Creek near Bonnie Downs Station. An inspection of the area about Daylight Creek marked on the Balfour Downs 1:250 000 sheet produced no sign of tin workings. Local information suggested that the P.A. was further east, being reached by a track branching from the Great Northern Highway about 19 km south of Nullagine. The track leads to an old camp near which were faint signs of diggings along a small gully, and a single pit on a pegmatite vein. These are assumed to be the Daylight Creek workings. The diggings are within the Bonnie Downs Granite which here is a porphyritic variety containing a few albite pegmatite veins. What may be other tin workings in the area were noted close to the access track. Two samples of concentrate obtained by panning creek gravels in this locality assayed respectively 0.01 and 0.04 per cent tin, equivalent to only a few grams per m^3 of tin concentrate. Samples taken from near the "main workings" at Daylight Creek, also returned very low tin values.

UPPER FIVE MILE CREEK

Small quantities of cassiterite, tantalite and beryl were produced from Upper Five Mile Creek in 1955. The occurrence is noted by de la Hunty (1964) as a columbite and beryl locality and is shown on the Balfour Downs 1:250 000 geological sheet. It is reached by way of a rough track following Five Mile Creek upstream from the crossing of the Nullagine to Mount Cook road. The area is made up of outcrops of gneissic granite intruded by porphyritic granite. Superficial deposits are scant, comprising mainly pockets of soil among the rocks, and shallow sands and gravels in the creek beds. Some shallow pits were seen in pegmatite dykes near the old camp, but the site of the former alluvial diggings could not be established. Any such workings in the sandy creeks of the area would have been obliterated by one or two wet seasons.

MOUNT HALL

In 1960, a group of Aboriginals led by Mr D. McLeod, pegged a number of Prospecting Areas for beryl in the old Police Paddock, about 2 km south of Mount Hall trig, near Roebourne. Subsequent work by the group yielded about 106 tonnes of beryl, 8.6 tonnes of tantalo-columbite and 1.10 tonnes of tin concentrate.

The deposits were described by Ellis (1962) and their position is shown on the Roebourne 1:250 000 geological sheet (Ryan, 1966). They occur in a tract of hilly country composed mainly of metamorphosed serpentinite and gabbro. The hills are surrounded by granitic rocks, which, at their nearest point to the deposit, comprise foliated weakly-banded leucocratic granite (15254, 26222, Table 51). Coarse pegmatite-textured lithium-bearing granite (15258) also crops out in the valley floors within the hills, suggesting that the greenstones are underlain by granite at shallow depth.

Most of the mining took place on, or about, three pegmatite veins cropping out in the north-western part of Mineral Claim 244 and extending into Mineral Claim 245.

The longest vein strikes easterly. It measures about 140 m by a maximum of 20 m. The other pegmatites strike northeasterly, and are respectively 120 m and 60 m long. Two of the pegmatites show a crude zoning, having quartz cores surrounded by shells of various proportions of quartz, albite (cleavelandite) and muscovite, together with beryl, zinnwaldite, cassiterite, tantalite and prehnite. The beryl is present both as large crystals and in a disseminated form. It is commonly pale green, but Ellis recorded some intensely flawed prisms of emerald.

Probably the greater part of the tin and tantalum concentrates were obtained from the eluvial workings which surround the pegmatites, and the shallow alluvial diggings that extend for several hundred metres along a narrow creek draining the claims. These secondary deposits are now exhausted, and any future tin production from the centre is likely to be as a by-product of more systematic mining of the beryl.

ABYDOS EAST

Simpson (1928, 1948) recorded an unimportant find of cassiterite about 16 km east of Abydos Station but no local information could be obtained on the precise position of this deposit. Ishihara Sangyo Kaisha Ltd (1969) reported briefly on the occurrence of eluvial cassiterite near this locality and on another about 8 km easterly from Woodstock. In both prospects the cassiterite occurred near outcrops of small clusters of pegmatites.

HAYSTACK WELL

The writer was informed by residents of Nullagine of old diggings for cassiterite and beryl in the vicinity of Haystack Well. About 5 km east of the well an old camp shown on the Balfour Downs 1:250 000 geological sheet is situated near several aplite-pegmatites intruding mica schist. No signs of old workings were seen but a concentrate panned from a gully draining the most prospective pegmatite assayed 1.76 per cent Sn representing about 0.15 kg/tonne SnO_2 in the original sample.

About 2.5 km west of the camp, near a track junction, a quartz-cored pegmatite vein 60 m long and 3 to 6 m wide has been mined in a small way for beryl. Two small gullies draining from the vein have each been dug over for a distance of about 75 m, apparently for alluvial cassiterite or tantalo-columbite. A panned concentrate from eluvial material collected below the vein assayed only 0.009 per cent Sn.

MOUNT FLORANCE

The discovery of tin ore 3.8 km east of Mount Florance is recorded by Simpson (1948). The area is within granitic rocks close to the northern boundary of the Hamersley Basin. No production has been reported.

NULLAGINE

A little cassiterite was noted in concentrate obtained from the gold-bearing Beaton Creek Conglomerate which forms the local base of the Fortescue Group at Nullagine. Deposits similar to that at Daylight Creek may have been the original source of the mineral. Further details are given in the Annual Report of the Chemical Branch of the Mines Department for 1932.

WHITE SPRINGS

Simpson (1948) recorded unusually twinned cassiterite crystals found by prospectors between 1929 and 1932 on White Springs Pastoral Lease. Apparently no details of the precise locality or the mode of occurrence were available to him. In 1970, D. R. Adamson pegged a number of Mineral Claims centred about lat. 21°53′S, long. 118°51′E, 10 km south-southeast of the old White Springs homestead and carried out some prospecting for tin ore. The claims have since lapsed and no production has been recorded, although there are a number of old diggings in the area.

The prospect is reached by a track branching easterly from near the old 123-mile peg on the Port Hedland to Wittenoom road. It lies within a large area of migmatite drained by small tributaries of Beabea Creek. The only primary deposit seen was a quartz-microcline pegmatite located about 1km east of the road. Samples from the dumps of two or three old pits on the body yielded one piece of coarse cassiterite.

Most creeks in the vicinity are narrow and contain only 0.5 to 1m depth of alluvium in the form of loose sand over claybound granite debris.

Grace (1971) reported on the results of a sampling programme carried out under an option agreement by Bamboo Creek Gold Mines N.L. In all, 93 costeans were bulldozed to test the creeks draining the area. The highest assays recorded were 200 ppm Sn (from two costeans) and 180 ppm Sn from one other costean. All other results were less than 100 ppm Sn. Grace concluded that no creek tested averaged 1.2 kg/m^3 Sn or more over its length, although some pockets in which 2.4 kg/m^3 Sn could be obtained were irregularly dispersed throughout the claims. The richest tin-bearing creek averaged about 0.6 kg/m^3 Sn over a distance of about 2.4 km.

Other minerals recorded during the sampling were tantalo-columbite and monazite. Gadolinite was suspected by reason of a high yttrium content in a specially prepared concentrate.

PASTORAL CREEK

Production records for the Cooglegong centre show 86.31 tonnes of tin concentrate mined by Shaw River Alluvials from D.Cs 26, 27 and 105. D.C.105 is actually located on Pastoral Creek, a small tributary of the Turner River, at latitude 21°16′S longitude 118°46′E. About 3 t of tantalite and columbite were mined from the same locality. The creek which drains the Numbana Granite has been mined over a length of about 200 m. The ore was treated at a plant on Kunagunarrina (or Stinking) Pool.

MOUNT EDGAR

A stream sediment sampling programme by Antelope Exploration Pty Ltd (unpublished data, G.S.W.A. file M333) yielded tin contents of 125 to 150 ppm tin in a creek cutting the Great Northern Highway about 1.5 km north of the turnoff to Mount Edgar Station homestead.

CHAPTER 3

Yilgarn Block

SUMMARY

The Yilgarn Block, of mainly Archaean granitic, metavolcanic and metasedimentary rocks, occupies an area of over 657 000 km^2 and is divided into three tectonic provinces (Fig.2). It contains only one important tin field, that of Greenbushes, situated in the Southwestern Province. Production from Greenbushes is 17 689 tonnes of tin concentrate (Table 26). Other small tin deposits, with a combined recorded production of 16 tonnes of concentrate, have been mined at Smithfield, Poona, Coodardy, Dalgaranga, Kathleen Valley, Ubini, Binneringie, Mount Deans, Mount Thirsty and Holleton. Production from these minor deposits is given in Table 29, and for the purpose of description, they are grouped by tectonic provinces.

The regional geology of the Yilgarn Block has been reviewed by Prider (1965), Gee (1975), and G.S.W.A. (1975). In view of the large area of the Yilgarn Block, and the sparseness of tin mineralization outside the Greenbushes field, no general summary of regional geology is appropriate in this bulletin. Relevant geological information is given in the description of each deposit, as is data on water supplies and climate, where this seems warranted.

All primary tin deposits in the Yilgarn Block are in pegmatites intruding greenstones or metasedimentary rocks. The deposits in the Murchison and Eastern Goldfields Provinces are related to the main phase (ca. 2 600 m.y.) of granite intrusion in these areas. The Greenbushes and Smithfield deposits are also apparently of Archaean age, but cannot be related directly to any known granite intrusion.

The clearest association of tin mineralization with an identified granite source is in the Murchison Province, where the Poona, Coodardy and Dalgaranga deposits are related to the Poona-Dalgaranga Batholith (Muhling, 1969).

GREENBUSHES TIN FIELD

GENERAL INFORMATION

The *Greenbushes tin field* lies near the extreme southwestern part of the Yilgarn Block about 70 km southeast of the port of Bunbury and 200 km south of Perth. The principal township in the field, Greenbushes (population about 240), is situated on the bituminized Southwestern Highway, and the nearby settlement of North Greenbushes is on the Bunbury to Northcliffe Railway (Plates 6 and 7).

Greenbushes which has normal postal and shopping facilities is served by electricity from the S.E.C. Grid. Many of the tin miners live in Bridgetown, about 15 km south of Greenbushes.

The Greenbushes Mineral Field with an area of about 10 000 ha was created in 1907 to facilitate administration of the Mining Act by a Warden based in the town. At present this administration is carried out from Perth.

HISTORY AND PRODUCTION

As described in Chapter 1, the discovery of tin at Greenbushes is attributed to Mr D.W. Stinton, possibly acting on advice from the Government Geologist of the time.

Early development of the Greenbushes tin field was hindered by the then Minerals Land Act which permitted areas of 40.47 ha (100 acres) to be held without any labour obligations. After reaching a peak of 377 tonnes in 1894, production declined until rising prices and a change in the mining laws in 1899 introduced a new period of activity lasting until 1920. This was followed by a long interval of meagre production which ended in about 1967 when rising prices and the introduction of large scale mining methods brought the field into its present most productive stage. Annual production of tin concentrate from the Greenbushes tin field is given in Table 2 and detailed figures for production from individual tenements in various parts of the field are listed in Table 26. Tantalite/columbite concentrate amounting to 1 241 tonnes valued at $4 891 512 has been produced as a by-product of tin mining.

In its early days, production from the Greenbushes tin field came from large numbers of small holdings worked by individuals or small syndicates. As the higher grade deposits were exhausted, the numbers of operators declined and the ground controlled by each increased. This trend culminated during 1975 when Greenbushes Tin N.L. bought out the holdings of Vultan Minerals to acquire control over the entire field.

Until about 1940 mining methods comprised mainly hydraulic sluicing of alluvium and deep mining of the lodes, although many of the earlier claims were apparently worked by hand. During the 1940s hydraulic sluicing of weathered pegmatite on the Vulcan Lease represented the first attempt to exploit the primary deposits on a large scale. Since about 1960, open-cut mining methods using earth moving machinery have been used on both lode and alluvial deposits (Fig. 10A, B). Only two attempts to use floating bucket dredges have been made. The first by Greenbushes Tin Ltd in 1940 proved unsuccessful due to failure of the largely secondhand machinery to cope with the ground. The second, by Greenbushes Tin N.L.* from about 1965 to 1972, was found to be unprofitable because of shallow ground and the cost of constructing dredge ponds on the elevated Tertiary alluvials (Figure 10C).

Early references to dredges in the Greenbushes tin field were to floating barge-mounted hydraulic mining plants which disintegrated the ore with a strong jet of water, pumped the resulting slurry on board, and extracted the cassiterite content in sluice boxes.

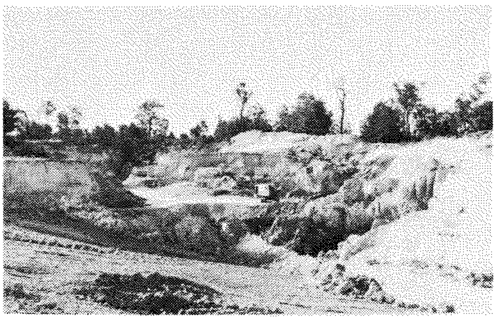
Cleland (1910b) gives an excellent description of these machines, which he calls suction dredges.

More details of the history of the Greenbushes tin field can be found in Hobson and Matheson (1949).

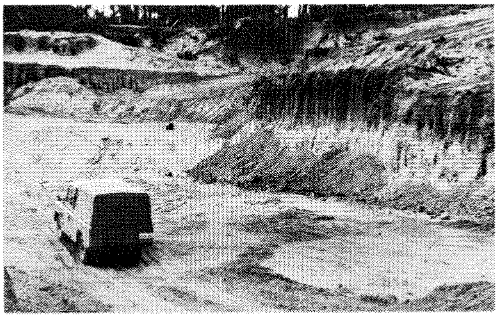
CLIMATE

The Greenbushes tin field has a temperate climate with distinct summer and winter seasons. Rain falls mainly in the winter months and averages about 970 mm per year with a range of from about 1 680 mm to 610 mm. Mean monthly rainfalls are given in Table 25, and details of monthly rainfalls from 1893 to 1943

*Not connected with the earlier company of similar name.



A



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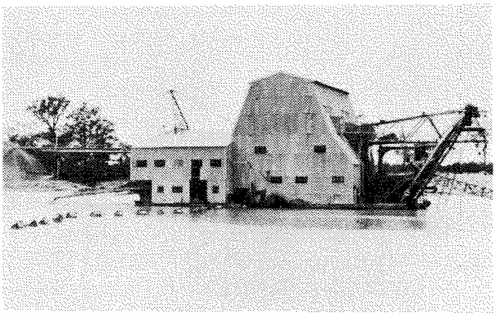

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Figure 10. Photographs of tin mining at Greenbushes.

A. Open cut in central pegmatite in the Lemonade Springs-Vultan area.

B. Pit in lateritized Greenbushes Formation near the old Mount Pleasant area. Section comprises: sand (loose material near surface); laterite (dark material); and kaolinized alluvium (lower light-coloured compact material).

C. Greenbushes Tin N.L.'s dredge operating in 1970.

appear in Hobson and Matheson (1949, Table 1). Mean maximum temperatures range from 30° in summer to 16° in winter and mean minimum readings vary from 12° to 4°. Monthly averages recorded at the nearby settlement of Bridgetown are also listed in Table 25.

WATER SUPPLY

Because of the low summer rainfall, miners in the Greenbushes tin field have always had difficulty obtaining enough water. Early practice was to mine and stockpile ore during the summer and treat it during the winter. In the early 1900s water was pumped from the Blackwood River, but the quantity pumped or the number of users are not known (Hobson and Matheson 1949, page 25). Water was also stored in abandoned sluice pits and from an early time in the field's history walls were built across the many steep narrow valleys to act as dams. At present most of the water requirements are met from dams with a total capacity of about 6 900 000 m³ to meet an hourly requirement of about 2 500 m³, of which about 60 per cent is recycled. These dams have ensured adequate supplies of water even during extended dry periods. The largest, on Cowan Brook, has a capacity of 3 400 000 m³. Although wells and bores at Greenbushes have yielded water for domestic purposes, supplies of groundwater have never been sufficiently abundant to be used for treating ore.

PHYSIOGRAPHY

The Greenbushes tin field lies within the western part of the Darling Plateau (Jutson, 1914), an uplifted peneplain currently being dissected by westerly flowing rivers and streams. The landforms and valley systems developed are described respectively by Mulcahy (1973) and Bettenay and Mulcahy (1972). Typically the peneplain remnants form gently undulating uplands with drainages marked by swamps, lakes and broad alluviated valleys. Where dissected, the plateau has sharply incised stream valleys which cut down as much as 200 m below the peneplain surface. Depth of incision of the streams increases progressively from shallow, flat-floored depressions to deep, V-shaped valleys. A few remnants of river terraces, younger than the peneplain but older than the present stream channels, are preserved along the Blackwood River.

The topographic features of the Greenbushes tin field are shown on Plate 1 and Figure 4 of Hobson and Matheson (1949), and an excellent appreciation of the landforms of the surrounding areas can be obtained from the Bridgetown and Donnybrook 1:100 000 military sheets. The township of Greenbushes and the larger pegmatite deposits are located on a broad southeasterly trending ridge, which, at 300 to 320 m above sea level, is the highest feature for some 10 or 12 km. The western side of the ridge is drained by Norlup Brook and its tributaries Dumpling Gully, Spring Gully, Gibney Gully and Cowan Brook. Drainage from the eastern side is by way of small streams flowing easterly into Saltwater Gully which flows south to meet Hester Brook. Both Norlup and Hester Brooks join the Blackwood River, which is the principal stream in the vicinity of Greenbushes. In the northern part of the Greenbushes Mineral Field, beyond the northern limit of the tin workings, several small streams flow northwards to join Balingup Brook, a major tributary of the Blackwood River. The streams draining from the ridge show the typical features described for the Darling Plateau. They have broad alluviated valleys in their upper courses but quickly become deeply incised downstream. This characteristic is important for tin mining as commercial cassiterite deposits in the younger alluvium are restricted to the upper, less incised sections of the valley.

PREVIOUS INVESTIGATIONS

Regional geology

Systematic regional mapping of the Yilgarn Block has not as yet (mid-1976) included the Greenbushes tin field. The broader aspects of the regional geology of the southwestern part of the Block, as reviewed by Prider (1948, 1952), Wilson (1958), Johnstone and others (1973) and Williams (1975), are known from reconnaissance surveys and the study of a large number of small areas. More detailed maps and descriptions dealing specifically with the geology of the Greenbushes Mineral Field are included in the accounts of Maitland (1900b), Woodward (1908), Hobson and Matheson (1949), Ellis (1953) and Mason (1965).

TABLE 25. RAINFALL AND TEMPERATURE INFORMATION GREENBUSHES AREA

	Mean monthly rainfall—Greenbushes(1) (mm)	Mean monthly temperature—Bridgetown(2)	
		Maximum (°C)	Minimum (°C)
Jan	14	29.7	11.6
Feb	16	29.6	11.3
Mar	29	27.1	10.2
April	52	23.4	7.9
May	129	19.1	6.4
June	180	16.6	5.0
July	173	15.6	4.2
Aug	144	16.6	4.4
Sept	102	18.3	5.4
Oct	77	20.4	6.4
Nov	33	24.4	8.3
Dec	21	27.6	10.1
Annual mean	969	22.3	7.6

(1) Averages from 1893-1974

(2) Bridgetown is 15 km southeast of Greenbushes

Descriptions of the enigmatic pre-laterite conglomerates of possible Tertiary or Mesozoic age which overlie the crystalline rocks in many parts of the southwestern Shield are given by Hobson and Matheson (1949—Greenbushes), Lord (1952—Collie), Taylor (1971—Kirup), and Churchward and Bettenay (1973—Harvey). Cope (1972, 1975) interpreted the Tertiary tectonics which affected the southern part of the State.

Geophysics

The Commonwealth Bureau of Mineral Resources has published results of a regional gravity survey over the southern part of the Yilgarn Block. No Government aeromagnetic maps are available for the Greenbushes field, but the area does fall within an aeromagnetic survey flown privately for Kennecott Explorations (Australia) Pty Ltd (Yeaman, 1971).

Geochronology

The only geochronology done at Greenbushes is a mineral age determined by de Laeter and Blockley (1978) on a sample of tin-bearing pegmatite. The work of Wilson and others (1960), Compston and Arriens (1968) and Arriens (1971) throws some light on the age and metamorphic history of the host rocks of the tin deposits (p.65).

Petrography

Petrographic descriptions of rocks within the Greenbushes Mineral Field are given by Miles (1949). Rocks from near Balingup and Bridgetown are documented by Chung (1957), and Samaust (1974) respectively.

Economic geology

The earliest geological accounts of the Greenbushes tin deposits were those of Woodward (1890, 1891, 1894). Maitland (1900b) published the first geological map of the field, together with descriptions of the properties being mined at the time of his inspection. Further information on the mining properties was given by Simpson and Gibson (1907), and in 1907 the field was resurveyed and the results published as a Bulletin of this Survey (Woodward, 1908).

In the period 1909 to 1944, a large number of reports dealing with individual deposits, mining methods, mineralogy and diamond drilling were produced. In 1944, the field was again assessed by the Mines Department, and a comprehensive account of the work, which included geological mapping, drilling and underground development, published by Hobson and Matheson (1949). This account also includes a bibliography of all published and unpublished reports concerning the field up to and including 1944. Many of these are referred to in the descriptions of individual mining areas, but the full list is not repeated here.

Only a little of the information acquired since 1944 has been published in scientific journals, although some useful data on ore reserves and tin recoveries are available in the annual reports of Greenbushes Tin N.L. A review of the field by Ellis (1953) was revised by Mason (1965), who also included the results of exploration work done by the Aberfoyle Tin Development Partnership. MacLeod (1962) reported on drilling near North Greenbushes and C.S.I.R.O. (1964) and Farrand (1965) gave results of tests on the treatment of alluvial ores and concentrates from the field.

Stone (1968) reviewed and reinterpreted the geology of the field in an unpublished report for Aberfoyle Management Pty Ltd. Results of a comprehensive drilling programme begun by Greenbushes Tin in 1971 are summarized annually in unpublished reports by geological consultants for the Company.

GEOLOGICAL INFORMATION

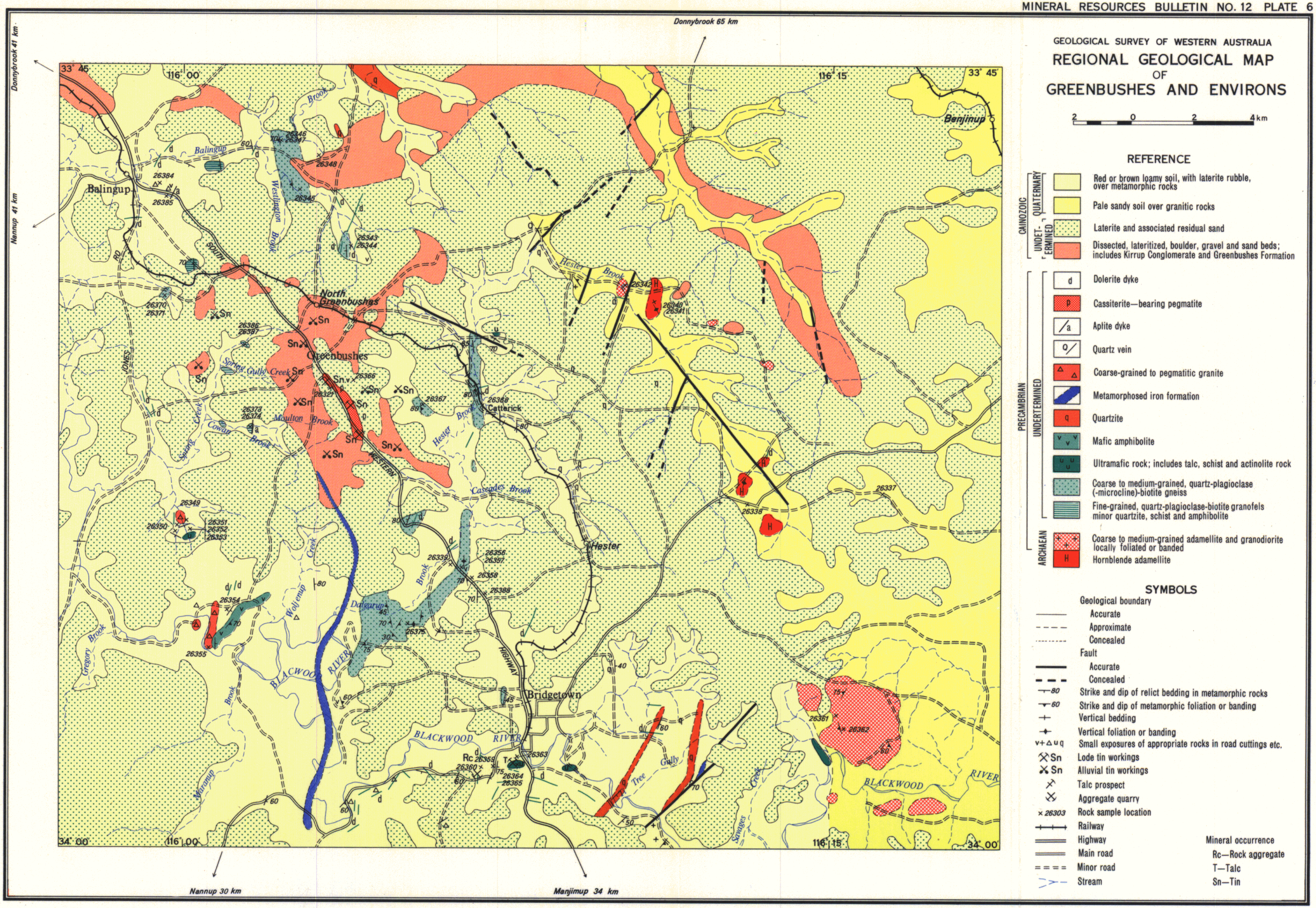
Due to the very poor exposure of the crystalline rocks in the vicinity of Greenbushes, many features of the geology of this important field remain conjectural. The following summary is based on examination of scattered natural outcrops, road and rail cuttings, and available aeromagnetic data supplemented by interpretation of soil types.

A regional reconnaissance geological map of an area of about 200 km² surrounding Greenbushes is shown in Plate 6 and the more detailed geology of the tin field on Plate 7.

Regional setting and nomenclature

The Greenbushes tin field lies in a tract of metamorphic, predominantly meta-sedimentary, rocks which occupies the southwestern corner of the Yilgarn Block and for which the name Balingup Metamorphic Belt is proposed.

Westward from Greenbushes the metamorphic rocks extend to the Darling Fault, about 20 km distant, where they abut against Mesozoic sediments of the Perth Basin. Brief reconnaissance surveys suggest that near Donnybrook, north of the area covered by Plate 6, the metamorphic rocks tongue into migmatite and gneissic granite. To the south of the mapped area, at about the latitude of Manjimup (34° 15′S), aeromagnetic contours show the distinctive northerly trend of the Balingup Metamorphic Belt partly truncated by, and partly swinging to merge with, strong easterly magnetic trends reflecting the Proterozoic Albany-Fraser Province. The magnetic data suggest that the southern part of the belt was incorporated in the metamorphism which produced the younger province.


GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REGIONAL GEOLOGICAL MAP OF GREENBUSHES AND ENVIRONS
2 0 2 4 km
REFERENCE
CAINOZOIC
QUATERNARY
Red or brown loamy soil, with laterite rubble, over metamorphic rocks
Pale sandy soil over granitic rocks
UNDETERMINED
Laterite and associated residual sand
Dissected, lateritized, boulder, gravel and sand beds; includes Kirrup Conglomerate and Greenbushes Formation
PRECAMBRIAN
UNDERTERMINED
Dolerite dyke
Cassiterite—bearing pegmatite
Aplite dyke
Quartz vein
Coarse-grained to pegmatitic granite
Metamorphosed iron formation
Quartzite
Mafic amphibolite
Ultramafic rock; includes talc, schist and actinolite rock
Coarse to medium-grained, quartz-plagioclase (-microcline)-biotite gneiss
Fine-grained, quartz-plagioclase-biotite granofels minor quartzite, schist and amphibolite
ARCHAEAN
Coarse to medium-grained adamellite and granodiorite locally foliated or banded
Hornblende adamellite
SYMBOLS
Geological boundary
Accurate
Approximate
Concealed
Fault
Accurate
Concealed
Strike and dip of relict bedding in metamorphic rocks
Strike and dip of metamorphic foliation or banding
Vertical bedding
Vertical foliation or banding
Small exposures of appropriate rocks in road cuttings etc.
Lode tin workings
Alluvial tin workings
Talc prospect
Aggregate quarry
Rock sample location
Railway
Highway
Main road
Minor road
Stream
Mineral occurrence
Rc—Rock aggregate
T—Talc
Sn—Tin
Donnybrook 65 km
Donnybrook 41 km
Nannup 41 km
Nannup 30 km
Manjimup 34 km
33° 45
116° 00
116° 15
34° 00
Balingup
North Greenbushes
Greenbushes
Catterick
Hester
Bridgetown
Benjinup
Balingup Brook
Westbridge Brook
Hester Brook
Spring Gully Creek
Cowan Brook
Moulton Brook
Cascades Brook
Dalgurup Brook
Woljenup Creek
Gregory Brook
Maranup Brook
BLACKWOOD RIVER
Tree Gully
Sevages Creek
SOUTH WESTERN HIGHWAY

About 10 km northeast of Greenbushes, the northerly trend of the metasediments is obliquely truncated by the western edge of a large mass of granitic rocks. The contact between the two major rock groups strikes northwesterly and follows, at least in part, a feature known as the Hester Lineament.

The full extent of the granitic rocks east of the Hester Lineament was not traced during this investigation, but they appear to be part of the large batholith mapped by Wilson (1958), who referred to samples from it as 'granites of the Darling Range' (cf. Wilson's figures 3 and 4). Part of the same batholith was included in samples referred to by Arriens (1971, p.15) as 'granites from the Wheat Belt', and Wilson himself used the term 'granites of the Central Wheat Belt' for samples from the eastern portion of the pluton.

Although Wilson did not imply any formal status for these names, using them merely as convenient expressions for the geographic locality of his samples, the terms have come to be used informally for a specific, if somewhat poorly mapped, body of rock. Current regional mapping by the Geological Survey of Western Australia has confirmed Wilson's picture of a large granite batholith extending from the Darling Range near Perth to at least the vicinity of Boyup Brook. Until the mapping is completed sufficiently to permit precise definition it is proposed to use the informal name "Darling Range-Wheat Belt granite" for this pluton.

Intruding the rocks of the Balingup Metamorphic Belt at Greenbushes is a swarm of tin-bearing pegmatite dykes which cannot, on field relations, be connected to any known granitic rock.

Cutting the Balingup Metamorphic Belt, the Darling Range-Wheat Belt granite, and the tin-bearing pegmatites are numerous dykes of dolerite and epidiorite.

At a number of localities in the southwestern Yilgarn Block the Precambrian rocks are overlain by pre-laterite conglomerate and associated sandstone and claystone. These deposits cross the present water sheds and show evidence, in their appreciable contents of large boulders, that they were laid down in fast-running or turbulent water. The sedimentary environment of these deposits has been variously interpreted as alluvial (Woodward, 1908; Taylor, 1971), marine or lacustrine (Hobson and Matheson, 1949), lacustrine or inland marine (Ellis, 1953) and glacial (Low, 1971).

One such deposit which forms the principal source of cassiterite at Greenbushes was referred to by earlier writers as the 'Old Alluvium' (Hobson and Matheson, 1949), but to bring the stratigraphic nomenclature into accord with the Australian Code, it is renamed here the Greenbushes Formation. Another deposit shown in the northern part of Plate 6 is named the Kirup Conglomerate (Taylor, 1971).

Concealing much of the crystalline rock in the southwestern Yilgarn Block is a 1 to 5 m thick capping of Cainozoic laterite, which also overlies or pentrates the conglomerate deposits. The laterite-forming processes also caused deep weathering of the underlying bedrock, and fresh rock is usually seen only in the valleys of the more deeply incised streams, such as Balingup Brook and the Blackwood River.

Shallow deposits of Recent alluvium occur in the upper, mature portions of the present streams. In the rejuvenated parts of the valleys, alluvium is restricted mainly to old terraces, and to very narrow flood plains.

Summary of geochronological data

Darling Range-Wheat Belt granite: Wilson and others (1960) determined a total rock Rb/Sr isotopic age of about 2 650 m.y. for a granite collected near Hester, and a metamorphic age of 740 m.y. for biotite from the same sample. Arriens (1971) found a Rb/Sr age of 2 605 ± 50 m.y. for 61 samples of granite from the Wheat Belt area. These ages are compatible with the field assessment that the granitic rocks east of Greenbushes, as represented by the sample from Hester, are part of the large batholith extending from the Darling Range into the Wheatbelt.

Balingup Metamorphic Belt: All radiometric ages available from this belt are on samples of pegmatite and therefore may reflect only comparatively late metamorphic or igneous events. Wilson and others (1960) report an age of 1 075 m.y. for muscovite from a pegmatite at Mullalyup, 15 km north of Greenbushes. Compston and Arriens (1968) determined Rb/Sr ages of 660 m.y. on pegmatite at Wellington Dam (probably on the northern extension of the Balingup Metamorphic Belt), and another of ± 660 m.y. on pegmatitic feldspar, muscovite and pegmatized gneiss from Donnybrook.

De Laeter and Blockley (1978) determined a mineral age of about 2 650 m.y. on mica and feldspar from an apparently undeformed pegmatite from the Dixie tin mine at Greenbushes. The age is in good agreement with that found by Wilson and others (1960) on a granite sample from Hester and may represent the age of intrusion of the pegmatite.

The age of the metamorphic rocks within the Balingup Belt is unknown, but the rock assemblage present is similar (allowing for differences in metamorphic grade) to that in the Jimperding Belt (Wilde, 1974) from which 18 samples of gneiss contributed to an isochron of 3 019 ± 187 m.y. (Arriens, 1971).

The Proterozoic ages of 1 075 m.y. and 660 m.y. from pegmatites within the Balingup Metamorphic Belt agree well with those of important periods of tectonic activity in nearby parts of the State. Doepel (1975) summarizes the geochronological data which shows that the granites of the Albany-Fraser Province were intruded about 1 075 m.y. ago, and Compston and Arriens (1968) determined an age of 655 m.y. for metamorphic rocks of the Leeuwin Block.

The available age determinations within and near the Balingup Belt indicate that it comprises mainly Archaean (?3 000 m.y.) metamorphic rocks intruded by granitic rocks at about 2 650 m.y. and affected by later pegmatite injection, probably accompanying metamorphism, at about 1 075 m.y. and 660 m.y. This interpretation is consistent with evidence of multiple deformation found in many of the rocks within the belt.

Balingup Metamorphic Belt

Within the area of Plate 6 the Balingup Metamorphic Belt is made up predominantly of fine-grained granofels, coarse to medium-grained, quartz-feldspar-biotite gneiss, feldspathic gneiss, quartzite, mica schist, quartz-magnetite-grunerite rock, mafic amphibolite, and several varieties of ultramafic rock. Within the granofels and gneiss are many thin, lenticular bodies of coarse granite, graphic granite and microcline pegmatite. Many of these are folded along with the host rock.

Fine-grained granofels: This is the rock which Miles (1949) called granulite gneiss. Typically it is a dark grey, fine-grained rock with a characteristic sugary or sandy texture. Banding, due to variations in the contents of dark minerals in some outcrops and changes of grain size and their intercalations of quartzite or mica schist in others, probably reflects original sedimentary bedding. Typical specimens consist largely of granoblastic to lepidoblastic aggregates of quartz, plagioclase and biotite. Other minerals present are hornblende, pink garnet, epidote and accessory zircon and ilmenite. The biotite and, where present, amphibole are aligned to give a fine gneissic texture, visible under the microscope but not always apparent in outcrop. The mineral assemblage, textures and relict bedding structures suggest that the granofels formed from fine greywacke or clay siltstone.

Natural exposures of the granofels are poor but from the number of sightings in road cuttings this rock is thought to be the most common within the Balingup Belt, at least in the area of Plate 6.

Medium-grained gneiss: Medium-grained gneissic rocks ranging in composition from granitic to feldspathic were grouped together for the purpose of reconnaissance mapping. Miles (1949) and Chung (1957) described similar rocks as injection gneisses and permeation gneisses respectively. The rocks crop out more boldly than the granofels and locally form useful marker horizons within otherwise poorly outcropping sequences. Descriptions of typical specimens are given in Chapter 5.

Chemical analyses of samples of granitic gneiss (Table 59) show them to have compositions very similar to the Darling Range-Wheat Belt granite, but analyses of feldspathic gneiss show a greater variety of composition.

The origin of medium-grained gneiss is less certain than that of the granofels. From the general lack of relict bedding and the mineralogical and chemical similarity to granitic rocks to the east it is assumed that most are of meta-igneous origin. However the feldspathic gneiss may be metasedimentary.

Mafic amphibolite: Mafic amphibolite is known from exposures in workings at Greenbushes where it forms the main wall rock of many of the tin-bearing pegmatites (Plate 7). A prominent band crops out in the valley of the Blackwood River, 11 km west of Bridgetown, and another is described by Chung (1957) from Ferndale, a little west of the area of Plate 6. Many narrow bands which do not crop out naturally can be seen in road cuttings.

In outcrop the rock is dark blue-grey with a prominent lineation due to alignment of amphibole grains. Thin sections show it to consist of more or less aligned prisms of green to blue-green pleochroic hornblende set in a mosaic of poorly twinned plagioclase and quartz. Accessory minerals include magnetite, apatite, sphene and rare epidote. As noted below, metamorphism of the margins of older dolerite and gabbro dykes has also produced amphibolite.

The mafic amphibolites appear to have been derived from igneous rocks of basaltic composition, but no evidence favouring either an intrusive or extrusive origin was noted. The pillow structures recorded by Hobson and Matheson (1949) and assumed by them to indicate a pillow-lava origin for the mafic amphibolites seem more likely to be due to the spheroidal weathering of a partly recrystallized dolerite. The rock has a well-preserved ophitic texture despite the recrystallization of the original pyroxene to amphibole.

Ultramafic rock: A number of lenses of talc-chlorite schist are exposed in the road cuttings south of the Blackwood River near Bridgetown, and another in an orchard on Location 564 has been mined for talc.

Tremolite-chlorite rock crops out 7 km southwest and 9 km north of Greenbushes. A body of serpentinite crops out north of the Blackwood River 10 km east of Bridgetown. This and other occurrences of ultramafic rock along the Blackwood River are described by Samaust (1974).

Quartzite: White, granular-textured fuchsite-bearing quartzite with crude partings, possibly reflecting bedding, crops out in two ridges 4 to 5 km east of Bridgetown. Another more poorly exposed band is present 10 km north of Greenbushes. Very thin beds of quartzite are interlayered with granofels and schist in rail cuttings east of Greenbushes and in road cuttings east of Bridgetown.

Banded iron-formation (BIF): A prominent BIF 9 km west of Bridgetown was traced by aeromagnetics. The rock is described by Yeaman (1971) as a banded magnetite quartzite. Banded hematite quartzite crops out 6 km south-southeast of Bridgetown and quartz-grunerite rock is recorded by Samaust from the same general locality.

Pegmatitic granites and related rocks: Coarse-grained to pegmatitic microcline granite occurs as thin bands and lenses. Usually it is between the foliation planes of the granofels and gneiss, but in places forms small stocks cutting the metamorphic foliation. Textures and grain size vary widely even within one outcrop. Graphic intergrowths are common, but other specimens would best be described as aplite. Most outcrops show a strong cataclastic foliation. In places pegmatite bands have been disrupted and folded during deformation of the host rocks (Fig. 27B). These pegmatitic rocks, in contrast to the distinctly different albite pegmatites at Greenbushes, are barren of economic minerals.

Information on the petrography and chemistry of these rocks is given in Chapter 5. It is concluded that they were formed by segregation of an alkali-rich aqueous phase during metamorphism.

Aplite dykes and stocks: In a few localities thin aplite dykes cut the metamorphic rock. They are usually closely associated with the conformable pegmatites and coarse granites and appear to be mobilized portions injected along fractures. Two chemical analyses are given in Table 60.

Darling Range-Wheat Belt granite

Biotite granites make up most of the rocks exposed east of the Hester Lineament. They comprise intergradational massive, foliated, and gneissic varieties which are not distinguished on Plate 6. There was no field evidence for the massive varieties being "younger granite" in the manner described by Prider (1948) for similar exposures in the Darling Range. Some outcrops immediately east of the Hester Lineament are hornblende adamellite.

Foliation and banding in the Darling Range-Wheat Belt granite commonly strike northwest parallel to the contact with the Balingup Metamorphic Belt. The contact between the granitic and metamorphic rocks was not seen. In the northern part of the area of Plate 6 the approximate position of the contact is marked by quartz veins and quartz scree; it is probable that the contact here is a fault. Further south along the Blackwood River valley there appears to be a gradation from metamorphic rock through increasingly migmatitic rock to the granite. The petrography and chemistry of the Darling Range-Wheat Belt granite are given in Chapter 5 where it is concluded that the granite has no characteristics of typical tin granites.

Dolerite and gabbro dykes

Mafic dykes of two probable ages are present in the area around Greenbushes. The earlier dykes show alteration ranging from uralitization to almost complete recrystallization. Chung (1957) described a metagabbro which cuts amphibolite and varies in texture and composition from a gabbro at the centre to a plagioclase amphibolite at the margins. Miles (1949) described a fine-grained amphibolite with relict ophitic texture which comes from what is now interpreted as a dolerite dyke at Greenbushes. Other gabbroic dykes seen during the reconnaissance mapping have sheared margins and one is cut by dolerite. Younger dykes, of which specimen 38098 is typical, are made up of completely fresh ophitic-textured aggregates of labradorite, augite and iron oxide.

Tin-bearing pegmatites

The pegmatites which are the source of the tin and tantalum minerals mined at Greenbushes lie in a belt about 5 km long extending south-southeasterly from the White lode workings near North Greenbushes rail siding, to about 500 m south of the Vulcan cut on the road to Bridgetown. The width of the swarm varies from 600 to 800 m. The largest pegmatite body, termed the 'central pegmatite' by the mining companies, has been traced over a length of 3 km and has a greatest width of 230 m in the vicinity of the Enterprise workings (Plate 7). Other smaller dykes, mainly to the north and east of the central pegmatite are termed the 'fringe pegmatites'. Most of the dykes, including the central pegmatite, strike north-northwest and have an average dip of 70° west with local variations. Some of the north-northwest trending dykes dip easterly and a few of the smaller bodies strike across the main trend. The pegmatite dykes intrude amphibolite, quartz-biotite schist, and quartz-feldspar-biotite gneiss.Contacts are sharp and more or less parallel to the metamorphic foliation (Fig. 11A). Xenoliths and rafts of the intruded rock appear in the pegmatite, and wall rocks and xenoliths are veined by apophyses of pegmatite.

Deep weathering has kaolinized the feldspars in the pegmatite to a depth of 30 to 50 m and fresh material suitable for petrographic work comprises mainly a few specimens from drill cores and old mine shafts which are in the collections of the Geological Survey of Western Australia and the University of Western Australia. Petrographic descriptions of this material are given by Miles (1949) and Koon (1973).

Although the pegmatite is kaolinized in almost all exposures, relict textures and structures are well-preserved in openings deeper than about 10 to 15 m. Relationships between the various phases of the pegmatite, and between pegmatite and wall rocks, can therefore be studied in the weathered exposures. However some guesses by analogy with texturally-similar fresh material have to be made concerning the original composition of the materials examined. Unlike many large pegmatites, the central pegmatite body does not show any signs of regular zoning, although in places there are segregations of massive quartz or quartz-muscovite-tourmaline griesen. The most common textural feature seen in both kaolinized and fresh pegmatite is a gneissic banding picked out by lines of stretched quartz and oriented tourmaline grains (Fig. 11 B,C). The banding near the margins is parallel to the walls of the dyke and to the foliation of the wall rocks, but flattens to 30° or 40° in the central part of the intrusion. The reason for this is not clear; presumably it is due to refraction of the shearing stress in the more competent pegmatite. Fresh specimens of gneissic-textured pegmatite consist mainly of cataclastic aggregates of quartz, albite, muscovite and tourmaline. The typical grain size is about that of a medium to coarse-grained granite. These pegmatites differ markedly from the microcline-bearing pegmatites formed by metamorphic segregation in the gneiss and granofels.

In many places in the working faces the gneissic banding is cut by narrow, flat-dipping veins (Fig. 11B)

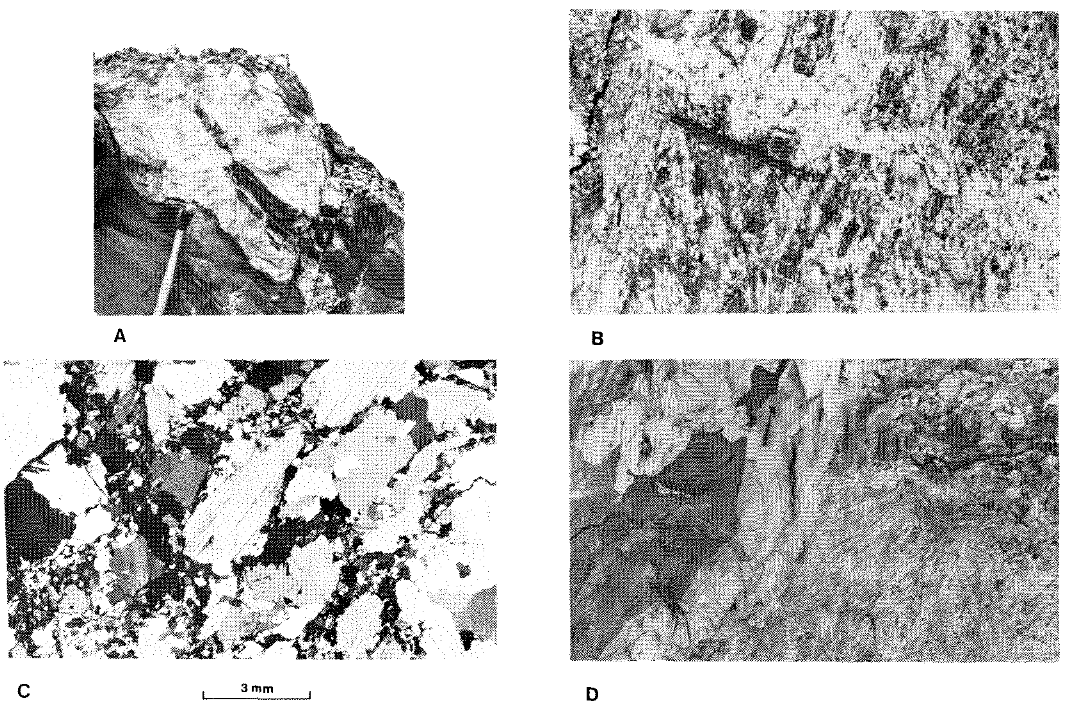


Figure 11. **Photographs of tin-bearing pegmatite at Greenbushes.**

A. **Contact of weathered pegmatite and amphibolite, North Cornwall cut. The sharp contact and the xenolith of amphibolite indicate an intrusive rather than metasomatic mode of emplacement for the pegmatite. They also suggest that the pegmatite was emplaced after the main period of regional metamorphism.**

B. **Cataclastic foliation preserved in kaolinized pegmatite, Tantalite Corner area. White cross-cutting vein, now mainly kaolin, is interpreted as being originally albite.**

C. **Photomicrograph of pegmatite (990) showing cataclastic texture.**

D. **Contact of foliated pegmatite and weathered dolerite. Dolerite has patches of leisegang-banded iron staining. Foliation in pegmatite is truncated and apparently bent by the dyke.**

now made up of granular-textured quartz and kaolin but thought to represent original quartz-albite aplite (e.g. specimen 703) observed in drill core. The latter material is not noticeably foliated or banded in hand specimen, but thin sections show it to have a somewhat cataclastic texture, although not so pronounced as in the gneissic pegmatite. Cutting both the gneissic pegmatite and the aplite are thin stringers of almost pure structureless kaolin. Similar material forms a series of flat-dipping veins in some faces of the Vulcan cut. Its original composition is unknown, but is assumed to have been almost pure feldspar.

East-trending dolerite dykes cut the pegmatite in a number of places. In the cuts they are represented by weathered kaolin bodies with much liesegang-ringed iron staining (Fig. 11D).

Cassiterite is disseminated throughout the pegmatite but the greatest concentrations are near the sides. Richer tin 'lodes' worked in the past included many quartz-rich and greisen-rich zones.

The cassiterite is zoned, shows twinning, and in many specimens, is fractured, apparently by cataclastic deformation. Its colour in thin section ranges from deep brown to pale pink. Apart from the principal minerals quartz, albite and/or microline, tourmaline and muscovite, a number of other minerals have been recorded from the Greenbushes pegmatites. Those to which reference is made by Hobson and Matheson (1949) are apatite, arsenopyrite, asbolite, beryl, biotite, cassiterite, corundum, eastonite, garnet, glaucophane, ilmenite, orthoclase, pyrite, pyrrhotite, pyrochlore and polyclase (doubtful), rutile, siderite, sphene, spodumene, stibiotantalite, tantalite, topaz, and zircon. In addition Koon (1973) noted the presence of lepidolite and re-identified the glaucophane as holmquistite, a lithium-bearing amphibole. Holtite has also been recently identified from the pegmatite by the Government Chemical Laboratories.

Wall-rock alteration of amphibolite near the dykes has produced biotite and holmquistite by potash and lithium metasomatism.

Chemical analyses presented in Table 60 and by Koon (1973) show the pegmatites to have crystallized from an extremely differentiated magma. Koon noted in particular low potassium:rubidium ratios of about 4 to 9. Evidence such as the sharp contacts of the pegmatite with wall rock, the lack of signs of folding of the pegmatite, and the replacement of metamorphic minerals in the host rock by metasomatic products, indicates that the pegmatite was intruded after the main period of folding and amphibolite-grade regional metamorphism. At the time of intrusion the country rock was sufficiently brittle to allow the formation of tension fractures into which the pegmatites were injected; the presence of xenoliths and rafts within the pegmatite indicate that it was intruded into a low pressure zone and not formed by replacement of the host rock. At some period subsequent to its intrusion, the pegmatite was affected by dynamic metamorphism which was sufficiently intense to produce strong cataclastic foliation but did not produce substantial recrystallization of the pegmatite, host rock or alteration products.

Dolerite dykes which cut the pegmatite were apparently affected by later metamorphism and converted to epidiorite, or in some cases, amphibolite with relict ophitic texture. The metamorphism (or heat of intrusion) apparently remobilized lithium from the pegmatite to form holmquistite in the dolerite.

Greenbushes Formation

The Greenbushes Formation is proposed as the name for a unit of weakly lithified conglomerate, sandstone and claystone unconformably overlying rocks of the Balingup Metamorphic Belt in the Greenbushes Mineral Field. The name is taken from Greenbushes town and replaces the term "Old Alluvium" which does not conform to the Australian Code of Stratigraphic Nomenclature. Owing to rapid changes in exposures caused by mining operations no type section can be nominated. A typical section through the formation is figured by Hobson and Matheson (1949, Fig. 5), and another is tabulated on page 84 of this bulletin. The thickest section known is about 32 m in a borehole in the Three Cs area (Forman, 1937). Over much of its area of exposure the Greenbushes Formation is only 1 or 2 m thick. It is commonly overlain by laterite.

No fossils or other direct evidence of the age of the Greenbushes Formation are known. Hobson and Matheson (1949) correlate it tentatively with the Kirup Conglomerate and the lake beds (Nakina Formation) at Collie. Taylor (1971) discusses evidence of the age of the Kirup Conglomerate and concludes that it may be anywhere between early Cretaceous and late Tertiary. Lord (1952) favoured a late Miocene or Pliocene age for the Collie lake beds, but Balme (in GSWA 1975, p. 424) notes the possibility of an Eocene age based on the correlation with sediments beneath Darkin Swamp, 84km east-southeast of Perth. Conglomeratic sediments near Harvey are tentatively regarded by Churchward and Bettenay (1973) as being Mesozoic. The age of the Greenbushes Formation is likely to remain uncertain until fossils are recovered from it, but the usual practice of assigning it tentatively to the Tertiary is followed in this Bulletin.

The most common rock types in the unit which are mined for tin are interbedded sandstone and conglomerate. Conglomerate clasts range from pebble to boulder size and consist mainly of quartz, quartzite and more rarely, pegmatite. They are set in a matrix of white clayey sand containing tourmaline and cassiterite. The shape of the clasts varies from angular (most commonly) to well-rounded. The conglomerates are seldom well-sorted. Sandy horizons are cross bedded and contain heavy mineral streaks. Claystone sequences within the formation are recorded mainly from drillholes and shafts put down in the Three Cs area. Holes logged by Forman (1937) penetrated a clay zone 6 to 22 m thick, overlying further sand and conglomerate.

The Greenbushes Formation has previously been referred to as the "Old Alluvium", "deep leads" or "ancient river channels". While most of the sedimentary features observed accord best with the formation being a fluviatile deposit derived from locally exposed Precambrian rocks, some authors have preferred a shallow marine or lacustrine origin. Further sedimentological studies are required but are hindered by present mining practice which requires the back-filling of cuts with tailings.

Distribution of tin deposits

As already noted, cassiterite occurs in pegmatite, and in sandstone and conglomerate of the Greenbushes Formation. It is also present as secondary concentrations in eluvium overlying or adjacent to pegmatite, as concentrations in Recent alluvium, and in the A-horizon of the laterite profile. The last two forms are mainly third-stage concentrations of secondary cassiterite from the Greenbushes Formation. Complete distinction between the tin deposits on a geological basis is difficult because in most mines two or more types of tin ore have been worked. For this reason an areal subdivision which has also an underlying geological basis is used in describing the deposits in the following sections. The principal lode deposits together with closely associated eluvial and alluvial concentrations are grouped as the central pegmatite belt. Deposits of secondary tin ore with some lode tin occurring north and east of Greenbushes town are grouped as the Northern and Eastern deposits respectively. The entirely secondary deposits lying west of the central pegmatite belt are referred to as the 'western alluvial tract'.

Lastly, some outlying deposits are grouped together. The scheme is also used in the tabulation of production figures (Table 26).

CENTRAL-PEGMATITE-BELT DEPOSITS

The central belt of deposits includes the alluvial diggings in Bunbury and Westralia Gullies, the former underground mines on the Dixie, Cornwall and South Cornwall leases, and the present line of open cuts extending from the southern edge of Greenbushes townsite to the Vulcan cut.

Production which can be attributed to this belt amounts to 2 642.17 tonnes of tin concentrate, but a considerable proportion of the production from Sundry Claims and by Greenbushes Tin N.L. (totalling about 10 720 tonnes) also came from this area. At present most mining activity at Greenbushes is concentrated on weathered pegmatites within the central belt.

The subdivisions used here are arbitrary, following where possible current terminology in the field, but where this is lacking or obscure, older names are used.

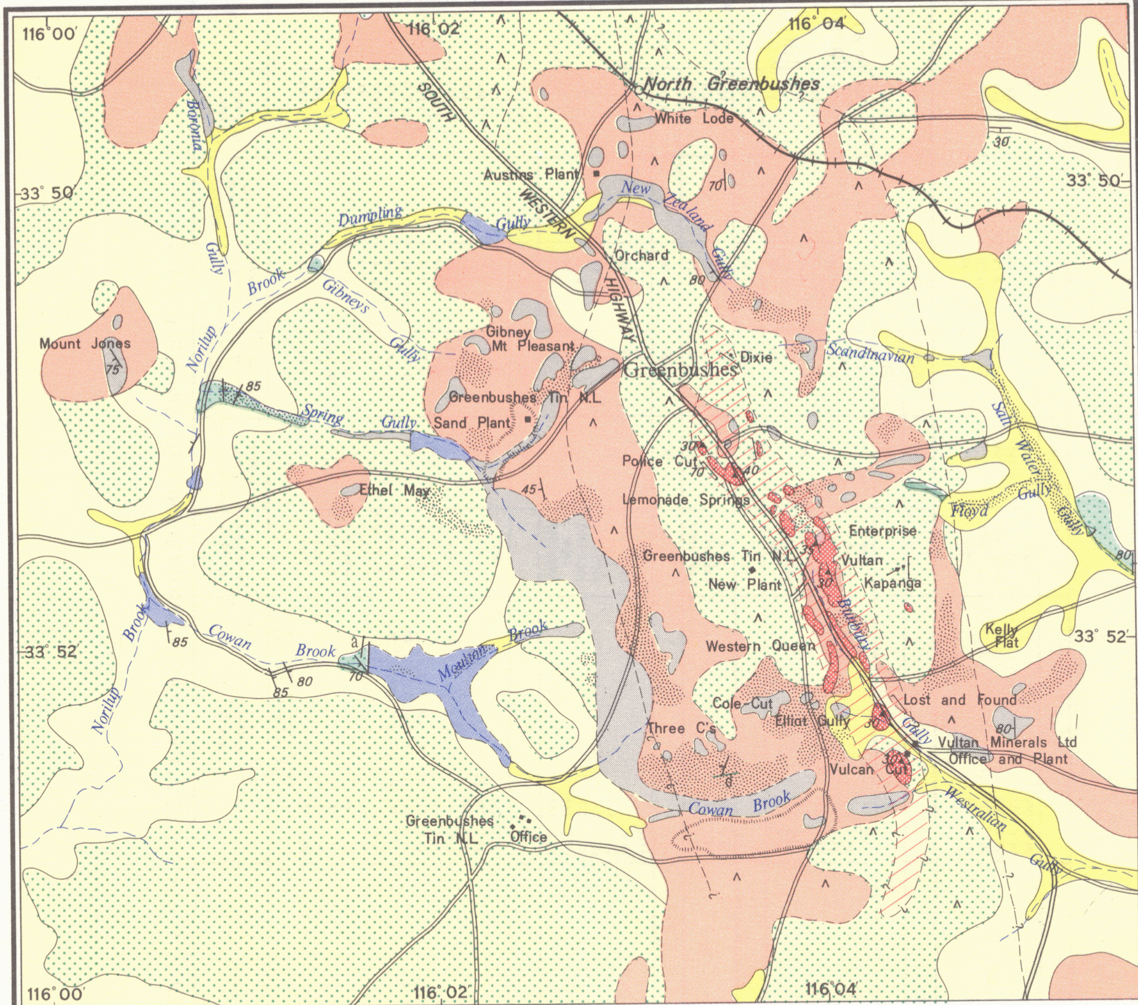
Dixie mine

The Dixie workings, situated immediately east of Greenbushes townsite, consist now of a number of collapsed or water-filled shafts with weathered pegmatite and amphibolite on the dumps. Descriptions of the underground workings by Campbell (1906) and Woodward (1908) indicated that the main lode was a pegmatite vein striking at 122 to 128 degrees and dipping 65 degrees west. Woodward's Plate 2 shows it to be a continuous feature 280 m long, but Hobson and Matheson (1949) suggested that it is more probably a series of small lenses. A number of "cross lodes" striking at 180 to 190 degrees were also mined. The principal ore shoot, mined from a small open cut and several shafts, was located at the intersection of the main lode and a cross lode. The main lode was worked to 36 m, and shafts on cross lodes ranged from 9 m to 21 m deep.

A specimen of pegmatite (6998) consists largely of albite with lesser amounts of quartz, tourmaline, muscovite, garnet and cassiterite. The average grade of ore treated in 1906 (242.8 tonnes for 1.95 tonnes of concentrate) was about 0.55 per cent tin.

Greenbushes townsite

The presence of tin-bearing pegmatites in the southwestern part of Greenbushes was established from exploratory work supervised by the Mines Department in about 1942 (Hobson and Matheson, 1949, p.110). During 1972, Greenbushes Tin N.L. drilled 139 mechanical auger holes within the town boundaries in a search for extensions of the central pegmatite belt. Work was abandoned, partly because of the generally poor results and partly because of difficulties inherent in mining within a town. Details are given by Thomson (1972a).



REFERENCE

CAINOZOIC

QUATERNARY

- Alluvium; sand, gravel and clay in present stream valleys
- Red or brown loamy soil, with laterite rubble, over metamorphic rocks

UNDETERMINED

- Laterite and associated residual sand
- Dissected, lateritized boulder, gravel and sand deposits, with cassiterite—Greenbushes Formation

PRECAMBRIAN — UNDETERMINED

- d — Dolerite dyke
- Cassiterite bearing pegmatite
- Central pegmatite zone
- a — Aplite dyke
- Amphibolite; exposed/known at subsurface
- Quartz-feldspar-biotite (-garnet) gneiss and granofels

SYMBOLS

- Geological boundary—accurate
- Geological boundary—approximate
- Geological boundary—concealed, approximate
- 70 Strike and dip of relict bedding in metamorphic rocks
- 40 Strike and dip of metamorphic foliation or banding
- 70 Strike and dip of pegmatite
- Open cut
- Dredged area
- Scattered workings in secondary deposit
- Shaft
- Dam and water catchment
- Mine building
- Vultan — Mine name
- Tailings dump
- Highway
- Other roads
- Railway
- Stream

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL PLAN OF PART OF THE GREENBUSHES MINERAL FIELD

1 0 1 2 km

TABLE 26. PRODUCTION OF TIN CONCENTRATE FROM THE GREENBUSHES TIN FIELD 1891-1975

Mine or group	Lease or tenement holder	No. of tenements	Period of production	Tin concentrate: Lode (tonnes)	Tin concentrate: Alluvial (tonnes)	Tin concentrate: Total (tonnes)	Metallic content (tonnes)	Value ($ Aust)	Notes
	NORTHERN DEPOSITS								
New Zealand Gully	Greenbushes Tin Fields Ltd	M.L. 105	1899		1.02	1.02		240	
	New Zealand Syndicate N.L.	M.L. 17, 24	1899		.81	.81		100	
	Horan's	M.L. 35	1899-1901		191.37	191.37		23 210	(1)
	Horan's No. 1 North	M.L. 169	1900-1901		9.65	9.65		1 368	
	Horan's No. 1 West	M.L. 21	1899		.10	.10		24	
	Westralian Stanneries Ltd	179C	Prior to 1899		95.76	95.76		10 698	
	Westralian Stanneries Ltd	M.L. 35, 169, 195, 218, 228, 272, 287	1902-1906		111.08	111.08		16 342	(3)
	Greenbushes Development Co. Ltd	M.L. 35, 169, 195, 218, 221, 228, etc.	1906-1921	.35	987.51	987.86		174.020	
	Nickel Kramer Tin Mining Co. Ltd	M.L. 413, 423, 425, 470, etc.	1907-1909		9.32	9.32		1 452	(6)
	Little Wonder	M.L. 470	1908-1913	5.08	50.53	55.61		10 910	(3)
		178C	1899		4.34	4.34		752	
	Caledonia Tin Mines N.L.	M.L. 156	1901-1902		12.46	12.46		1 370	
	Ivy & Lady Esther	M.L. 350, 331	1903		7.11	7.11		1 064	(3)
	Lady Esther	M.L. 331	1905		3.05	3.05		424	
	Total			5.43	1 484.11	1 489.54		241 974	
White lode workings	North Junction	M.L. 154	1900-1902		.46	.46		56	(2)
	North Junction	M.L. 394	1906	.10	.05	.15		34	
	W.A. Mount Bischoff	M.L. 218	1901-1902		5.47	5.47		684	(10)
	Stanrighan	M.L. 294	1902-1903		.49	.49		56	(10)
	Great Boulder	M.L. 419	1907	.15	.25	.40		80	
	Hector Patterson	M.C. 24	1936-1937		11.68	11.68		3 268	
		671C	1906		.55	.55		98	
	Total			.25	18.95	19.20		4 276	(4)
Dumpling Gully	Old Sport	M.L. 400	1906-1907	1.47	.05	1.52		300	
	Turn of the Tide	M.L. 565	1913-1921		20.79	20.79		5 378	= part
	Hamel	M.L. 608	1918		1.45	1.45		560	M.L. 400
	Total			1.47	22.29	23.76		6 238	
Herberts Orchard	Glasgow	M.L. 166	1900		.48	.48		66	
	Glasgow	M.L. 234	1901-1902		.34	.34		56	(2)
	Glasgow	M.L. 375	1905-1906	.94	.62	1.56		300	
	Central	M.L. 296	1903-1906		101.77	101.77		19 456	
	Gladstone	M.L. 337, 706C	1904-1910		61.94	61.94		10 388	(3)=M.L. 377
	Scadden	M.L. 531	1913		1.43	1.43		352	
		726C	1906		5.90	5.90		1 206	in M.L. 296
	Total			.94	172.48	173.42		31 824	
	TOTAL NORTHERN DEPOSITS			8.09	1 697.83	1 705.92		284 312	
	CENTRAL BELT								
Dixie	Dixie	M.L. 297	1902		.05	.05		9	
	Dixie leases	M.L. 257, 273	1901-1903		13.18	13.18		1 636	
	Dixie	M.L. 388	1905-1908	9.34	.20	9.54		1 918	(2)
	Dixie	M.L. 527	1911	.61		.61		130	
	Dixie	M.L. 566	1913	.05		.05		12	
	Total			10.00	13.43	23.43		3 702	

Table 26 cont.

Mine or group	Lease or tenement holder	No. of tenements	Period of production	Tin concentrate Lode (tonnes)	Alluvial (tonnes)	Total (tonnes)	Metallic content (tonnes)	Value ($ Aust)	Notes
Police Cut-South Cornwall	North Cornwall	M.L. 399	1907	1.75		1.75		368	(3)
	North Cornwall	M.L. 564	1913	.25		.25		60	(3)
	Imperial leases	M.L. 188, etc.	1901		3.71	3.71		418	
	South Cornwall leases	M.L. 300, 315, 30H	1903-1913	59.82	.25	60.07		11 094	
	South Cornwall	M.L. 567 (=300)	1914	4.48		4.48		768	
	South Cornwall	105H	1920	19.36		19.36		5 166	
	South Cornwall Extended	M.L. 634	1935		5.77	5.77		1 900	
	Total			85.66	9.73	95.39		19 774	
Cornwall	Cornwall leases	M.L. 40, 356, 514	1902-1915	80.69		80.69		13 754	(3)
	Cornwall	M.L. 583	1917-1919	8.06		8.06		3 026	(3)
	Cornwall	M.L. 615	1919-1920	3.40		3.40		1 160	(3)
	Birds Nest	M.L. 587	1917-1918	5.10		5.10		1 862	(3)
	Satin Bird	M.L. 588	1917-1919	4.63	1.07	5.70		1 902	(3)
	Total			101.88	1.07	102.95		21 704	
North Cornwall	Dixon	M.L. 302	1902		.25	.25		36	
	Sunday Gift	M.L. 600	1918	1.75		1.75		654	
	Cornwall Extended	M.L. 422	1906-1907	.51		.51		110	
	Cornwall Extended	M.L. 508	1910	.05		.05		8	
	Returned Soldier	M.L. 616	1919-1920	7.35	.61	7.96		2 692	
	Grafter	M.L. 589	1918	1.70		1.70		638	
	Total			11.36	.86	12.22		4 138	
Lemonade Springs-Tantalite Corner	Hokitika No. 1	M.L. 308	1903		1.37	1.37		150	
	Enterprise	M.L. 369	1906-1918	.20	7.41	7.61		1 334	
	Wills	M.L. 370	1907	2.56	2.13	4.69		756	
	Gang Forward	M.L. 611	1918	.47	.28	.75		250	
	Two Battlers	M.L. 603	1919	.10		.10		24	
	Tantalite Ltd	M.C. 1	1937,42,45		7.47	7.47		2 933	
	McKay, A.	M.C. 9	1937		.37	.37		88	
		712C, 762C	1906		9.70	9.70		1 810	
		78♦C	1906		.36	.36		70	
	Total			3.33	29.09	32.42		7 415	
Bunbury Gully	Nelson leases	M.L. 73, 233	1899-1906		84.75	84.75		11 678	
	Glencoe	M.L. 217 (146)	1900-1902	3.72		3.72		402	(3)
	Lost and Found North	M.L. 393	1906-1909	11.20		11.20		1 830	(3)
	Lost and Found North	M.L. 507 (393)	1910-1912	8.36	.25	8.61		1 838	(3)
	Lost and Found North	M.L. 606 (393)	1918-1919	4.88		4.88		1 950	(3)
	Lost and Found	M.L. 374	1905-1911	13.52	.56	14.08		2 804	(3)
	Amanda leases	M.L. 56, 217	1899-1904		24.06	24.06		3 046	(3)
	Lost and Found	M.L. 543	1912-1913	4.90		4.90		1 160	(3)
	Bunbury End	M.L. 563	1913	.57		.57		120	(3)
	Lost and Found	M.L. 605	1918	.51		.51		174	(3)
	Lost and Found	M.L. 628	1927	.33		.33		100	(3)
	Nil Desperandum	M.L. 401	1906-1907	1.57		1.57		324	(3)
	Nil Desperandum	M.L. 596	1918	.25		.25		96	(3)
	Champion	M.L. 511	1910-1924	1.62	218.88	220.50		48 090	
	Haphazard	M.L. 147	1900-1909	.28	8.93	9.21		1 146	
	Windoor leases	M.L. 245, 246	1901		1.02	1.02		120	(3)
	Haphazard Extended	M.L. 246	1902-1903		2.26	2.26		272	(3)
	Pioneer	M.L. 271	1902		1.87	1.87		234	(3)
	King Tin leases	M.L. 73, 233, 271, 504	1906-1922	6.62	121.46	128.08		31 800	(3)
	Dreamland	M.L. 382	1905-1908	2.98	.61	3.59		736	
	Esperance Hill	M.L. 389	1906	.15		.15		30	
	Found at Last	M.L. 617	1920	.58		.58		260	

Table 26 cont.

Mine or group	Lease or tenement holder	No. of tenements	Period of production	Tin concentrate: Lode (tonnes)	Tin concentrate: Alluvial (tonnes)	Tin concentrate: Total (tonnes)	Metallic content (tonnes)	Value ($ Aust)	Notes
	Coleman, A.	M.C. 6	1938, 1940		1.07	1.07		184	(3)
	Greenbushes Tin Ltd	M.C. 9, 6, etc	1940-1945	1.24	2.29	3.53		1 310	
	Patterson, H.	M.C. 45	1946		.44	.44		151	
	Austin, H.J.	M.C. 63	1966		1.12	1.12	.72	2 183	
	Total			63.28	469.57	532.85		112 038	
Elliot Gully	Old Bunbury Star of the East G.M. Co. Ltd	M.L. 504	1909-1918		38.22	38.22		7 238	
	Barrymore, H.S.	D.C. 92	1934-1936		25.91	25.91		6 526	
		738C	1906		4.95	4.95		942	
		748C	1906		1.46	1.46		272	
		752C	1906		8.64	8.64		1 642	
		753C	1906		7.31	7.31		1 572	
		774C	1906		.76	.76		152	
		775C	1906		10.82	10.82		1 982	
		776C	1906		.30	.30		60	
		779C	1906		.61	.61		124	
		789C	1906		.78	.78		158	
	Total				99.76	99.76		20 668	
Vulcan	Queens Birthday	M.L. 58	1899		1.22	1.22		164	
	Caledonian	M.L. 76	1899-1900	8.19		8.19		1 084	
	Ironclad	M.L. 179	1900	.46		.46		60	(2)
	Ironclad	M.L. 456	1907	.96		.96		164	
	Aqua West	M.L. 478	1910	.20		.20		32	
	Baltory Hill: Caledonian Tin Mining Co. N.L.	M.L. 436	1910-1913	4.56	.05	4.61		824	
	Southern Cross	M.L. 580	1918, 1921	8.08		8.08		2 172	(3)
		M.C. 2, 4	1936-1937	11.68		11.68		3 268	
	Vulcan Minerals Ltd	M.C. 56, 57, etc.	1937-1950	185.31		185.31		59 481	
	Freeman and Party	M.C. 56, 57, etc.	1950	5.88		5.88		9 372	
	Western Queen (1936) N.L.	M.C. 56 etc.	1954-1956	40.04		40.04	24.70	39 407	(3) (11)
	South West Tin Pty Ltd	M.C. 56 etc.	1957	21.14		21.14	15.01	25 415	(11)
	Total			286.50	1.27	287.77		141 443	
Westralian Gully	Homeward Bound Tin Mining Syndicate N.L.	M.L. 247, 264, 265 etc.	1901-1902		2.03	2.03		230	
	Westralian North	M.L. 392	1907	(7)	1.80	1.80		310	
	Westralian Gully Tin Co. Ltd	M.L. 381, 435, 436, 472 etc.	1907-1910	6.48	34.93	41.41		6 470	
	Excelsior Tin Mining Co. Ltd	M.L. 472, 497, 510	1908-1922		125.89	125.89		36 422	
	Excelsior Tin Mining Co. Ltd	M.L. 491	1908		.46	.46		72	
	Excelsior Extended	M.L. 510 (=497)	1910		.05	.05		10	(3)
	Aqua	M.L. 472	1910		1.52	1.52		256	
	Champion	M.L. 484	1908-1909		3.10	3.10		496	
	Estanto Sluicing Co.	D.C. 12, 27, 33	1911-1920		456.56	456.56		96 670	
		695C	1906		.61	.61		120	
		746C	1906		12.04	12.04		2 350	
		750C	1906		13.92	13.92		2 794	
		771C	1906		.36	.36		74	
	Total			6.48	653.27	659.75		146 274	
Central Belt Generally	Vultan Minerals N.L.	M.L. 647, 648 etc.	1962-1975	795.63		795.63	491.56	1 614 465	(8) (11)
	TOTAL CENTRAL BELT			1 364.12	1 278.05	2 642.17		2 091 621	

Table 26 cont.

Mine or group	Lease or tenement holder	No. of tenements	Period of production	Tin concentrate: Lode (tonnes)	Tin concentrate: Alluvial (tonnes)	Tin concentrate: Total (tonnes)	Metallic content (tonnes)	Value ($ Aust)	Notes
		WESTERN ALLUVIAL TRACT							
Gibney Gully	Clarth and others	Loc. 289, 290	1904-1909		323.14	323.14		57 918	(3)
	McKay and Struthers	Loc. 290	1920-1921		5.48	5.48		1 524	(5)
	Total				328.62	328.62		59 442	
Mulligan Gully	Homeward Bound	M.L. 222	1901		9.56	9.56		1 194	
	Homeward Bound Tin Mining Syndicate N.L.	M.L. 19, 222, 225	1902		11.58	11.58		1 622	(3)
	Queen May Consols	M.L. 317 (=222)	1903-1905		22.36	22.36		2 908	
		758C	1906		.41	.41		86	
	Total				43.91	43.91		5 810	
Mount Pleasant	Redruth	M.L. 19	1900-1901		5.70	5.70		692	
	Redruth Extended	M.L. 225 (=39)	1901		.51	.51		60	
	Aqua	M.L. 214	1901-1902		4.52	4.52		512	
	Lindsay, J.	D.C. 56, 84	1930-1932		9.04	9.04		1 576	
	Mount Pleasant	M.L. 244	1902-1906		45.01	45.01		7 590	(3)
	Nickel Kramer Tin Mining Co. Ltd	M.L. 244	1907		2.97	2.97		532	
	Rat	M.L. 498	1913		.75	.75		168	
	Congdon, J. M.	P.A. 54	1937		.53	.53		178	
		608C	1906		22.25	22.25		4 166	
		652C	1906		1.57	1.57		310	
		700C	1906		59.28	59.28		11 856	in W.R. 292
	Total				152.13	152.13		27 640	
Spring Gully	Spring Gully	318C (=484)	1899-1906		164.57	164.57		23 982	
	Stanhope	M.L. 387	1906		6.63	6.63		1 408	
	Stanhope United leases	M.L. 450, 458, 485, 486, 487 etc.	1907-1919		578.94	578.94		142 580	(3)
	Substitute	M.L. 569	1914-1915		8.64	8.64		1 820	
	Total				758.78	758.78		169 790	
Austins	Spring Valley Tin Ltd (later Amalgamated Tin Ltd)	M.C. 58, 81	1949-1953		100.68	100.68		127 357	(3)
	Austin and Sweeney	M.C. 58, 69	1958-1965		131.65	131.65	90.93	165 981	
	Chapman, E. S.	L.T.T. 1273H	1953-1954		.73	.73	.46	586	(5)
	Coghlan, R. J.	L.T.T. 1399H	1958-1960		11.07	11.07	7.71	13 150	(5)
	Tin & Strategic Minerals Ltd	M.C. 70	1954-1957		285.00	285.00	186.28	304 208	
					529.13	529.13		611 282	
Three Cs	New Moon	M.L. 513	1910		.31	.31		52	
	Three Cs	M.L. 529	1912-1915		54.19	54.19		8 628	
	Phoenix Sluicing Co. Ltd	M.L. 529,555,571	1916-1917		59.90	59.90		11 106	(3)
	Three Cs leases	M.L. 529, 555	1920		9.30	9.30		3 026	
		759C	1906		.30	.30		52	
	Total				124.00	124.00		22 864	
Cowan Brook	Greenbushes Sluicing Co. Ltd	M.L. 357	1905-1906		25.74	25.74		4 468	
	Consolidated Tin Sluicing & Mining Co. N.L.	M.L. 357 etc.	1906-1907		37.44	37.44		6 858	
	Aurora leases	M.L. 357, 359 etc.	1907-1908		20.27	20.27		2 944	
	Westralia & Legado	M.L. 391, 454	1907-1909		21.23	21.23		3 290	(3)
	Legado	M.L. 454	1907, 1910		10.06	10.06		1 656	
	Westralia & Legado leases	M.L. 454, 501	1909, 1911		17.01	17.01		2 452	
	Westralia	M.L. 501	1910		.91	.91		128	
	Birthday	M.L. 496	1908-1909		1.68	1.68		214	
	Scotia	M.L. 505	1909-1915		37.66	37.66		6 654	
	Scotia leases	M.L. 505, 519, 614	1916-1929		64.26	64.26		17 462	(3)
	Jellicoe	M.L. 592	1918		.31	.31		114	

Table 26 cont.

Mine or group	Lease or tenement holder	No. of tenements	Period of production	Tin concentrate: Lode (tonnes)	Tin concentrate: Alluvial (tonnes)	Tin concentrate: Total (tonnes)	Metallic content (tonnes)	Value ($ Aust)	Notes
	Homeward Bound	M.L. 599	1918		1.09	1.09		400	
	Wilkes, W.	E.A.C. 949	1933		1.07	1.07		296	
	Payne, H. E.	E.A.C. 957	1933		.11	.11		52	
	Coleman & Hesketh	E.A.C. 963	1937		.67	.67		142	
	Barrymore, H. S.	D.C. 94	1937		5.13	5.13		1 446	} (3)=D.C. 97
	Joice Bros.	D.C. 97, 99, 100	1945		7.62	7.62		3 290	
	Wilkes, W.	E.A.C. 960	1942		.75	.75		420	
		705C	1906		5.89	5.89		1 142	
		734C	1906		1.83	1.83		334	
	Total				260.73	260.73		53 762	
Coles cut	Cole, W. A.	E.A.C. 876	1937		.81	.81		284	
	Lindsay, R. H. & R. J.	E.A.C. 961	1938, 1940		1.37	1.37		314	
	Lindsay Bros (later A. Gault)	D.C. 90	*1935-38,42*		*14.84*	*14.84*		4 404	
	Angus, A. J.	M.C. 126, 127, 128	1961-1962		1.17	1.17	.62	1 262	
		535C	1899		.41	.41		48	
		219A C	1906		16.86	16.86		3 278	
		683C	1906		2.74	2.74		510	
		710C	1906		2.13	2.13		398	
	Total				40.33	40.33		10 398	
	TOTAL WESTERN ALLUVIAL TRACT				2 237.63	2 237.63		961 088	
			EASTERN AREA						
Floyd Gully	Energetic	M.L. 303	1902-1903		1.89	1.89		218	
	Great Wonder	M.L. 383	1906		.15	.15		24	
	I.O.U.	M.L. 469	1907-1908		1.57	1.57		238	
	Last Chance	M.L. 598	1919-1920		.47	.47		132	
	Gold Coin	M.L. 620	1928-1929		3.09	3.09		648	
		M.L. 620	1937		.30	.30		78	
		D.C. 70	1938		8.33	8.33		2 558	
		670C	1906		1.12	1.12		226	
		741C	1906		.86	.86		170	
		745C	1906		4.73	4.73		820	
		770C	1906		.81	.81		160	
		801C	1906		2.44	2.44		520	
	Battery Reserve	17393	1938		.71	.71		168	
					26.47	26.47		5 960	
Scandinavian Gully	Olympia	M.L. 48	1899		1.02	1.02		180	
	Forget Me Not	M.L. 466	1907		.41	.41		80	
	Lindsay Bros	D.C. 50	*1935*		*.66*	*.66*		182	
		744C	1906		1.49	1.49		288	
		782C	1906		.17	.17		34	
	Total				3.75	3.75		764	
Kelly Flat-Salt Water Gully	Queen Victoria Tin Mining Syndicate	M.L. 93	1899		.30	.30		30	
	Westralian Tinfields Ltd	M.L. 182, 183, 184, 185, 224	1901-1902		8.03	8.03		868	} (3)
	Perseverance	M.L. 318	1903		.76	.76		72	
		315C, 648C	1906		.61	.61		114	
		792C	1906		.46	.46		88	
	Total				10.16	10.16		1 172	
South Greenbushes	South Greenbushes Tin Dredging Syndicate	D.C. 111	1952-1953		4.04	4.04	2.55	5 278	
	Tin & Strategic Minerals Syndicate	*D.C. 111*	1953-1954		12.81	12.81	9.49	14 501	
	Total				16.85	16.85		19 779	

Table 26 cont.

Mine or group	Lease or tenement holder	No. of tenements	Period of production	Tin concentrate Lode (tonnes)	Alluvial (tonnes)	Total (tonnes)	Metallic content (tonnes)	Value ($ Aust)	Notes
Last Chance Tract	Berkshire	M.L. 90	1900		.35	.35		34	
	You and Me	M.L. 550	1913		2.18	2.18		420	
	Last Chance	M.L. 552	1913-1915	1.57	7.44	9.01		1 662	
	Total			1.57	9.97	11.54		2 116	
Kapanga	Victoria	M.L. 110	1900		.25	.25		40	(2)
	Wheal Fortune	M.L. 219	1901		.20	.20		26	(2)
	Hokitika	M.L. 281	1902		.16	.16		20	(2)
	Tairua	M.L. 410	1906-1907	3.94		3.94		780	
	Kapanga	M.L. 515	1910-1929	36.54	1.37	37.91		9 606	
	Total			40.48	1.98	42.46		10 472	
	TOTAL EASTERN DEPOSITS			42.05	69.18	111.23		40 263	
	OUTLYING AREAS								
Boronia Gully	Boronia	M.L. 361	1905-1907		17.14	17.14		3 116	
		D.C. 20	1915-1916		13.83	13.83		2 434	
	Austin and Huitson	M.L. 707	1967-1971		39.00	39.00	26.11	72 204	
	Total				69.97	69.97		77 754	
Mount Jones-Norilup Brook	Norilup Tin Mining and Dredging Co. Ltd	M.L. 396, 397, 460, 461, 479, 480	1907-1908		3.88	3.88		582	(3)
	Mount Jones leases	M.L. 460, 461	1909-1914		169.73	169.73		39 576	(3)
	Total				173.61	173.61		40 158	
Ethel May	Ethel May	M.L. 577	1916-1918		18.58	18.58		4 534	
	Morning Star	M.L. 578	1916		1.57	1.57		294	
	Total				20.15	20.15		4 828	
	TOTAL OUTLYING AREAS				263.73	263.73		122 740	
	UNASSIGNED PRODUCTION								
	Commercial Minerals Pty Ltd	M.C. 59, 62 D.C. 101, 102, 103	1948		1.52	1.52		885	
	Greenbushes Tin N. L.	M.L. 660 etc.	1966-1975			4 578.72	3 232.23	11 426 587	(9) (10)
	Sundry Claims		1899-1972			6 148.08		933 584	(13)
	TOTAL UNASSIGNED PRODUCTION				1.52	10 728.32		12 361 056	(12)
TOTAL GREENBUSHES TIN FIELD TO THE END OF 1975						17 689.00		15 861 080	

NOTES:

(1) Many figures for 1899 include production prior to that year, and go back as far as 1891
(2) Same ground
(3) Partly same ground
(4) Some recent production may be attributed to Boronia Gully
(5) Tailings
(6) Some production from Mount Pleasant workings
(7) Probably from Vulcan lode
(8) Mainly from Vulcan lode and Tantalite Corner
(9) Mainly from Western Area and Central Belt
(10) Only total production recorded
(11) Production assigned to lode or alluvial production on basis of personal knowledge or earlier descriptions
(12) Includes some production not assigned to lode or alluvial origin
(13) Differs from official figure due to some production from claims being assigned to localities

Only one hole intersected alluvium. This was on town block 7 and appeared to be part of a narrow strip of Greenbushes Formation occurring beneath the South West Highway and widening out beneath the southeast corner of the town. Of the remaining holes, 11 intersected lode (or associated eluvium) containing 0.3 kg/m³ or more of tin oxide over intervals of 1.8 m. The best result came from town block 34 where a hole averaged 1.14 kg/m³ of tin oxide over its depth of 27.4 m.

Thomson noted that the pegmatites appeared to be less than 15 m wide, although more closely spaced drilling could not be carried out to confirm this. Two pegmatites were detected in the eastern side of the townsite. One extended northerly through blocks 263 to 295, and the other passed through block 238 on an unknown trend. Most of the better intersections were obtained in the southwestern part of the town between Stanifer Street and the school. These are a little east of the pegmatite veins described by Hobson and Matheson on M.C.47, but appear to be on strike with the lode worked in the Police cut.

Cornwall mine

The old Cornwall mine is located on M.C.125 near the southeastern corner of Greenbushes townsite. The ground was first pegged as M.L.40 in 1899, and to 1920 produced a recorded 102.95 tonnes of tin concentrate during several changes of tenure (Table 26). A further 100 tonnes of ore were treated during Government sponsored underground development in 1926-27, but the results are unknown. In 1928, the Government subsidized the drilling of four holes to test the main lode at depth.

Surface workings comprise a line of narrow open cuts on the main lode, and a large number of shafts sunk on at least four or five other pegmatite bodies.

No complete plans of the underground workings exist. Wilson (1928) published a plan of openings accessible in 1927 and the Department holds a longitudinal section of the western lode, which unfortunately cannot be related to surface features. Descriptions of the old workings given by Maitland (1901), Campbell (1906), Simpson and Gibson (1907), Woodward (1908), Cleland (1911) and Wilson (1926, 1928) are quoted by Hobson and Matheson (1949, p.196-200).

The lodes mined were foliated pegmatite or greisen dykes, mainly striking north-northwest and dipping steeply west. The main lode was mined over a length of 150 m to depths of 18 to 21 m from narrow open cuts. Its width ranged up to 3 m (Woodward 1908) and its grade was reported by Wilson (1926) as "at least 3 ounces to the dish", i.e. about 12.5 kg/m³.

The east lode is about 50 m east of the main lode. It strikes northeasterly, dips steeply and is about 30 m long at the surface. It was worked to a depth of 30 m from a three-compartment shaft. Information on the upper levels is restricted to verbal information given to Wilson (1928) by a miner, who stated that "the lode averaged 2.4 m in width, and contained from 3 to 4 ounces to the dish", i.e. about 16 to 21 kg of tin concentrate per m³. Four samples of ore from the lower levels of the mine averaged 1.79, 0.55, 3.46 and 1.09 per cent Sn respectively (Maitland, 1901).

An easterly cross-cut 40 m long from the three compartment shaft at the 27.4 m level intersected three narrow lodes, of which two had been stoped at the time of Wilson's visit.

A third lode, described by Woodward (1908), is parallel to, and 30 m east of, the northern part of the main lode. It consists of micaceous material (?greisen) about 60 m long and reaching 4.2 m wide. In 1907 it had been mined over a distance of 36 m to a depth of 9 m.

The distribution of shafts on the surface of the mine area (see for example, Hobson and Matheson, 1949, Plate 2) indicates that a fourth lode exists about 50 m west of the main lode, and that another tin-bearing pegmatite was worked about 100 m north of the east lode.

Drilling results: The results of four diamond drill holes put down by the Mines Department in 1928 are summarized in Table 27. Further details can be found in Larcombe (1929) and Howe (1929). The collar positions are shown on Plate 2 of Hobson and Matheson (1949).

South Cornwall-Police cut

The South Cornwall-Police cut deposits include three connected lenses of pegmatite situated near the southwest corner of Greenbushes townsite. Two of these are being mined from open cuts, but the third is largely unmined due to its proximity to the highway.

Published descriptions of the South Cornwall mine collated by Hobson and Matheson (1949) refer mainly to the lode mined from the main shaft. This lode was worked to a depth of 39.5 m over a maximum width of 2.4 m, but a cross-cut easterly from the main shaft passed through 23.7 m of tin-bearing material.

In 1907, during an attempt to test the lode at depth, a prospecting shaft was sunk to a depth of 62.3 m from a collar sited 24.3 m southerly from the main shaft, on the hanging wall (western) side of the pegmatite lens. Although pegmatite was apparently intersected in an easterly cross-cut from the prospecting shaft, no significant tin contents were recorded.

TABLE 27. DETAILS OF DIAMOND DRILLING ON THE CORNWALL LEASE—1928

Hole No.	Depression and azimuth	Location of collar (1)	Depth in hole of intersection (m)	Rock type	Horizontal width (m)	Assay (%SnO_2)
1	45° dep 102° az	260°,118m	17.02-17.18	Pegmatite	0.10	0.002
			51.98-52.39	Vein quartz	0.28	0.004
			73.87-74.78	Garnet-tourmaline pegmatite	0.63	0.22
2	45° dep 096° az	274°,124m	79.95-82.46	Tourmaline pegmatite	1.78	0.38
3	45° dep 100° az	287°,136m	31.92-34.35	?Tourmaline aplite	1.73	0.32
			36.48-38.00	Tourmaline pegmatite	0.86	0.12
			76.61-77.06	Albite pegmatite	0.33	tr.
4	45° dep 075° az	227°,126m	34.96-35.26	Greisen	0.20	0.13
			60.27-60.83	Tourmaline pegmatite	0.41	0.57
			64.45-65.36	Tourmaline greisen	0.63	0.17
			77.82-78.58	?Tourmaline pegmatite	0.56	tr.

NOTES:

(1) Locations of drill-hole collars—bearing and distance from the three-compartment shaft.

Reports suggest that the shaft itself was entirely in amphibolite, an impression also gained from material on its dump.

Other old workings in the vicinity of the South Cornwall mine are shown on Plate 2 of Hobson and Matheson (1949). They comprise a small open cut immediately south of the main shaft, and a line of shafts and pits extending northwards to cross the highway 60 m south of the Greenbushes town boundary. Subsequently most of the diggings on the western side of the highway have been incorporated in an open cut which is about 30 m deep and joins the Police cut to the north. From time to time, remains of the old shafts are exposed in the walls of the cut, where it can be seen that the narrow "lodes" described in early reports were in fact greisen lenses or richer streaks within a single pegmatite dyke about 30 m wide. Most of the dyke consists of quartz, kaolin and muscovite, with a prominent foliation, picked out by tourmaline bands, dipping at 40 degrees west. Veins 10 to 30 cm wide of massive kaolin, apparently replacing sugary albite, form stockworks cutting the pegmatite. Many of the kaolin veins dip at a low angle to the east. The overall dip of the pegmatite lens is about 70 degrees west.

In 1972, a sample of green-stained kaolin from the South Cornwall cut was determined by the Government Chemical Laboratories to contain turquoise (hydrous phosphate of aluminium and copper). This is the only record of copper minerals in the Greenbushes pegmatites.

Prior to about 1942, workings in the Police cut area consisted only of 2 or 3 shafts. Underground testing undertaken by the Mines Department in 1942 showed that beneath a capping of tourmaline-bearing laterite was a zone of tin-bearing pegmatite veins between 15.2 and 18.2 m wide. Sometime between 1942 and 1970, an open cut 12 m deep was excavated on this zone.

In 1970, the north face of the open cut showed a weathered pegmatite, 6 m in true width, intruding weathered amphibolite. The dyke dipped 45° west, but had more steeply dipping branches on its footwall side. Another similar dyke was exposed in the eastern side of the cut, but its full width could not be seen. Since 1970, the Police cut has been deepened and lengthened, and now connects to the South Cornwall cut.

An eastern branch of the South Cornwall vein is known as the Highway shoot. It has been traced, by drilling, to the south boundary of Greenbushes townsite, and for much of its length it lies beneath the South West Highway. The branch is about 30 to 35 m wide and dips 50 to 60 degrees west. Grade indicated by drilling is 1.42 kg/m^3 of tin oxide, and reserves of indicated plus inferred ore are assessed at about 520 000 m^3.

Drilling: In 1928, Government hole No. 6 was drilled to test the South Cornwall vein at a depth of about 60 m. The hole was collared about 50 m on a bearing of 265 degrees from the prospecting shaft and drilled on an azimuth of 060° at 45° depression to a hole depth of 89.9 m. Pegmatite with only traces of tin was intersected in the intervals 40.5 to 44.8 m, 60.7 to 61.0 m, and 70.4 to 71.8 m. Another intersection from 68.9 to 70 m was apparently not assayed for tin.

Two further vertical holes were drilled by Greenbushes Tin N.L. in 1973. The first, collared 50 m below natural ground level in the Police cut, intersected 4.5 m of kaolinized pegmatite, 10 m of friable pegmatite, 14 m of crystalline pegmatite and then passed into fine-grained biotite gneiss. The weighted average tin oxide contents of the pegmatite sampled were 0.17 per cent SnO_2, 0.026 per cent Ta_2O_5 and 0.031 per cent Nb_2O_5.

The second hole was collared over the Highway shoot and drilled with a rotary rig until unweathered pegmatite was met at about 39.5 m. The hole was then continued by diamond drilling, passing through the footwall of the vein at 49.8 m and terminating at 59 m in biotite gneiss. The 10.3 m of fresh pegmatite obtained assayed 0.16 per cent SnO_2, 0.014 per cent Ta_2O_5 and 0.016 per cent Nb_2O_5.

North Cornwall cut

The probable northern extension of the western lode worked on the Cornwall lease passes into the southeast corner of the Greenbushes townsite. It was formerly mined from a number of shafts and a small open cut for a recorded total of 12.22 tonnes of tin concentrate (Table 26). More recently (about 1974) Greenbushes Tin N.L. established the North Cornwall cut on the lode.

The pegmatite dyke exposed in the cut is about 20 m wide, strikes northwesterly and dips 65° southwesterly. It has a distinct cataclastic foliation parallel to its contacts. About midway along the cut the lode is interrupted by a 'bar' of barren rock regarded by the miners as an intrusion of 'greenstone'. The 'bar' consists of weathered amphibolite and granofels and is veined by many small pegmatites emanating from the main dyke. It seems to be a block of country rock rafted and rotated during intrusion of the pegmatite dyke. The contact between the dyke and the raft is illustrated in Figure 11a.

Lemonade Springs-Vultan workings

The workings grouped under this heading comprise a number of coalescing open cuts located on the principal pegmatite dyke here lying parallel to and immediately east of the South West Highway. They include the area known as Tantalite Corner, and the old Enterprise and Wills leases. Production shown in Table 26 is considerably understated, because much of the recent mining by Greenbushes Tin N.L. and Vultan Minerals Ltd has taken place on this group.

There is little published information on the old workings. Campbell (1906), reporting on the Enterprise lease near the south end of the group, described an open cut 3.6 m deep exposing 21 m of alluvium underlain by lode consisting of kaolinized pegmatite. Cassiterite, tantalite and stibiotantalite were mined from the cut. Where exposed in a shallow shaft the lode had a strike of 323° and dipped 22° southwest. It formerly passed beneath the highway, but subsequently the road was re-routed to the west, and the lode became available for mining.

Hobson and Matheson (1949, p.150, Fig.14) described and illustrated the Enterprise workings as they were in 1943. They recorded that pieces of tantalite weighing up to 23.6 kg were found in the northern end of the diggings, and that workings reached a depth of 12 m. Their Plate 2 also showed a number of shafts further to the east in the present position of the Vultan cut, but no details of these openings are given in the text.

Prospecting work on M.L.9 (now M.L.648) is described by Ellis (1944a) and shown on Mines plans 25/224 and 26/224. At a position about 80 m northeast of the northeast corner of W.R.289, two shafts were sunk to a depth of 10.6 m. A connecting drive along the footwall of the pegmatite vein was extended for 13.7 m north and south of the more northerly shaft, from which a crosscut was driven westerly for 7.6 m to the hanging wall of the vein. The pegmatite body tested was about 7.1 m wide, trended at 335° and dipped 40° west. In the drive it contained an average of 0.165 per cent SnO_2 and 0.164 per cent $(Ta,Nb)_2O_5$, while its average grade in the cross-cut was 0.066 per cent SnO_2 and 0.026 per cent $(Ta,Nb)_2O_5$.

Present workings in the group consist mainly of four open cuts, of which the two southernmost are too closely spaced to be distinguished separately on Plate 7.

The most northerly cut which was about 20 m deep in 1973, is in weathered pegmatite underlying 2 to 3 m of laterite, clay and older alluvium. Earlier work in the eastern part of the cut consisted almost wholly of mining Greenbushes Formation but in the deeper western part of the excavation, the material mined was mainly weathered pegmatite.

The next cut southwards is in the area known as Lemonade Springs. It is about 200 m long, 100 m wide and 15 to 20 m deep, exposing foliated kaolinized pegmatite with lenses of massive greisen and crosscutting veins of kaolin after ?albite. The marginal parts of the lode consist of stockworks of pegmatite veins cutting weathered amphibolite and gneiss.

The two southern cuts are separated only by a narrow wall of weathered rock marking the boundary of leases held by different operators working the same lens of pegmatite. The ore body has a width of at least 45 m in its central part, but divides into two narrower tongues to the north. Foliation in the pegmatite dips from 30° to 40° west, although the dyke itself seems to dip more steeply west.

The larger (Vultan) cut was worked by Vultan Minerals Ltd. It includes the tantalite workings on M.C.9 described above, remains of which can be seen at times in the walls or face of the cut. Where sampled in 1970, the pegmatite was 18 m wide, and in places reached a width of 30 m. The lode worked by Greenbushes Tin N.L. in the western cut is similar, but has an overburden of yellow sand and old tailings.

Grade: Twelve channel samples taken serially across the Vultan cut in 1970 contained an average of 0.035 per cent SnO_2, 0.008 per cent Ta_2O_5, and 0.0055 per cent Nb_2O_5. Quarterly returns of production published at about that time indicate an average grade of about 0.35 to 0.50 kg/m³, or about 0.002 to 0.03 per cent tin concentrate.

Reserves: Drilling by Vultan Minerals Ltd on M.L. 648 in 1969 indicated about 105 000 m³ of ore to a depth of 30 m, and allowed another 620 000 m³ to be inferred. The pegmatite lens is 45 to 60 m wide, and is kaolinized to a depth of 30 m (from *The West Australian*, 18/2/69).

Bunbury Gully

Bunbury Gully rises near W.R. 289 and flows southerly to join Westralia Gully on the Vulcan lease (M.L. 647). Workings along its upper part are now largely obliterated by the open cuts on the Vultan and Lemonade Springs pegmatite bodies. Those south of M.L. 648 include some of the earliest alluvial diggings on the field, and a few small lode mines such as the Lost and Found and King Tin.

The former alluvial miners worked deposits of iron oxide-cemented eluvium together with Tertiary and Recent alluvium. Simpson and Gibson (1907) recorded that shafts on M.Cs 712 and 762 were sunk to depths of 6 to 9 m to gain access to 30 to 75 cm of cassiterite-bearing gravel. On the King Tin lease, a little further south, the mined gravel was 90 to 120 cm thick at a depth of 10.3 m, and at the mouth of Elliot Gully 15 cm of gravel were worked beneath 12 m of overburden. Apart from the cassiterite, tantalite, stibiotantalite, and a little gold were recorded from Bunbury Gully.

A number of narrow lodes were also mined; the deepest opening recorded being a shaft 27.4 m (or possibly 31.9 m) deep on the Lost and Found lease. Other lodes were worked on the Haphazard, Amanda, and Lost and Found North leases. Descriptions of the old workings given by Maitland (1900b), Montgomery (1904), Campbell (1906), Simpson and Gibson (1907), Woodward (1908), Wilson (1929) and Ellis (1939a) are summarized or quoted by Hobson and Matheson (1949, p. 169-184).

In the Lost and Found mine, short levels were put in at depths of 22.8 m and 27.4 m from the main shaft. The lode on the 22.8 m level was 45 cm wide and dipped easterly. On the 27.4 m level, two lodes were encountered, one 30 cm wide in the drive and the other 60 cm wide in a westerly cross-cut. The main shaft was sunk (?deepened) to intersect a west-dipping lode worked at the surface, but it is not reported whether this objective was achieved. Ore treated during 1906 averaged 1.3 per cent tin concentrate.

Later work in Bunbury Gully consists of shallow sluice cuts (e.g. Angus and Western Queen cuts) in Recent alluvium and Greenbushes Formation, and some deeper cuts (e.g. Johns cut) excavated in weathered pegmatite beneath the superficial deposits.

The only mining in Bunbury Gully during the writer's inspections was in Johns cut. Here Vultan Minerals Ltd operated an open cut 5 to 10 m deep in white and blue clay underlying laterite and old tailings. Some patches of Greenbushes Formation were also present, particularly near the centre of the face, but most of the deeper exposures were weathered amphibolite (blue clay) cut by weathered, tourmaline-bearing pegmatite veins. No information on the grade of the ore is available.

During a (GSWA) kaolin survey in 1973, S. Lipple collected samples of kaolinized pegmatite from costeans and cuts located from about 150 m to 400 m north of Johns cut. It was in this area that Hobson and Matheson (p.175 and Plate 3) recorded that a large, well-defined lode formation had been indicated by drilling in the Fremantle cut.

Drilling: Two holes, numbers 7 and 8, drilled by the Mines Department in 1928 were aimed to test the Lost and Found lode at depth. Positions of the collars are shown on Plate 3 of Hobson and Matheson (1949). Hole 7, drilled easterly at a depression of 50° passed from weathered to fresh "greenstone" between 24.3 m and 30.4 m, and intersected pegmatite with an average grade of 0.90 per cent SnO_2 from 37.7 to 38.15 m depth. Completion depth was 76 m.

Hole 8, depressed at 70° and drilled easterly, cut 10 cm of pegmatite at a depth of 37.2 m. The intersection assayed 0.39 per cent SnO_2. The wall rocks were again "greenstone", determined petrographically as fine-grained hornblende schist.

Results of an extensive boring programme undertaken in Bunbury Gully during 1939 are summarized by Hobson and Matheson (1949, p.169-176 and Fig.15). The drilling indicated reserves of 565 000 m³ of alluvium averaging 0.78 kg/m³ of tin concentrate.

During 1942, another drilling programme designed to test a more northerly part of Bunbury Gully encountered trouble with hard laterite. Only six holes were completed, two of which indicated a small patch of alluvium 1.7 to 2.7 m thick. Details are given by Hobson and Matheson (1949, Table 21).

Vulcan lease

The Vulcan lease (M.L.647) is identical to former M.C.4 and M.C.56. It includes the Vulcan cut and the main workings of the former Caledonian, Ironclad, Battery Hill and Southern Cross leases, as well as alluvial diggings in the lower part of Westralia Gully.

Descriptions of the workings are given by Ellis (1939a) and Hobson and Matheson (1949, p.186-190).

The largest opening on the lease is the Vulcan cut, a sluice cut about 250 m long, 70 to 80 m wide and at least 12 m deep. Its main period of production was from 1937 to 1943. At the time of the writer's inspection, the cut was largely filled with water and tailings. The lode exposed in the southern end consisted of kaolin, quartz, muscovite and tourmaline. Some of the material had the texture of granite gneiss veined by pegmatite, and a relict schistosity striking 330° and dipping 35° southwest is generally well preserved.

Ellis regarded the lode as being formed by replacement of amphibolite by granitic material. However, in view of the better exposures of the primary tin deposits now present in other parts of the field, it seems more likely that the ore consists in part of pegmatite-veined amphibolite and gneiss, and in part of more continuous pegmatite. The greatest width of ore recorded by Ellis is 60 m, and the average width worked about 30 m.

Besides cassiterite, small amounts of beryl, tantalite, ilmenite and magnetite are recorded from the cut. Ellis estimated that the ore treated in 1937 averaged 3.2 kg/m^3 of concentrate containing 57 per cent tin.

The Ironclad workings, located south of the Vulcan cut, comprised a number of shafts sunk through laterite to mine pegmatite veins in amphibolite. The veins appear to be a continuation of the lode worked in the open cut. Recorded production is low, but is probably understated. A recent southern extension of the open cuts (not shown on Plate 7) probably incorporates the old Ironclad workings.

The Last Chance mine, located about 650 m south of the Ironclad, may also be on the same line of pegmatite. A shaft 11.5 m deep exposed a pegmatite vein striking at 020°, dipping steeply east, and ranging in width from 70 cm to 1.4 m.

Westralia Gully

Westralia Gully, a small east-flowing tributary of Bunbury Gully, was the scene of a considerable amount of early mining. Information on the old diggings is limited; at the time of Hobson and Matheson's (1949) investigation the cuts were filled with water. Subsequently they were covered by tailings from the Vulcan mine and the Greenbushes Tin N.L. dredge.

Woodward (1908, p.71) described one shaft 9.2 m deep sunk on rising ground south of the gully. The shaft intersected 30 cm of tin-bearing gravel beneath 4.6 m of sand and conglomerate.

NORTHERN DEPOSITS

The mainly alluvial diggings within the Greenbushes Formation extending northwards from Greenbushes to the railway line (Plate 7) include the localities known as the White lode, New Zealand Gully, Dumpling Gully, Herberts orchard, and Location 10441 as well as several small cuts and pits between the White lode and the Showground.

Production of tin concentrate which can be attributed to the northern deposits amounts to 1 705.92 tonnes, but as much of the early production was from unregistered claims the total figure must be considerably greater than this. Mining in the main period of production, 1906 to 1921, was principally by hydraulic sluicing, water being obtained from the Blackwood River. Woodward (1908) recorded that cemented alluvium retained in the screens was carted to the State Battery, crushed, and passed over concentrating tables. Some of the "lode" tin shown in Table 26 is probably from cemented alluvium. Prior to 1906 the deposits were exploited from handworked open cuts, the ore being carted to puddlers for treatment. Some underground mining of the richer gravels was also carried out but proved to be too dangerous. More recently earth moving machinery has been used to mine further material from the White lode and from the more easterly deposits. This ground was treated at Austin's plant and the production evidently included with that from M.L.707 (Boronia Gully).

White lode

The workings now known as the White lode contain the former W.A. Mount Bischoff and North Junction leases. They consist of shallow cuts and pits in lateritized Greenbushes Formation overlying kaolinized amphibolite. Veins of weathered tin-bearing pegmatite in the bedrock have been mined along with the alluvial material. The average depth of the tin-bearing ground (laterite, sand and Greenbushes Formation) seen in the recent cuts was about 3 m.

Drilling by Greenbushes Tin N.L. (Thomson, 1973a) has revealed some patches of ground with mineable depths of from 2.7 to 4.5 m, and cassiterite contents of from 0.4 to 1.0 kg/m^3.*

There is no information on the grade of ore mined in the past.

New Zealand Gully

The main workings in the northern area are along New Zealand Gully, a large alluvial flat at the head of

*These and other grades quoted from Thomson (1973a) have been converted from pounds per cubic yard of loose ground assuming an expansion factor of 1.2

Dumpling Gully. Among the more important early mines were the Lady Esther, at the head of the gully, the Little Wonder, Horans, and Mount Bischoff No. 2 located on its south side. Little if any recent work has been done in New Zealand Gully; some of the old pits have been converted to dams to provide water for Herbert's orchard and Austin's plant.

Almost all of the cassiterite produced in this area came from deposits in Greenbushes Formation. Exposures in the bank of the gully near the old Lady Esther workings show 3 m of clay-bound grit and pebble beds of which the uppermost 1.5 m are lateritized. Drilling done by Greenbushes Tin N.L. (Thomson, 1973a) indicated that the formation in the vicinity of the gully is 4.5 m thick, with an average cassiterite content of about 0.6 kg/m^3.

Locations 10441 and 11341 (M.L. 718)

Two shallow cuts in the Greenbushes Formation have been established on Locations 10441 and 11341, west of the road to North Greenbushes. In the larger cut on Location 10441 the sediments are 3 m thick and consist mainly of sandy clay with abundant ironstone nodules, overlying weathered amphibolite. The average grade of the sediments is about 0.6 kg/m^3. The smaller eastern cut is about 2 m deep in grey sand. The Greenbushes Formation on Location 10441 was tested by the Mines Department (MacLeod, 1962) and found to be tin-bearing only in the vicinity of the present workings.

Dumpling Gully

West of the highway a number of cuts have exploited old gravels on the southern side of Dumpling Gully. The cuts range from about 2 to 5 m deep and expose weathered amphibolite at the base of the alluvium. One lease, the Old Sport, yielded a small quantity of tin concentrate from weathered pegmatite averaging about 0.5 per cent tin oxide (Simpson and Gibson, 1907). Recent workings comprise a shallow cut adjacent to the recreation ground.

Herbert's orchard

Herbert's orchard (M.H.Ls 30, 35, 36 and G.As 49 and 50) covers the former Glasgow and Gladstone leases and part of the Central lease. Most signs of the old diggings have been covered by cultivation, and information on them in earlier reports is sparse. Simpson and Gibson (1907) recorded that a lode 1.5 m deep was mined to a depth of about 10 m on the Glasgow lease. Other diggings in the area were apparently in the "older alluvium" shown on Woodward's (1908) map. Immediately opposite the orchard on the western side of the highway is a large, shallow cut in Greenbushes Formation which here has a maximum thickness of about 2.5 m. The cut was worked by Vultan Minerals Ltd, the ore being carted to the Company's plant on the Vulcan lease.

Other deposits

Between the White lode workings and the Showground reserve are a number of small cuts and pits in Greenbushes Formation and associated laterite, ranging from about 1 to 3 m deep. Drilling by Greenbushes Tin N.L. has shown several small patches of mineable ground ranging in grade from 0.34 to 0.66 kg/m^3.

WESTERN ALLUVIAL TRACT

The extensive workings in Greenbushes Formation on the western side of the central belt are conveniently grouped for description and referred to as the western alluvial tract. The northern end of the tract includes a low laterite ridge forming the watershed between Dumpling Gully and Spring Gully. Further south, between Spring Gully and the head of Cowan Brook, the tract occupies the former position of a line of alluvial flats and ti-tree swamps.

Spring Gully, Mulligan Gully, Gibney Gully, Mount Pleasant

Early work in the northern part of the western tract was concentrated mainly in the vicinity of Spring Gully (both the main channel and the north branch), Mulligan Gully, Gibney Gully, and the laterite ridge between these features (Mount Pleasant). Woodward (1908) estimated that to 1907, 25 per cent of the field's production had come from Spring Gully.

In Spring Gully and Mulligan Gully both Recent and Tertiary alluvium were mined along the creeks. In the main channel of Spring Gully the younger alluvium was 30 to 90 cm thick and 16 to 18 m wide, overlying an unrecorded thickness of Tertiary alluvium made up of stiff white clay with heavy mineral bands. At the head of Mulligan Gully about 30 cm of tin-bearing gravel was worked beneath 5 m of overburden. The old workings on Location 289 and 290 (Gibney) consist of a number of sluice cuts some of which were recorded as 3 to 3.7 m deep. Between Mulligan Gully and the north branch of Spring Gully is a large area containing tin-bearing sand and laterite formed over Greenbushes Formation. This was worked extensively in the early days of the field and more recently has been stripped for treatment at the "sand plant" of Greenbushes Tin N.L. The sediments exposed in several cuts are generally fine grained. A typical section showed 90 cm to 1.5 m of yellow sand over 1.8 to 2.4 m of laterite with quartzite pebbles, overlying in turn 2 m or more of mottled clay with small quartz and tourmaline grains.

On the old Mount Pleasant lease at the head of Spring Gully, old shafts and cuts from 4.5 to 9 m deep worked tin-bearing gravel and laterite. Maitland (1901) noted tin-bearing, weathered granite at the head of Mulligan Gully but this has not been confirmed by later workers; possibly he was misled by the resemblance of finer grained Tertiary alluvium to weathered granite. Most cassiterite obtained from the area is water worn. The vicinity of Mount Pleasant has also been called the "sand plant area".

A short section of the south branch of Spring Gully was mined prior to 1943 (Hobson and Matheson, 1949). More recent work commenced in 1949, continuing until 1965, with the production of 529.13 tonnes of concentrate. The area now know as Austins was again worked as part of Greenbushes Tin N.L.'s dredging operations in 1971-2. Old cuts were reported by Hobson and Matheson to have had a maximum depth of 4.2 m and to have probably reached bed-rock. Sections seen in various cuts prior to dredging suggest that most of the work in the 1950s was aimed at stripping between 60 cm and 2 m of sand overlying the laterite. At least one cut exposed 3 m of lateritized alluvium. However, a considerable part of the material dredged by Greenbushes Tin N.L. in this locality must have been old tailings from the former operations. Hobson and Matheson reported cassiterite contents between trace and 0.3 kg/m³ in shallow samples taken in this area.

Three Cs

The principal old diggings in this area were at the head of Moulton Brook (Battlers Hope) and near the southeast corner of M.L.681 (Three Cs). They consisted mainly of shallow cuts in residual sand over Greenbushes Formation. Between the two groups of cuts an horizon of gravel was mined from a large number of shafts sunk to depths of between 3 and 10 m. This gravel horizon apparently lensed out before reaching the Battlers Hope workings and surfaced north of the Three Cs cuts. Two deep shafts sunk prior to 1902 (Woodward, 1908) and nine bores put down in 1936 (Forman, 1937) indicate that there is a considerable thickness of blue, sedimentary clay beneath the old workings. This clay is underlain by a deeper horizon of sand and gravel with cassiterite contents between trace and 0.8 kg/m³. Because of the thick clay overburden and the generally low tin contents no attempt has been made to mine this lower sand and gravel horizon. However, the deposit may warrant investigation in the future.

Hobson and Matheson (1949 p.119-132, Plates 8 and 9) gave the results of samples taken from the old shafts and dumps in this area. As most of this ground has been either dredged or strip-mined the results are not reproduced in detail here. Briefly, they indicate that in the ground worked from the shafts (now on M.L.681), the overburden contained up to 0.3 kg/m³ of tin oxide; ore (sampled *in situ*) had between 0.9 and 4.7 kg/m³ of tin oxide, and the main dumps held between 0.2 and 1.2 kg/m³ of tin oxide. Near the present large cut in the central eastern part of M.L.676 further samples were taken from dumps of shafts sunk through blue-grey clay into gravel. Remnants of the gravels found near the old shafts yielded between 2.9 and 5.9 kg/m³ of tin oxide but the shaft dumps and the overburden contained less than 0.3 kg/m³ of heavy mineral concentrates.

Cowan Brook

The swampy ground at the head of Cowan Brook includes the area known as Poverty Flat. Prior to being dredged by Greenbushes Tin N.L. it contained extensive shallow workings. In some places laterite was worked and in others mining was of sand overlying the laterite. Samples taken by Hobson and Matheson (1949, p.145) yielded about 0.6 kg/m³ of heavy minerals. Woodward (1908) notes that the bed of Cowan Brook had been worked where it cut the Greenbushes Formation to yield about 65 tonnes of tin concentrate. The annual reports of Greenbushes Tin N.L. for 1965-66 and 1966-67 indicated that the sand dredged at the head of Cowan Brook had an average depth of 4.2 m and contained about 0.36 kg/m³ of tin concentrate, although actual recovery for these years was only 0.11 and 0.18 kg/m³ respectively. The material dredged comprised sand, laterite, older alluvium and tailings. An extensive area of ground north of the dredge path was either sluiced or strip-mined, with the dredge being used as a treatment plant. These workings consist of cuts 1 to 2 m deep in sand and lateritized Tertiary sediments resting on weathered amphibolite.

Coles cut-Elliot Gully

The workings in the vicinity of Coles cut and Elliot Gully are included in western alluvial tract although they merge with the diggings in Bunbury Gully in the central belt. An attempt to split the production between these areas is made in Table 26, but the result is only approximate. Elliot Gully is a short, southeasterly-flowing tributary of Bunbury Gully, draining a low rise underlain by Greenbushes Formation. It was at the junction of Elliot and Bunbury Gullies that Stinton discovered the first tin ore at Greenbushes.

Coles cut very nearly covers the area of Elliot's original claim (219A). With adjacent cuts, it exposed up to 15m of sandy clay and pebble beds overlying from 60cm to 2.4m of coarse ferruginous boulder conglomerate. A section formerly well-exposed in Keysers cut, immediately east of Coles cut, is as follows:—

Description	*Thickness (m)*
Laterite	1.5
Sand, sandy clay with pebble beds and heavy mineral streaks; crossbedded in places	9.0
Pebble conglomerate with patchy ferruginous cement and heavy mineral bands	1.5
Boulder conglomerate with ferruginous cement and heavy minerals	1.8—2.4
Basement; blue-grey clay derived from weathered amphibolite	

In Coles cut the lowermost conglomerate bed, 30 to 60m thick, is overlain by 1.8 to 4.5m of tourmaline-bearing sand. Early work in Elliot Gully was in Recent alluvium which passed into the Greenbushes Formation at shallow depth. Near the mouth of the gully the older sediments are about 12m thick consisting of cemented gravels resting on an uneven floor of residual clay. In the period 1937 to 1940 an attempt was made to dredge the alluvium in the lower part of Elliot Gully and over a contiguous part of Bunbury Gully. However, the dredge proved incapable of treating the ground and the enterprise was abandoned after the production of only 1 or 2 tonnes of tin concentrate.

EASTERN AREA

In the largely laterite-covered area between the central pegmatite belt and Salt Water Gully, a recorded total of 111.23 tonnes of tin concentrate has been mined from Recent and Tertiary alluvium and from a few lode deposits.

Deposits in Recent alluvium

The earliest diggings in the eastern area were in Recent alluvium along Salt Water Gully and its tributaries Scandinavian Gully, Floyd Gully and Kelly Flat. Workings extended from the head of Salt Water Gully to its junction with Kelly Flat, and along the lower parts of the three tributaries. The principal cuts were at the junction of the main stream and Scandinavian Gully. The material mined was sand or sandy clay, but few details of thicknesses or grade were recorded.

Deposits in Greenbushes Formation

Extensive cuts have been made into Tertiary sediments east of the South Greenbushes townsite, at the head of Floyd Gully and on the water shed between Scandinavian and New Zealand Gullies. In 1972-73 Greenbushes Tin N.L. stripped shallow deposits of older alluvium from M.Ls 666 and 680 at the head of Floyd Gully, and from the central part of M.L.650 near Wilkie's Road.

The former South Greenbushes Tin Dredging Syndicate workings on D.C.111 (now M.C.675) comprise sluice cuts in 3 m of gravel overlain by 50 cm to 1 m of laterite. The gravel is made up of poorly-rounded cobbles and boulders of quartzite in a tourmaline-bearing matrix.

The deposits near the head of Floyd Gully consist of 60 cm to 1.5 m of laterite containing semi-rounded quartz boulders and detrital material shed from nearby pegmatites. Strip mining of this material was in progress in 1973.

The Tertiary alluvium at the head of Scandinavian Gully contains a number of scattered openings, the largest of which is a cut about 3 m deep on former D.C.53.

The tract of Greenbushes Formation extending from South Greenbushes to Floyd Gully has been worked from several clusters of shafts, and, more recently, by strip mining carried out near Wilkie's Road. The deposit is only 1 to 2 m deep near South Greenbushes but further north near the head of Kelly Flat it increases to a depth of 5 or 6 m. At the northern end of the tract the alluvium was reported to be 13 m thick. Samples collected by Hobson and Matheson contained between trace and 2 kg/m^3 concentrate.

The Greenbushes Formation in the eastern area has been almost completely tested by drilling at 45.6 m (150 ft) centres, and is estimated to contain 1 130 000 m^3 of mineable ground with 645 tonnes of tin oxide (Thomson, 1973a).

Lode deposits

The only important lode in the eastern area was that worked in the Kapanga mine. A small production of lode tin is recorded from the Last Chance lease, and apparently unsuccessful attempts were made to mine or search for tin lodes in Elias' tunnel (Woodward, 1908), and the old Queen of Greenbushes and Ruby leases (Maitland 1901, p.13-15).

Kapanga mine: The Kapanga (or Katanga) mine operated from 1910 to 1929, although previously the same ground was held at various times as the Victoria, Tairua, Hokitika and Wheal Fortune leases. Total production recorded from the lode is 42.46 tonnes of tin concentrate.

The only plans of the now inaccessible underground workings accompany the report of Feldtmann (1914). At the time of his inspection, several years before the mine finally closed, the workings consisted of four shafts spaced over a distance of 80 m. The main shaft was 29.2 m deep and from it about 27 m of driving was carried out at the 14.3 m level, over 75 m at the 22.8 m level, and about 6 m at the 26.7 m level. The lode strikes north and dips 70 to 80 degrees east. It ranges in width from 1 m to 4.6 m on the 14.3 m level but narrows to a stringer in places between the 22.8 m and 26.7 m levels. Foliation planes in the lode dip at about 65 degrees west, across the dip of the lode but parallel to the foliation in the amphibolite wall-rock.

Feldtmann noted two further parallel lodes on the lease and some other old shafts are situated about 300 m south of the main workings.

In 1929 the Mines Department drilled three holes to test the Kapanga lode beneath the old workings. All holes reached their intended depths but failed to intersect lode material. Details given by Howe (1930) are reproduced by Hobson and Matheson (1949, p.163).

OUTLYING AREAS

A recorded total of 263.73 tonnes of tin concentrate was mined from outliers of the Greenbushes Formation at Boronia Gully, Mount Jones and the old Ethel May lease. Production has come entirely from secondary deposits.

Boronia Gully

Old workings in Boronia Gully consist of a large sluice cut extending southwards from the southern boundary of Location 9948 for about 600 m to the junction of a west-flowing tributary (Hobson and Matheson 1949, Plate 1). This cut was mainly in Recent alluvium derived from Greenbushes Formation exposed at the head of Boronia Gully. More recent work on M.L.707 has produced shallow cuts in 1.2 to 2.4 m of sand over about 1.5 m of lateritized Tertiary alluvium. Grid boring by Greenbushes Tin N.L. has indicated 19000 m^3 of material containing 17.6 tonnes of cassiterite.

Mount Jones

The main workings at Mount Jones are old sluice cuts in about 2 m of Tertiary sediments. Some production may also have come from a small creek flowing into Norilup Brook. The material mined was white sand with a few pebbles of quartzite, mostly unconsolidated, although in places it was clay-bound or cemented by iron oxide. Weathered quartz-feldspar gneiss is exposed in the floors of the cuts. Maitland (1910, p.15) recorded that the cassiterite was fine grained and angular, and accordingly postulated a nearby source.

Ethel May

The former Ethel May and Morning Star leases cover an outlier of Greenbushes Formation on the south side of Spring Gully. The leases cover a number of old shafts and cuts and some more recently stripped areas. The ore is mainly residual sand, apparently overlying the Tertiary deposits.

RESERVES AND RESOURCES

No recently published ore reserves are available for Greenbushes. In 1974 Greenbushes Tin N.L. had indicated reserves sufficient for 5 years operations, and subsequently have attempted to replace mined reserves by further drilling.

Reserves are located mainly within the weathered pegmatites of the central belt, but also include some secondary deposits.

Unexplored depth extensions of the pegmatites appear to be the main remaining resource in the Greenbushes field. Unfortunately mining by present methods is restricted to the weathered zone and will probably find bottom at about 40 m average depth. Strike extensions of the pegmatites are possible, especially beneath the laterite extending northwards from Greenbushes townsite. Southwards from Greenbushes the terrain is more dissected and any pegmatites are likely to have been located by conventional prospecting methods.

Many parts of the Greenbushes Formation which were only patchily mined in the past may again become economic if the price of tin continues to rise. The extent of these areas can be gauged from Plate 7. Many of the partly worked exposures shown on the map are now covered by tailings, making them more costly to explore and exploit.

The deep (30 m) channel penetrated by old shafts and drill holes in the Three Cs area should contain concentrations of cassiterite below the present economic depth of alluvial mining, and may become worthy of more attention in the future.

PROSPECTING RECOMMENDATIONS

The absence of an identified tin granite at Greenbushes makes planning of regional exploration a difficult task. If, as the writer believes, the tin is not related to the presently exposed Darling Range-Wheat Belt granite, then prospecting in that batholith is unlikely to produce results. However, adjacent to this batholith is a major structural feature the Hester Lineament, which parallels the Greenbushes pegmatite zone and may have offered a channel for similar bodies.

MINOR DEPOSITS IN THE SOUTH-WESTERN PROVINCE

SMITHFIELD

General information

Several small tin deposits have been reported in an area of State Forest centred about 15km southwest of Bridgetown, south of the Brockman Highway. The first discovery was made by W. Smith and G. Gough in 1907. The news of the strike caused a minor rush, bringing about 70 men to the area, mainly from Greenbushes. Shortly after the discovery, the find was inspected by Talbot (1907) and by Warden Geary of Bridgetown, who named the locality Smithfield, and a small cassiterite-bearing creek Gough Gully. (*'The West Australian'*, April 11th, 1907). The field was declared to be suitable only for claims, with the result that no lease surveys were made, and the position of the field was never located accurately. Estimates placed it anywhere from 10 to 16 km southwest of Bridgetown.

The rush seems to have been short-lived, for the field was found to be abandoned when visited in 1917 by R. C. Wilson in the company of Gough. Some further activity in the area was noted by Crabb (1921) when he inspected a 'new' discovery which proved to be on the site of old diggings in the vicinity of Willow Springs.

In 1931, another find was reported by Donovan and examined by Blatchford (1932), who showed its position on an unpublished plan. Although the locality was some distance from earlier plots of Smithfield, Blatchford's description of the new discovery tallied remarkably well with those of the older field. This locality subsequently became known as Donovans Find, and is shown as such on some current plans. However, it is almost certainly identical with Smithfield; confirmation of this common identity seems to be implied by Brisbane (1951), who visited the find with Donovan, but referred to it as Smithfield.

Unpublished file reports indicate that the Donovans Find area was tested by drilling in 1942, 1951, 1963 and 1966, and that an attempt to mine it was made in 1951.

Little information is available on the other tin finds in the Smithfield area. Wilson (1917) briefly describes deposits at Native Dog Gully, Coated Tin Hill and Willow Springs. Only the last of these localities is known to the writer.

There is no official record of any tin concentrate having been produced from the Smithfield deposits, and it seems likely that any reported to the Department was attributed to Greenbushes. Blatchford (1932) estimated that about 100 kg had been recovered from Donovans Find at the time of his inspection and a note on Mines File 525/31 (p.75) records that a total of 600 kg was produced in December 1931 and January 1932. From the extent of the old diggings at Donovans the production is judged to be considerably more than this.

Geological information

Because of the extensive cover of laterite, and the small amount of geological mapping that has been done, there is little information on the bedrock geology of the Smithfield deposits. Study of the aeromagnetic maps, and observations of a few weathered exposures, indicate that the deposits lie within the Balingup Metamorphic Belt, more or less on strike with the deposits at Greenbushes. The deposits are about 12 km north of the edge of the Albany Fraser Province, as defined by the change in direction of the aeromagnetic contours. Nearby kyanite deposits may indicate that the metamorphic grade increases towards the younger mobile belt.

The primary tin deposits worked in the Smithfield area are albite pegmatites with tourmaline and muscovite. They are similar to, but smaller than, those at Greenbushes. Secondary deposits include lateritized alluvium, possibly of similar age to the Greenbushes Formation. Economic minerals recorded from the deposits include cassiterite, columbite, struverite and gold.

Donovans Find

The tin discovery attributed to Donovan, at what is probably the original site of Smithfield, is located at lat.34°03′S, long.116°01′E. The most direct access is by way of a forestry track signposted Tin Mine Road, branching southeasterly from the Brockman Highway about 18 km west of Bridgetown. At about 2.5 km from the highway, a side track named Mine Road leads to the diggings.

The main workings are in the valley of a short creek, variously called Gough Gully or Donovan Creek, flowing east-southeasterly into a south-flowing tributary of the Donnelly River. The workings consist of shafts, pits and small cuts on a north-striking line of pegmatite veins, together with alluvial workings in the floor and sides of the valley. The largest opening is a sluice cut located where the creek cuts the line of pegmatites. About 120 m downstream from the cut are the remains of a circular puddling trough. Some 70 m further east, on the northern slope of the valley, are the foundations of a plant erected in about 1951. A hole some 15 m in diameter and 6 to 7 m deep immediately below the plant was probably excavated as a sump, although it is close to the site of an old shaft shown on Leevers' (1942) plan.

At the time of the writer's inspection, most of the old shafts were inaccessible, and much of the information given below is taken from the reports of Talbot (1907), Blatchford (1932), Leevers (1942), Brisbane (1951) and Forman (1963).

Pegmatite deposits: Although the line of pegmatites trends at about 360° individual veins seen in the cuts strike either northeast or northwest. Forman concluded that they were small pipes or lenses, and not a continuous body extending between clusters of shafts.

The first pegmatite worked (Blatchford, 1932) was located beneath the present sluice cut, underlying the rich alluvial deposits being worked at the time. The pegmatite was reported to be 1.5 to 1.8 m wide, and was worked from two or more shafts over a length of 24 m.

Mainly shallow diggings extend northwards from the sluice cut for a total distance of 130 m, with small clusters of deeper (4 or 5 m) shafts, centred at 35 m, 50 m, and 95 m from the cut, sunk on weathered pegmatite. Widths and assay results of pegmatites in some of the shafts are given in Table 28.

About 80 m south of the sluice cut, a narrow pegmatite vein striking 030° is exposed in surface workings over a distance of 25 m. Leevers stated that drives 6 m below the surface showed the tin content to be erratic, but wherever the vein did carry cassiterite, it was 60 to 90 cm wide and averaged about 0.09 per cent SnO_2.

The most southerly group of shafts is about 425 m south of the creek, alongside a track connecting Tin Mine Road and the southern continuation of Mine Road. It consists of four shafts sunk on two en echelon pegmatites striking at 300°. The larger vein was traced for 30 m in a number of pits and one shaft. The second vein, which is a little further north, was tested by three shafts each at least 6 or 7 m deep. One of these openings is probably Payne's shaft, which, according to Leevers, was originally 12 m deep with 11 m of drives from its foot. Some widths and grades reported from this group are listed in Table 28.

Alluvial deposits: Shallow alluvial workings extend down Donovan Creek to its junction with the main stream, and further patches are scattered over the valley floor. In several places, deeper pits have penetrated laterite or coffee rock to intersect older alluvium at depths of from 2 to 7 m. This older tin wash was reported to be 25 to 30 cm thick, consisting of boulders of quartz, small pieces of tourmaline and feldspar embedded in a stiff white clay. It was mined in the sluice cut and from a cluster of shafts near the puddling trough. Near the sluice cut the wash was overlain by 3.5 m of puggy clay.

Results of drilling programmes: Four investigations involving the drilling of shallow holes have been carried out in the vicinity of Donovans Find. Details of the earlier work are incomplete, but full reports exist on the later programmes. Available information on all four investigations is held on G.S.W.A. files.

Drilling carried out for Austmac Investments Ltd was supervised and reported on by J. C. Leevers (1942). About 60 holes were put down with a hand plant, mainly near the old pegmatite workings. The holes varied from about one to 10 m deep, most going down 6 to 7 m.

The investigation showed that there is no continuity of mineralization between the groups of old workings and that the grade of the lodes tested was too low to be payable at that time. The best results were obtained in the vicinity of two shafts about 100 m north of the intersection of Mine Road and Fly Road where Leevers estimated a probable 2000 tonnes of weathered pegmatite averaging 0.08 per cent SnO_2 in an area 27 m long and 6 m wide.

The hand drill used was apparently unsuitable for testing below the water table and no attempt was made to evaluate the alluvium in the valley.

A plan prepared by J. Smith showing results from bores and shafts at Donovans Find was brought to the Department's attention in 1951 with a request for advice on mining the deposit. The plan seems to indicate a considerable area of alluvial ground, possibly 7.5 m deep, with cassiterite contents averaging 5 kg/m^3. The prospect was inspected by E. Brisbane who sampled two further holes drilled during his visit. He concluded: "I am unable to reconcile the values shown on the plan with the results of the two bores put down. The plan is not to scale and possibly I have not interpreted it as the maker intended, but I do not think that there is a big tonnage of alluvial in the area".

TABLE 28. SAMPLING RESULTS FROM PEGMATITES AT DONOVANS FIND

Details	Width (m)	Grade (%SnO_2)	Source
Shaft, 35 m north of the sluice cut		Trace	Blatchford (1932)
Shaft, 50 m north of the sluice cut		0.76	Blatchford (1932)
Shaft, 95 m north of sluice cut		0.05	Blatchford (1932)
Shaft, about 135 m north of sluice cut	36	0.056	Leevers (1942)
Lode, exposed 9 m from previous sample	0.60	0.09	Leevers (1942)
In drive at foot of Payne's shaft	16	0.13	Leevers (1942)
Pegmatite near Payne's shaft	0.45	0.15	Leevers (1942)
Pegmatite near Payne's shaft	0.10	0.53	Leevers (1942)

In 1962, F. G. Forman applied for a Temporary Reserve over the Donovans Find area on behalf of Aberfoyle Tin Ltd., a New South Wales tin mining company. During 1963 he supervised a drilling programme designed to cover the most prospective areas on the T. R. These he considered to be — in the vicinity of the pegmatite veins; the adjacent flats extending in a general southerly direction to Ross Swamp; an area of sand plain covering possible alluvium northeast of Donovans Find; and a drainage system rising in the sand plain and running into the Donnelly River.

The pegmatite outcrops and the sand plain areas were investigated with a "Gemco" rotary drill on a systematic grid pattern. Holes were spaced at about 5 m on lines 40 m apart near the pegmatites, and 160 m apart on 320 m lines elsewhere. They drilled to depths of between 3 and 17 m. The presumed deeper ground in the drainage channels was tested by "Bucyrus" percussion holes at right angles to the stream flow on lines selected at irregular intervals down the channels.

Forman (1963) reported that the only samples containing more than a trace of tin concentrate were found in the vicinity of the pegmatites which he concluded were probably small pod-like bodies.

During 1966, Westralian Oil Ltd took out T.R.3742H over the Smithfield area and employed Geotechnics Ltd to carry out a reconnaissance survey (Ward and Mullumby, 1967).

About 16 scout holes were drilled to test the creek in the vicinity of Donovans Find, and three lines of closely spaced holes were put down to test Gough Gully. The highest assay returned in a scout hole was 150 ppm Sn. Assays from the close-boring at Donovans ranged from 36 to 560 ppm Sn.

Willow Springs

The Willow Springs tin diggings referred to by Wilson (1917) and Crabb (1921) are probably those on M.C.1106, situated 2.5 km south-southeast of the former timber milling settlement of the same name. The deposit is best reached by following Tin Mine Gully Road westerly from Willow Springs. It is at lat.34°03′25″S, long.115°51′30″E in a small northwesterly-flowing gully, close to the junction with a southwest-flowing tributary of the west branch of the Donnelly River.

The creek bed has been excavated over a width of 10 to 15 m for a distance of about 100 m. The walls of the cut expose about 1 m of cellular laterite overlying a maximum of 50 cm of well-cemented ferruginous conglomerate containing poorly rounded pebbles of quartzite, blue-grey quartz and rare kaolinized pegmatite. Cassiterite grains 1 to 2 mm in diameter can be seen in the matrix.

For 200 to 300 m upstream from the cut the cemented alluvium has been explored by a number of old test pits and by some costeans bulldozed more recently. According to Wilson the test pits extended the full length of the gully, but the best results were found in the lowermost 400 m.

Ward and Mullumby (1967) record that the tin-bearing conglomerate occurred in three old stream beds, 50 to 100 m south of the present stream. Later excavations have obscured this relationship.

A brief search of M.C.1295 to the northwest of the deposit located only a few old pits put down to test alluvium along the southwesterly flowing tributary.

The source of the cassiterite is apparently the pegmatite found as pebbles in the alluvium, and noted by Crabb (1921) in a few shallow shafts. No exposures of country rock were seen.

Remains of a former treatment plant are located about 0.4 km southeast of the diggings described, close to the road to Wheatley.

Native Dog Gully

In 1917, Wilson was shown some tin diggings by G. Gough at Native Dog Gully. The prospect was about 1.6 km west of Ross' farm (presumably near Ross Swamp) and may be identical with the Ross Find of Simpson (1948), as Ross' shaft is mentioned by Wilson (1917).

Wilson described a group of shafts sunk in a west-flowing gully between north-striking pegmatite veins. The deepest shaft was sunk to 5.5 m, passing through 1.5 m of loose sandy gravel, 1.8 m of ironstone (?laterite), 30 cm of sandy pug, 90 cm of wash with cassiterite, and bottoming in weathered granite. Another shaft sunk a further 140 m upstream intersected tin-bearing quartz gravel between 2.1 and 3 m.

Ross' shaft was put down on the south side of the gully alongside a quartz reef. Lode material sampled by Wilson assayed 0.016 per cent SnO_2.

Coated Tin Hill

Wilson (1917) described this occurrence as follows:—

> "About 1¼ miles (2 km) north of Native Dog Gully several pot holes have been sunk in ironstone gravel on the side of a hill. Coated tin is found in small quantities in these holes through the gravel."

Tin ore was also reported from a shaft 4.2 m deep sunk in sand south of the hill.

MISCELLANEOUS OCCURRENCES

Brookton

Campbell (1908) inspected a reported find of wolframite and cassiterite on Locations 5868 and 6100 about 19km east of Brookton. He was unable to confirm the presence of cassiterite although the mineral had been recognized earlier in samples said to be from the same locality.

A later reported tin find in the same general locality was investigated by Talbot (1915). Again no confirmation was obtained, Talbot concluding that ilmenite had been mistaken for cassiterite.

North Dandalup

Honman (1916) reported finding traces of tin oxide in gravel from Kronin Brook, a tributary of the North Dandalup River. He was inspecting a small gold discovery at the time.

Cuballing

A reported tin find at Cuballing proved to be banded iron formation (Gibson, 1905).

Chittering Valley

In a left-bank tributary of the Chittering Brook, near its confluence with the Swan River, a prospector obtained a concentrate consisting mainly of spinel, but carrying also a little cassiterite (Simpson, 1948, p.376).

Grass Valley

A quartz floater from Grass Valley sent to the Department contains a little cassiterite associated with wolframite and tourmaline (Simpson, 1948).

Nelson Locations 1395, 3600

A sample of concentrate submitted from Location 1395 in 1965 contained 79 per cent cassiterite and 5 per cent columbite. The location is at about lat. 34°04′S, long.116°01′E, approximately 2km south of Donovans Find (Government Chemical Laboratories, 1965).

Another sample submitted in the same year from Location 3 600 (lat. 34°08′S, long. 116°04′E), about 11.5km northwest of Manjimup, contained cassiterite and tourmaline. This location is near the estimated position of Native Dog Gully (Government Chemical Laboratories, 1965).

Wagin

A black sand from about 5 km south of Wagin consisted mainly of magnetite, but contained about 0.5 per cent cassiterite (Government Chemical Laboratories, 1942).

Serpentine

A small amount of cassiterite was observed in a tourmaline-bearing pegmatite from Location 454, near Serpentine, about 50 km south of Perth (Government Chemical Laboratories, 1965).

MURCHISON PROVINCE

POONA DEPOSITS

General information

The Poona centre is located 50 km northwest of Cue at lat.27°07′S, long.117°27′E. It is best reached by following the Cue to Kalli road for 51 km, then taking a track leading southwesterly for a further 16 km.

Tin was discovered at Poona in 1909 by Messrs Paton and Roddy, and for a short time twelve men were engaged in dry-blowing and washing tin-bearing gravel. The alluvial ground was quickly worked out and subsequent mining activity at Poona has been concentrated on the beryl and emerald deposits, although from time to time attempts have been made to work tin-bearing pegmatites in the area. Total recorded production is 2.02 tonnes of tin concentrate (Table 29).

At the time of the author's visit to the centre (November, 1970), one patch of eluvial ground was being treated and a plant had been recently erected on one of the larger pegmatites, although at the time work on the deposit was in abeyance.

The former mines are described by Montgomery (1910) and Woodward (1914). The regional setting of the deposits is given by Muhling (1969) and de la Hunty (1962).

Geological information

The Poona mining centre covers an area of amphibolite, tremolite schist and meta-gabbro striking northwesterly and dipping northeast. A line of laterite escarpments to the south of the centre marks the approximate contact of the metamorphic rocks and the northeastern edge of the Poona-Dalgaranga Batholith (Muhling, 1969). A zone of migmatite extending outwards from the edge of the batholith contains veins of granite which are folded and foliated, suggesting that the main granite in this area is synkinematic. What may be a post-kinematic granite (Muhling, pers. comm. 1971) forms a prominent tor near W.R.59, 1.3 km northwest of the Poona tin mine. This granite is slightly porphyritic and, although it shows flow banding, has little metamorphic foliation. Its contacts with the metamorphic rocks are quite sharp. As the tin-bearing pegmatites are also later than the metamorphism, they may be related to this granite. A brief description and chemical analysis of the granite are

TABLE 29. PRODUCTION OF TIN CONCENTRATE FROM MINOR CENTRES IN THE YILGARN BLOCK*

Centre	Mining tenement	Operator or Tenement name	Period	Tin concentrate (tonnes)	Metallic content (tonnes)	Realized value ($ Aust)	Remarks
Poona	M.C.64	L. M. Ryan	1969	.23	.16	487.89	Ryan's prospect
	D.C.1	J. Goodwin	1963	.13		195.50	Tin Creek
	Sundry claims		1909	1.54		236.00	Mainly from Tin Creek
	Sundry claims		1956	.06	.05	69.40	
	Crown Land		1968	.06	.04	95.25	
	Total Poona			2.02		1 084.04	
Coodardy	P.A.3772	M. Hronsky	1966	.15	.07	48.75	Covered former M.L.13
	Sundry claims		1913	3.25		484.00	Mainly from M.L.13
	Total Coodardy			3.40		532.75	
Dalgaranga	M.C.42	Dan Todd	1965	.07	.04	105.70	
Kathleen Valley	P.A.1295	Hinde, Scott & Jessop	1943-1945	.39		205.66	} Same ground as M.C.24
	P.A.1460	W. A. Hinde	1953	.30	.19	243.80	
	Total Kathleen Valley			.69		449.46	
Ubini	Sundry claims		1913	.15		30.00	From M.L.62 and 63
Binneringie	M.L.30	Binneringie Tin Syndicate	1961-1965	1.85	1.14	3 175.20	
Mount Deans	M.C.93 & P.A.2603	B. T. Weston	1966-1968	6.28	4.01	11 162.70	
	M.C.94	L. V. Blake & B. P. Norton	1966	.85	.54	1 807.90	
	P.A.2600	Swaine & Graham	1967	.05	.02	47.35	
	Total Mount Deans			7.18		13 017.95	
Holleton	Reward M.C.30	Great Pegmatite Reward	1930	.61		92.00	
Total Minor Centres				15.97		18 487.10	

*There is no official record of tin production from Smithfield or Mount Thirsty

given in Chapter 5 (Tables 63 and 64). The main Poona-Dalgaranga Batholith was dated by Muhling and de Laeter (1971) at 2 535 ± 20 m.y.

Tin Creek

The initial, and only significant, discovery of tin at Poona was in a small northwesterly-flowing gully now known as Tin Creek (D.C.1). The gully has been worked from its head downstream for a distance of about 1.1 km. In this stretch it is no more than 9 m wide and always shallow, with many outcrops of bedrock in its bed and banks. Except for a few small patches of shallow alluvium along its banks, it appears to be completely worked out.

Downstream from the worked section, the gully crosses a rocky bar which probably held back most of the cassiterite and for this reason, further prospecting downstream is unwarranted. However, one place that may be worth further testing is shown in Figure 12. Here a tributary of Tin Creek has captured the headwaters of an older north-flowing creek, which may have once drained the area containing the tin lodes. It is suggested that the old creek is worth testing for a distance of 300 to 600 m downstream from the point of capture.

Mines Department records show a total production from Tin Creek of 1.67 tonnes of concentrate, although Montgomery (1910) reported an estimated production of 4 tonnes.

A sample of tin concentrate submitted to the Government Chemical Laboratories contained 33.4 per cent cassiterite, 26.2 per cent wolframite, 4.2 per cent columbite, in addition to magnetite, hematite, tourmaline, garnet and ilmenite.

White lode

A prominent line of shafts at the edge of the laterite escarpment at the head of Tin Creek is now known as the White lode, although it was formerly called the Poona tin mine (M.L.12), and, by Montgomery (1910), Harrison and Hewitt's lode.

The line of shafts and other workings extends for a total length of 105 m and to a maximum depth of 12 m along a zone containing lenses of pegmatite. The pegmatites dip steeply south and cut the banding of their migmatite host rock. Owing to their proximity to the old laterite surface, the pegmatites are kaolinized and consist of a soft mixture of quartz and clay with mica and some cassiterite. Some fresh pieces of pegmatite were seen in the dump of the deepest shaft, suggesting that the depth of weathering extends to about 12 m. The widths of the pegmatites range between a few centimetres and 1.0 to 1.3 m.

No production has been recorded from the White lode. Old benches cut into the hillside contain remnants of machinery and indicate the former presence of a battery, but apparently this was not used. In 1970,

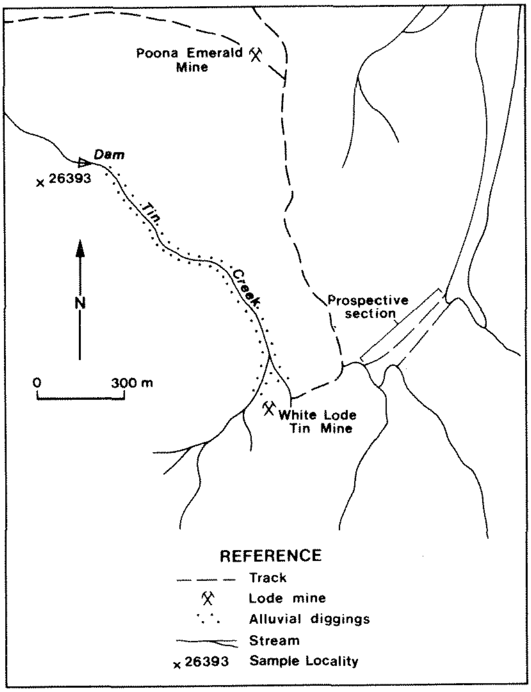


Figure 12. Map of the Poona centre showing possibly prospective section of a captured stream

Tin Creek Mining Corporation Pty Ltd had a plant consisting of a trommel and a double cone on the lease, but apparently it was never used to treat tin ore.

Assays of two grab samples from the dumps of the deeper shafts are listed in Table 30.

Ryans prospect

About 4 km west-northwest of the White lode, two pegmatite veins and a patch of eluvial ground were worked by Mr M Ryan on M.C. 64. The workings are in the vicinity of "Roddy's lode" described by Montgomery (1910) and are within or close to M.L. 40 shown on the map accompanying Woodward's (1914) report.

Ryan's principal lode workings comprise two shafts sunk on a pegmatite vein striking easterly and dipping southwards at a low angle. The northern shaft was sunk on the outcrop of the vein and intersected 3.7 m of pegmatite before passing into country rock. The upper 2.7 m of the vein consists of coarse-grained microcline and blue quartz, with patches of green muscovite and some massive lenses of quartz.

Below this coarse layer is a band ranging from 30 to 90 cm wide made up of fine-grained albite pegmatite, and below this again, a further 60 cm of coarse pegmatite. Cassiterite is concentrated on the contact of the coarse and fine-grained layers, although a few coarse pieces were seen on the edges of the massive quartz lenses. The average tin content of the lode is quite low.

The southern shaft was sunk to the south of the outcrop of the vein to intersect it at a depth of a metre or two. In it, the pegmatite was 4 m thick, but contained even less tin than in the northern shaft. A few pieces of spodumene are present on the dump.

A patch of shallow eluvium on the downhill side of the pegmatite outcrop is said to average 1.8 kg/m^3 of tin concentrate. It was processed by Ryan at a small dry-treatment plant on his claim. The volume of tin bearing ground available is quite small.

About 135 m northwest of the main workings, another pegmatite outcrop can be traced northerly for 30 m and then northwesterly for a further 60 m. Crystals of cassiterite are present in several places along the outcrop, but the average grade is again very low. A few shallow pits have been sunk on the tin-bearing parts of the vein.

Mineral Claim 117

About 0.5 km northwest of Ryans prospect and probably on M.C. 117 is a long outcrop of lithium-bearing pegmatite and vein quartz from which a little cassiterite and tantalite have been reported. This is probably "Paton's lode" of Montgomery's report.

Great Eastern

The Great Eastern lode (M.C. 7) is about 1.3 km north of Ryans prospect. It consists of a vein of blue quartz containing a little cassiterite. One sample of concentrate from eluvium near the outcrop contained 92.7 per cent cassiterite and another had 11.9 per cent cassiterite, 64.2 per cent manganocolumbite and 6.4 per cent manganotantalite.

COODARDY DEPOSITS

General information

Coodardy (lat. 27°18′S, long. 117°39′E) has been a gold mining centre since 1903. Tin was discovered there in 1909 by a prospector returning from the

TABLE 30. ASSAY RESULTS FROM WHITE LODE PROSPECT, POONA

Sample No.	Assay results				
	Sn (ppm)	$\%SnO_2$	Ta (ppm)	Nb (ppm)	
26394	500	.06	110	70	Dump western 40′(12 m) shaft
26395	1400	.18	170	100	Dump eastern 30′(9 m) shaft

Poona field. The first leases were pegged in 1912, and during 1913 3.25 tonnes of tin concentrate were produced, mainly from the treatment of detrital soil and shallow alluvium. Production since 1913 has amounted to only 0.15 tonnes (Table 29).

The tin deposits are about 3.2 km northeast of the Big Bell gold mine and 27 km northwest of Cue. They can be reached by a track leading from Big Bell to the Cue-Coodardy road.

A map and description of the deposits can be found in Woodward (1914) and further information is available in Simpson (1948).

Geological information

The gold and tin deposits of Coodardy are in a narrow belt of metamorphic rocks comprising metabasalt, hornblende schist, metasediments and porphyry. The rocks strike northeast, dip steeply southeast and crop out in a series of parallel ridges. Granite crops out along the western edge of the belt.

The pegmatite lodes, which have been the source of the cassiterite at Coodardy, form a set of interlacing veins trending parallel to the strike of the host rocks, but dipping mainly to the west. They occur in hornblende schist close to the contact with metabasalt and probably occupy tension fractures formed by bedding-slip strain during folding and granite intrusion. The veins can be traced for about 900m through former M.Ls 17, 13 and 15.

The composition of the pegmatites varies in an apparently irregular manner. Commonly, the pegmatite consists of medium to coarse-grained albite and quartz, with large, irregularly distributed crystals of microcline and books of muscovite. This type gives way in places to a fine-grained albite-quartz rock containing spessartine and green muscovite. The tin is found mainly in the fine-grained pegmatite and is particularly concentrated where two branches of the vein system meet.

Mineral Lease 13

The principal tin workings are on M.L.13. Two shafts were sunk about 2.7m apart on diverging branches of the vein 280m from the northern boundary of the lease. The east branch dips at 70 degrees west and the west branch at 45 degrees in the same direction. No cassiterite was seen in the dumps of the shafts.

A further 61m south, only one vein is present. A shaft inclined at 45 degrees west was sunk for 4.6m down the dip of the vein. Cassiterite is present in the dump but not in the face of the shaft.

Close to the southern boundary of the lease two shafts were put down 15m apart on the eastern sides of each of two branches of the pegmatite. The veins dip easterly in this locality and their outcrop widths are much exaggerated on the east-sloping hillside. Very little cassiterite remains in the dumps or outcrops.

Mineral Lease 15

The network of veins worked on M.L.17 passes southwards onto M.L.15. At a distance of about 137m from the northern boundary of the lease, the normal pegmatite grades into a vein consisting mainly of white quartz with a narrow pegmatite border. A few shallow pits were sunk along the edges of the vein, apparently in search of tin. One piece of tantalocolumbite was seen in the workings.

Mineral Lease 17

Mineral Lease 17 adjoins M.L.13 to the north. Near its northern edge an open cut 12m long, 4.5m wide and 1.8m deep was excavated close to the junction of two branches of the pegmatite. The vein exposed in the workings dips steeply east and consists of fine-grained quartz and albite with green muscovite and disseminated cassiterite.

Alluvial workings

A few very small gullies draining the line of pegmatites have been worked for tin, but there are no large accumulations of alluvium suited to present machine mining methods.

Assays

Maitland (1919) recorded that three assays of the richer parts of the vein yielded 0.046, 1.26 and 1.90 per cent tin respectively. Columbite and wolframite have been recorded in concentrates from the centre.

DALGARANGA DEPOSITS

General information

Since their discovery by the Todd brothers in 1961 several pegmatites on Dalgaranga Station property have yielded appreciable quantities of beryl, tantalite and tapiolite. Cassiterite was also reported from several pegmatites by the discoverers, but only one small parcel of tin concentrate has been marketed (Table 29). This came from M.C. 42, about 0.5 km south of the beryl-tantalite quarry on M.C. 27 at lat. 27°42′S, long. 117°13′E.

The deposits are about 24 km northeast of Dalgaranga homestead and 72 km northeast of Mount Magnet. They can be reached from Yalgoo by way of Dalgaranga, or from Mount Magnet through Mount Farmer.

A report by de la Hunty (1962) described several of the pegmatites from the Dalgaranga centre.

Geological information

The Dalgaranga pegmatite deposits are in mafic and ultramafic amphibolites with minor mica schist and quartzite close to the southern edge of the Poona-Dalgaranga Batholith. Typically they have a core of blue quartz and in addition to the economic minerals contain fluorite, cleavelandite, and onion-shelled balls of zinnwaldite.

The pegmatite which yielded the tin on M.C. 42 strikes 070 degrees and dips 70 degrees northwest. It crops out over a length of about 200 m but cassiterite is restricted to the southern 75 m. Where unmineralized, the vein consists of blue quartz, albite, green muscovite, and blue-grey feldspar crystals 7 to 15 cm across. Where worked, the pegmatite is lenticular, each lens having a core of blue-grey quartz containing segregations of coarse feldspar and muscovite, and an outer zone made up of quartz, cleavelandite, zinnwaldite, fluorite, tourmaline and cassiterite.

The small amount of tin concentrate obtained from the claim came from three pits in the pegmatite and a nearby patch of eluvial ground.

MINOR OCCURRENCES

Weld Range

A sample of cassiterite sent to the Department in 1927 was said to have come from Weld Range, north of Poona (Simpson, 1948, p. 376).

Lake Moore

Cassiterite was noted by Simpson (1948) in a specimen of albite pegmatite stated to have been broken from an outcrop between Mount Singleton and Lake Moore.

EASTERN GOLDFIELDS PROVINCE

KATHLEEN VALLEY DEPOSIT

A small amount of tin concentrate has been mined from a pegmatite vein on M.C. 24, 2.9 km southwest of the Kathleen Valley hotel and about 230 m southeast of the main road through Kathleen Valley, at lat. 27°32′S, long. 120°33′E.

The vein strikes at 300 degrees, dips gently southwards, and has a maximum exposed thickness of 2.4 m. It cuts across the northeasterly trend of its amphibolite host rock. Workings consist of two shallow open cuts and a few pits, spaced over a 40 m long portion of the vein. The outcrop of the vein can be traced for 105 m east and 75 m west of the workings.

The pegmatite has a prominent layering produced by differences in the grain size and proportions of its mineral constituents. Cassiterite is most abundant in a coarse-grained quartz-albite layer below a fine-grained band rich in lepidolite. The pegmatite also contains an appreciable amount of lepidolite, and aggregates of fine-grained, pale green muscovite, possibly pseudomorphing some other mineral.

The production figures for 1953 indicate that the average grade of ore treated from the deposit is 2.4 per cent tin. However, examination of the dumps and worked faces, shows that this was picked material, the grade of the whole vein being much less than 1 per cent tin.

BINNERINGIE DEPOSIT

The Binneringie tin deposit (M.C. 30) is located 58 km east of Widgiemooltha and 8.9 km northeast of Binneringie homestead at lat. 31°31′30″S, long. 122°10′30″S. It is on the southern slope of a low ridge known as Bald Hill, which rises to a height of about 30 m above the alluvial flats flanking the northern margin of Lake Cowan.

Access to Binneringie homestead is by way of a graded dirt road branching from the Eyre Highway 4.8 km south of Widgiemooltha. Station tracks lead from the homestead to the workings.

Production from the deposit has amounted to 1.85 tonnes of concentrate valued at $3 175 (Table 29).

Water used to treat the tin-bearing ground was obtained from seepage trenches sunk into the bed of Lake Cowan.

Sofoulis (1966) described the regional geological setting of the tin deposit. Its position is shown on the Widgiemooltha 1:250 000 Geological Sheet.

All of the cassiterite produced at Binneringie has come from two patches of eluvial ground. The bedrock underlying the eluvium is amphibolite, which forms part of a group of metamorphic rocks intruded by small stocks of granite, greisen and a few pegmatites. Most of the tin ore was derived from the pegmatites, although some may have come from the greisen. Similar pegmatites have been reported over a distance of about 15 km north-northwest of Bald Hill.

The two eluvial patches worked are about 180 m apart. The western patch was mined over an area of about 23 000 m^2 and ranged from 15 to 60 cm deep. The eastern patch was scraped over an area of 5 600m^2. Most of the dirt mined from the patches still remains on site as dumps.

According to a former operator, Mr M. Cotter, the eluvium treated by his party averaged 2.4 kg/m^3 tin concentrate, but due to dilution during subsequent bulldozing operations the remaining dumps now average only 1.2 kg/m^3 of concentrate. He also reports tin concentrate values of up to 0.6 kg/m^3 in extensive areas of shallow alluvium south of Bald Hill.

The area of alluvium surrounding Bald Hill is worth prospecting for buried drainage channels which may contain concentrations of cassiterite suitable for a small-scale mining operation.

UBINI DEPOSIT

Small quantities of tin concentrate variously reported as coming from Ubini, Bullabulling or Coondarrie have been recovered from the vicinity of M.Ls 62 and 63, near Ubini, 22.5 km west of Coolgardie (lat. 30°57′S, long. 120°55′E). The area is reached by a track branching from the Great Eastern Highway at 538 km (near the former 334-mile peg). Recorded production amounts to only 0.15 tonnes of concentrate (Table 29).

Information on the deposit can be found in Simpson (1948), and, on the regional geology, in McMath and others (1953) and Kriewaldt (1969). The locations of the deposit are shown on the Kalgoorlie 1:250 000 Geological Sheet (Kriewaldt, 1969) and on Plate III (Sheet 1) of McMath and others (1953).

The cassiterite recovered from Ubini was found close to a large northwesterly-trending quartz-cored pegmatite cropping out over a distance of 245 m. Dry-blown ground at the northern end of the vein close to old workings for amblygonite indicates the site of some of the tin mined.

An area a little south of the amblygonite deposit also yielded some cassiterite. This came partly from eluvium and partly from veins in a micaceous pegmatite. Other lithium-bearing pegmatites are known near M.C.67, but the probability of further important tin discoveries in the area is remote.

MOUNT DEANS DEPOSITS

General information

Between 1965 and 1967, 7.18 tonnes of tin concentrate were mined from an area 3.2 km long and 0.8 km wide on the east flank of Mount Deans at lat.32°19′S, long.121°46′E 13 km south of Norseman (Table 29). Most of the concentrate came from M.C.93, with smaller quantities from M.Cs 94 and 136. Details are given in Tables 29 and 31. The deposits are reached by a track branching from the Norseman to Esperance road 736 km from Perth (former 457-mile peg).

Newton-Smith (1970) mapped and reported on the tin deposits and Doepel (1973) has an account of the regional geology.

Geological information

The Mount Deans deposits are near the southern extremity of a greenstone belt intruded by granite on its eastern and western margins, the western granite being regarded by Newton-Smith (1970) as the source of the mineralization. The host rocks to the tin-bearing pegmatites are mafic lavas and associated intrusives. Alteration about the pegmatites has produced a mild bleaching of the host rocks.

Mineral Claim 93

An irregular pegmatite vein striking north-northwest and dipping from 20 to 50 degrees westerly, has been worked on M.C.93 from two open cuts and tested by a number of costeans. The vein is made up mainly of quartz and plagioclase, the latter ranging from albite to calcic oligoclase in composition. Much of the albite is the lamellar variety cleavelandite. Other common minerals are zinnwaldite, muscovite and lepidolite. Cassiterite is found mainly in the upper part of the vein, being associated with a zone containing more than the usual amount of albite and zinnwaldite.

Newton-Smith (1970) recorded composite minerals which proved to be mixtures of quartz with chlorite, kaolinite or illite.

In the 6 m deep southern cut, the vein is 0.6 to 1.2 m thick and shows a crude zoning. The shallower northern cut is on a roll in the vein, which at this point, strikes at 250 degrees, dips 25 degrees southerly and is joined by a steeply dipping branch vein. The full thickness of the vein is not exposed in the cut. Cassiterite seems more abundant than in the southern cut.

Grade: Records of ore treated at the Norseman State Battery (Table 31) show that 930 tonnes of ore from M.C.93 yielded 6 380 kg of concentrate, or about 0.5 per cent Sn.

Mineral Claim 94

On M.C.94, 2.25km north-northeast of M.C.93, a pegmatite dyke striking 200 degrees and dipping 50 degrees east can be traced for about 90m. The southern part of the vein has been opened up to a depth of 4.6m by an open cut 18m long. The pegmatite is mainly coarse-grained, consisting of subhedral crystals of plagioclase up to 5cm across set in a groundmass of finer quartz, zinnwaldite, lepidolite and fine muscovite. Finer grained patches, composed of albite and mica, contain most of the cassiterite.

North of the workings and extending beyond the boundaries of the claim, are a number of more or less parallel veins which have not been worked.

TABLE 31. DETAILS OF TIN ORE TREATED AT THE NORSEMAN STATE BATTERY

Date	Tenement	Ore crushed (tonnes)	Concentrate recovered	
			kg	%
7.7.1965	M.C.94	16.2	272	1.68
6.8.1965	M.C.94	19.3	272	1.41
15.10.1965	M.C.93	71.1	759	1.07
12.11.1965	M.C.94	86.4	218	.25
10.12.1965	M.C.93	137.2	1727	1.26
11.3.1966	M.C.94	54.4	203	.37
18.3.1966	M.C.136	23.4	9	.04
20.5.1966	M.C.95	48.8	n.a.	—
28.9.1966	M.C.93	119.9	610	.51
12.12.1966	M.C.93	119.9	914	.76
20.12.1966	M.C.93	85.8	198	.23
28.2.1967	M.C.93	90.4	216	.24
20.3.1967	M.C.93	104.1	457	.44
9.6.1967	M.C.93	101.6	762	.75
6.8.1967	M.C.94	57.9	140	.24
15.9.1967	M.C.93	100.1	736	.73
27.10.1967	M.C.95	27.4	102	.37

A total of 234.2 tonnes of ore from M.C.94 treated at Norseman (Table 31) yielded 1 105kg of concentrate, or about 0.5 per cent Sn.

Mineral Claim 136

The line of pegmatites worked on M.C.94 extends south-southwesterly onto M.C.136. Here there are two groups of shallow diggings about 60m apart on two unconnected lenses of pegmatite. The composition of these veins is similar to those on M.C.94. The one crushing treated at the Norseman State Battery contained only 0.04 per cent tin concentrate (Table 31).

Drilling results

Norseman Gold Mines N.L. drilled about 15 core holes to test pegmatites on M.C. 94, and a further four holes on a large pegmatite dyke exposed about midway between M.Cs 94 and 93. Some results are held by the Geological Survey of Western Australia. Most intersections assayed less than 0.1 per cent Sn, the only exception being the interval 17.93 to 19.51m in hole T.15, which contained 0.76 per cent Sn.

Hole T.15 was sited about 40m from the northwest boundary of M.C.94, near the principal pegmatite.

The holes showed that individual pegmatites extend to depths of at least 27m, and dip easterly at a low angle.

MOUNT THIRSTY DEPOSITS

Records of the Norseman State Battery (see Table 31) show that two parcels of ore from M.C.95, 6.5km southwest of Mount Thirsty, were crushed in 1966 and 1967. Returns, available for one parcel only (Table 31), are not entered in official Department statistics. The claim is 19.4km northwest of Norseman at lat.32°07′S, long.121°36′E. It is reached by a track turning westwards from the Coolgardie-Esperance Highway about 3km north of the Mission Station.

The main deposit is described by Newton-Smith (1970) and the regional geology by Doepel (1971). Newton-Smith's report contained a sketch of the workings and the position of the deposit is marked on the Norseman 1:250 000 Geological Sheet (Doepel, 1971).

The Mount Thirsty tin deposits occur in an area of felsic volcanic rocks, amphibolite and tremolite-actinolite rock intruded by small stocks and veins of granite and associated pegmatite. There is a large outcrop of granite about 1.6 km west of the claim. The immediate host rock of the tin-bearing pegmatites is tremolite-actinolite schist which is altered to a biotite-tremolite-actinolite rock close to the lodes.

Two parallel pegmatite dykes were mined on M.C.95. They consist of quartz, plagioclase (including cleavelandite), lepidolite, zinnwaldite, muscovite in books up to 25 cm long and 5 cm thick, black, blue, green, and pink varieties of tourmaline, and small amounts of cassiterite and beryl. The western vein was originally worked from two small open cuts, but has since been opened up by a bulldozed trench extending for 75 m along the length of the vein. Openings on the eastern vein comprise a few pits which are now almost concealed by later costeans put in to test the ultramafic rocks for nickel ores.

Further cassiterite was reported from a small fine-grained albite pegmatite, associated with fine-grained albite granite, cropping out on M.C. 882, about 1.6 km southwest of the workings on M.C. 95.

Returns are available for one crushing of ore; the grade was about 0.26 per cent Sn.

HOLLETON DEPOSIT

General information

Eluvial cassiterite was discovered at the gold mining centre of Holleton in 1921, and traced to its source in Moller's vein on M.L.30 (lat. 31°58′S, long. 119°00′E) in 1927. Holleton is 89 km southwest of Southern Cross and can be reached by road from Moorine Rock and Narembeen. Production records show a total of 0.6 tonnes of tin concentrate derived from 32.6 tonnes of ore (Table 29).

The deposit is described by Wilson (1930), Ellis (1939b), Matheson and Hobson (1940), Simpson (1948) and MacLeod (1965).

Geological information

The Holleton deposit is at the northwestern edge of the Holleton greenstone belt, close to the contact with the surrounding biotite granite. Rock types exposed in the vicinity of the tin deposit are coarse-grained uralitized pyroxenite, metabasalt and ultramafic rocks. The cassiterite occurs in a swarm of pegmatites trending 030 degrees and dipping easterly. Normally the pegmatites consist of quartz, microcline, biotite and garnet, but where they carry cassiterite they are made up of quartz and albite. Other minerals noted by Simpson in the pegmatites are tourmaline, ilmenite and zircon. A gold-bearing quartz reef on the claim appears to displace a pegmatite vein and therefore to be later, although Wilson (1930) recorded an opposing view.

The principal workings are on the most prominent pegmatite traced over a distance of 75 m. Older openings on the vein consist of pits and a shaft 15 m deep. More recent workings comprise bulldozed trenches and costeans. Nine metres north of the 15 m shaft, another line of pits follows a branch vein cropping out over a distance of 18 m. Further north again this branch vein rejoins the main dyke to form a cymoid loop structure. Other pegmatite veins in the lease have been tested, but yielded generally poor tin assays.

Sampling results taken from the reports of Wilson (1930) and Simpson (1948) are listed in Table 32. The average grade of ore treated was about 2 per cent tin oxide.

MINOR OCCURRENCES

Cassiterite has been recorded in association with other rare metals from pegmatites at Londonderry, Tantalite Hill and Cattlin Creek. It has also been reported from a number of other localities but generally these reports have not been confirmed or the localities are imprecise.

Londonderry

A little detrital cassiterite was found in 1909 in a pegmatite 6.4 km southwest of the Londonderry railway siding (lat. 31°07′S, long. 121°04′E). The discovery was on the present site of the Londonderry feldspar quarry on M.L. 80 operated by Australian Glass Manufacturers Ltd. The pegmatite, which is up to 12 m thick where exposed in the quarry, can be traced for a distance of 370 m along strike. In addition to yielding microcline for ceramic purposes, the pegmatite has been the source of commercial beryl and columbite and contains lithium minerals such as petalite and lepidolite (McMath and others, 1953).

Tantalite Hill

A second occurrence near Londonderry is at Tantalite Hill, formerly called Mercer's Find (lat. 31°06′S, long. 121°04′E) about 2.4 km north of the feldspar quarry. Here the tin was reported from concentrates composed of manganocolumbite, manganotantalite and ixiolite. The concentrate richest in tin assayed 13.16 per cent SnO_2 (McMath and others, 1953).

Cattlin Creek

Cassiterite has been noted as a minor constituent of a lithium pegmatite at Cattlin Creek, 2.1 km north of Ravensthorpe (lat. 33°34′S, long. 120°02′E). The cassiterite was reported from M.H.L. 28, a short distance north of the main pegmatite vein. Other potentially economic minerals present are spodumene, lepidolite, microcline, amblygonite, beryl and manganocolumbite (Ellis, 1944b; Sofoulis, 1958; Grubb, 1963).

Mount Venn

Mineralogical investigations by Amdel for Tasminex N.L. determined cassiterite in two specimens from Mount Venn. In the first sample cassiterite is present as a rare accessory in a partly recrystallized adamellite. In the second specimen the mineral forms about 5 per cent of a thin quartz vein cutting gabbro.

Laverton area

Analex Pty Ltd found cassiterite in three samples of soil or alluvium collected north of Laverton. No details are available.

Baumgartens find (Lake Nabberu)

Baumgartens gold find is situated near the extreme northern edge of the Yilgarn Block, in an area of quartz-muscovite schist intruded by granite. In 1931 an albite pegmatite in the vicinity of the gold prospect was found to contain cassiterite (Simpson, 1948).

TABLE 32. SAMPLING RESULTS FROM THE HOLLETON TIN DEPOSIT*

No.	Location	Width (cm)	Sn (%)	SnO_2 (%)
1	Picked sample—maximum values		16	20
2	1.5 m depth in shaft	91	0.48	0.61
3	3 m depth in shaft	76	1.47	1.87
4	Broken ore at surface		1.17	1.49
5	Broken ore at surface		0.94	1.19
6	Pit 52 m south of shaft		1.02	1.30
7	Pit 15 m north of shaft		0.56	0.71

*From Wilson (1930) and Simpson (1948)

CHAPTER 4

Minor deposits in other tectonic units

HALLS CREEK PROVINCE

The only Western Australian production of tin concentrate outside the Pilbara and Yilgarn Blocks has come from three, or possibly four, small deposits in the Halls Creek Province. Recorded production dates only from 1951, although cassiterite appears to have been recognized in the Halls Creek Province before 1900 (Maitland, 1900a, p. 84).

Details of the 1.8 tonnes of tin concentrate produced are given in Table 33. Other localities from which cassiterite has been reported are Dyasons Creek, Leopold Downs, Richenda River, Cummins Range, Bow River, Lennard River (Mount Broome), and an island in Sunday Strait. In some instances the same deposit has probably been referred to two or more localities, and the only deposits to have their positions definitely fixed are the King Sound tin-tungsten mine, Mount Dockrell and Dyasons Creek.

The Halls Creek Province occupies an isolated part of Western Australia, with one major trunk road, but otherwise poorly served by facilities. It has a tropical climate with a monsoonal summer rainfall of between about 450 and 630 mm in the tin-bearing area (approximately Halls Creek to Derby).

GEOLOGICAL SETTING OF DEPOSITS

A recent review by Thom (1975) summarized geological information on the Halls Creek Province. Most of her data comes from 1:250 000 map sheets and explanatory notes prepared by joint Commonwealth-State geological parties. A more comprehensive account of the eastern part of the Province is presented by Dow and Gemuts (1969).

The Province comprises mainly eugeosynclinal sediments, and in its eastern part, interlayered volcanic rocks, intruded by several types of granite at about 1 800 m.y.

Tin mineralization is most closely associated with the Lennard, Dyasons and Sophie Downs Granites but some may also be related to the Mondooma Granite. Descriptions and analyses of some of these granites are given in Chapter 5, and further petrographic information is available in Gellatly and others (1968, 1969), and Dow and Gemuts (1969).

KING SOUND TIN-TUNGSTEN DEPOSIT

General information

The King Sound tin-tungsten deposit (known also as Taylor's Wolfram Reward, the Federal Downs wolfram mine, the King Sound tin mine, the Clara Hill mine, or Wolfram Hill) is about 32 km north-northwesterly from Napier Downs Station homestead and about 193 km by road from Derby (lat.16°59′S, long.124°40′E). It is best reached from Napier Downs by following a station road leading to Limestone Springs for 29.4 km, then travelling overland for about 9.6 km in a northerly direction.

The deposit was first pegged in 1907 and an attempt made to mine it in the period 1911 to 1913 when a five-head stamp mill was erected. Water was obtained from a well 24 m deep.

Department records show only tungsten production from the King Sound mine. This amounts to 27.4 tonnes of ore and concentrate containing 203 m.t.u. of WO_3. Some production of tin concentrate from the "Patterson Range" may in fact have come from this deposit.

Campbell (1909), Blatchford (1914), Finucane (1938a), Simpson (1951), Harms (1959), and Gellatly and others (1969) described the deposit. The last-named reference gives a detailed account and plan of the regional geology of the area.

Geological information

The host rocks of the mineralization at the King Sound mine are shale, greywacke and sandstone of the Halls Creek Group, metamorphosed to phyllite and quartzite. Cleavage planes in the phyllite strike at 115 degrees and dip at about 80 degrees south. Bedding planes strike at 070 degrees and dip 60 to 70 degrees

TABLE 33. PRODUCTION OF TIN CONCENTRATE FROM THE HALLS CREEK PROVINCE

Centre	Mining tenement	Operator or lease name	Period	Tin concentrate (tonnes)	Metallic content (tonnes)	Realised value ($Aust)	Remarks
Patterson Range	Sundry claims	J. A. Stuart	1951-55	.43		627.56	Probably King Sound mine and Silent Valley
Mount Humbert		Sundry persons	1964	.06		99.10	Locality of deposit unknown—possibly Silent Valley
	Total			.49		726.26	
Mount Dockrell	M.Ls 13, 15-24		1962	.47	.30	591.90	
	P.A. 120	C. M. Shaw	1943	.61	.40	286.00	
	Crown Land	Bolton & Sherwood	1951-52	.23	.16	318.86	Recorded as from "Willy Willy"
	Total			1.31		1196.76	
Total Halls Creek Province				1.80		1923.42	

southeast. At a distance of about 1.2 km north of the mine, the metamorphic rocks include some large sills of recrystallized dolerite.

Two granite masses intrude the Halls Creek Group in the vicinity of the deposit. The older Mondooma Granite crops out about 2.0 km north of the mine, and the younger Lennard Granite is exposed 2.8 km east-southeast of the mine. More details of these granites are given in Chapter 5. There is no direct evidence to indicate which of these granites produced the mineralization. Most of the granite masses in the area have a west-northwest trend parallel to the regional folding, and from this it could be inferred that the King Sound mine is more likely to be underlain by Lennard Granite than Mondooma Granite.

The tin and tungsten minerals of the deposit occur sub-parallel to anastomosing quartz veins which have been injected along the cleavages of the host rocks. The veins crop out in a belt from 3.0 to 21.4 m wide over a distance of 400 m. The general strike of the belt is 115 degrees and the most persistent veins dip south at from 70 to 80 degrees. Apart from the main through-going veins, there is another set parallel to the bedding planes, yet another dipping at 60 degrees south into the main veins, and a later set of flat-dipping veins which displace the other sets. The maximum number of veins in any one section across the belt is fourteen. In width, the veins range from 2.5 to 38 cm. Bulges in the veins of the main set plunge in the direction of the intersection of bedding and cleavage in the host rocks, that is, at about 60 degrees southeasterly.

Minerals present in the quartz veins are cassiterite, wolframite, scorodite (hydrous ferric arsenate) and rarely scheelite. Limonite is present in some veins, especially those of the youngest, flat-dipping set, and may indicate pyrite at depth. The three principal minerals, together with quartz, show a consistent paragenesis, with scorodite forming the outer part of the veins and quartz the inner part. Cassiterite is found mainly close to the scorodite, while wolframite is scattered throughout the central quartzose part of the veins. Blatchford (1914) and Finucane (1938a) regarded the scorodite as an alteration product of arsenopyrite, but Gellatly and others (1969) believed it to be primary.

The workings

Most of the mining activity at the deposit was concentrated on two lines of workings, each line following one vein of the main set with its attendant branches, splits and en echelon offsets. The southern line of workings is 107 m long, and comprises two open cuts and a number of pits and trenches. The western-most open cut (the No.1 cut mentioned in Finucane's report) is 41 m long and has a maximum depth of 3.3 m. It exposes two quartz veins, separated by 60 to 75 cm of phyllite, with cassiterite and wolframite. To the east of the No. 1 open cut, the mineralization follows a closely parallel branch vein which was worked from an open cut (No.2) over a length of 21 m to a depth of 4.6 m.

The principal opening on the northern line of workings is an open cut (No. 3) located 55 m east of the No.2 cut. It is 24 m long, 3 m deep and was excavated on a narrow quartz vein carrying wolframite. At a distance of 40 m westerly from this opening, is another cut 4.6 m deep and 6.1 m long which postdates Finucane's report. It exposes two veins 85 cm apart. The southern vein is 18 to 25 cm wide and contains an appreciable amount of wolframite and scorodite. The northern vein is almost barren. This open cut was at one time connected to a two-head stamp battery on the southern side of the ridge by means of a flying fox. About 49 m easterly of the No. 3 open cut, a narrow en echelon vein has been mined from a cut (No. 4) 6 m long and 1.2 m deep.

In all of the open cuts, appreciably more phyllite than quartz was excavated, and a considerable amount of hand sorting must have been necessary to obtain an acceptable battery feed. Blatchford (1914) estimated that 203 tonnes of rock were broken to obtain 40.6 tonnes of ore.

Assays

The results of sample assays which have appeared in previous reports are listed in Table 34.

Drilling results

During 1969, Pickands Mather and Co. International drilled two diamond holes to test the King Sound mine (Harris, 1970). The first hole encountered only minor mineralization, with maximum assays of 1 800 ppm Sn and 1 100 ppm W. The second hole intersected three small wolframite-bearing quartz veins between 97.3 and 97.9 m, the section assaying 5.1 per cent W. Tin grades of 3 600 ppm and 4 100 ppm were recorded from 97.3 to 97.9 m, and 97.9 to 98.8 m respectively.

SILENT VALLEY PROSPECT

General information

The Silent Valley tin prospect was discovered and worked in a small way by J. A. Stuart. Its exact locality has not been recorded. The queried latitude and longitude given by Harms (1959) places it at the headwaters of King Creek, a position which agrees with the topographic information in his report. Gellatly and others (1969), using information given to them by Mr. Stuart, placed it in a more southerly position, at about 4.8km north of the King Sound tin-tungsten deposit, although the topography here does not conform to that described by Harms. No production figures are available, but it is likely that some of the tin concentrate attributed to Stuart in Table 33 came from Silent Valley.

Harms (1959) and Gellatly and others (1969) described the deposit, the former author having inspected it in 1953.

Geological information

The general area of the prospect is occupied by Mondooma Granite which is intruded by stocks of Lennard Granite. Harms' (1959) description is quoted in full below.

> 'About five miles (8km) in a general northeasterly direction from the Clara Hills mine the amphibolites, schists and dolerites give way to granitic and more basic igneous rocks. In the region of the headwaters of a north-flowing gully within this granite there are pockets of cassiterite-bearing wash which carry up to three pounds (1.7kg) of cassiterite to the dish; further down the gully larger quantities of wash under some three feet (1m) of alluvium carry about an ounce (28gm) of cassiterite to the dish.'
>
> 'The wash has been traced to small quartz leaders, one to two inches (2.5 to 5cm) wide, which carry rich specimen cassiterite on their walls, and to a few very thin seams of cassiterite in griesen.'
>
> 'The richer pockets have been worked by the discoverer, J. Stuart, and about a ton (1 tonne) of cassiterite has been recovered. Water supplies are lacking, except during storms in the wet season, and this precludes working the lower grade material.'
>
> 'The adjoining creeks and gullies for about five miles (8km) to the northwest have also been prospected by Stuart, and at least one of them contains amounts of cassiterite comparable with the above. This area is inaccessible except on foot, and also suffers from lack of water except immediately after rain. It has not been worked.'

DYASONS CREEK PROSPECT

Tin has been recorded from two areas in the vicinity of Dyasons Creek, about 16 and 19km respectively east of McSherrys Gap (lat.17°33′S, long.125°15′E). No production has been recorded from the deposits.

The deposits are described by Finucane (1939), Harms (1959) and Gellatly and others (1968), and the position of the prospect is shown on the Lennard River 1:250 000 Geological Sheet.

TABLE 34. SAMPLING RESULTS FROM THE KING SOUND TIN-TUNGSTEN MINE

Location	Width (cm)	%SnO_2	%WO_3	Remarks	Source
Main trench, No. 1 vein		1.24	.09	Probably No. 1 open cut	Blatchford, 1914
Main trench, No. 1 vein		.86	.06	Probably No. 1 open cut	Blatchford, 1914
Main trench, No. 2 vein		4.86	.77	Probably No. 1 open cut	Blatchford, 1914
Concentrate		23.74	32.46	Probably No. 1 open cut	Blatchford, 1914
No. 1 cut, south vein	20	2.16	.27	Represents 18.2 m length	Finucane, 1938a
No. 1 cut, north vein	28	2.82	.26	Represents 12.2 m length	Finucane, 1938a
No. 1 cut		1.90	2.20	Dump sample	Finucane, 1938a
No. 2 cut	15	.40	.30	Represents 4.6 m length	Finucane, 1938a
No. 2 cut		1.50	3.11	Dump sample	Finucane, 1938a
No. 3 cut	18	.16	.66	Represents 21.3 m length	Finucane, 1938a
No. 4 cut	7.5	1.26	2.02	Represents 3.0 m length	Finucane, 1938a
Concentrate		84.6	Not det.		Simpson, 1948

The Dyasons Creek deposit comprises a tin-bearing pegmatite vein and a small patch of alluvial ground about 3.2 km further west. Both are located on the north side of a mass of Dyasons Granite.

The pegmatite vein cuts fine-grained leucogranite. It strikes northeasterly and crops out over a length of 107 m. Nine samples taken at intervals of 9.4 m by Finucane averaged 0.09 per cent SnO_2 over an average width of 36 cm.

The alluvial ground occurs in a small south-flowing gully on the north side of Waggon Flat. The area is 275 m long and 73 m wide. Samples taken from 13 tests pits indicated an average grade of 715g/m³ SnO_2.

MOUNT DOCKRELL DEPOSITS

General information

The Mount Dockrell cassiterite-columbite deposits (lat. 18°55′S, long. 127°14′E) were discovered by two prospectors, Brens and Lidster, in 1927. Intermittent attempts to work the deposits between 1943 and 1962 resulted in the production of 1.31 tonnes of tin concentrate containing 870 kg of metallic tin.

The deposits are located about 16 km south of Mount Dockrell, and are reached by means of a station track from Lamboo homestead.

Blatchford (1930), Finucane (1938b) and Simpson (1948) described the deposits. Dow and Gemuts (1969) gave a detailed account of the regional geology and briefly described the tin deposits.

Locations of the deposits are shown on the Mount Ramsay 1:250 000 Geological Sheet (Roberts and others, 1968).

Geological information

The area of the tin deposits is underlain by metamorphosed greywacke, siltstone, shale, sandstone, and, more rarely, limestone of the Halls Creek Group. The sediments are folded, but have a general north-easterly strike. About 6.5 km east and 4.8 km south-east of the deposits, the metasediments are intruded by stocks of Sophie Downs Granite, which are considered to be the ultimate source of the tin and niobium. A description of this granite is given in Chapter 5.

The immediate source of the cassiterite and columbite is a number of pegmatite dykes which crop out in an irregular northeasterly-trending belt. Individual pegmatites range up to 150 m long, and from 3 to 60 m in outcrop width. The most productive workings are where one such pegmatite cuts a calcareous band in the metamorphic rocks.

The pegmatites are made up of bluish quartz, microcline, lamellar albite, greenish muscovite and black tourmaline and carry accessory garnet, ilmenite, lithiophyllite, cassiterite and columbite. Some are zoned, having quartz or quartz-muscovite cores.

Most of the tin concentrate was won from shallow alluvium in the narrow creek beds immediately downslope from the source pegmatites. The old diggings have been obliterated by subsequent rain storms but the area indicated to the writer as the most productive is in Columbium Creek and corresponds to the section tested by Finucane's sample number one. Other workings seen in the area are a few shallow pits sunk into pegmatite veins, or into the scree shed from these bodies.

Sampling results

Several of the more promising sections of alluvium were sampled by Finucane. Table 35 contains a summary of his results. Sample 1 was taken from Columbium Creek at about lat.18°54′S, long.127°14′E (8 cm E and 5 cm N of southwest corner of air-photo Mount Ramsay, Run 13 No.D5149 dated 19th July 1947). Sample No. 2 is from Columbium Creek 1.20 km southwest of No. 1. Sample No. 3 is from a small creek near a large pegmatite dyke 4 km southwest of No. 1 sample. Sample No. 4 is from the southern branch of Columbium Creek 1.6 km south of No. 1 sample. The locations of the samples correspond to the four crossed-pick symbols on the Mount Ramsay 1:250 000 Geological Sheet.

MISCELLANEOUS OCCURRENCES

Bow River

Alluvial cassiterite was reported from the head of the Bow River prior to 1900, but apparently the discovery has not been confirmed (Maitland, 1900a; Simpson, 1948).

Lennard River, Richenda River, Fairfield Station

Cassiterite-bearing samples have been received from the Lennard and Richenda Rivers (Simpson,

TABLE 35. SAMPLING RESULTS FROM MOUNT DOCKRELL TIN-NIOBIUM PROSPECT*

Sample No.	1	2	3	4
Length creek sampled (m)	243	274	334	152
Average depth wash (cm)	60	60	30	60
Average depth sampled (cm)	15	15	15	15
Calculated content of concentrate (kg/m³)	0.55	0.19	0.06	0.10
Assay of concentrate				
SnO_2 (per cent)	74.3	69.3	7.3	60.6
$(Ta, Nb)_2O$ (per cent)	20.0	22.3	72.4	27.9

*From Finucane (1938b)

1948) and Fairfield Station (Government Chemical Laboratories, 1959). All three positions could refer to the Dyasons Creek deposits.

Leopold Downs Station

A sample of cassiterite from Leopold Downs Station is held in the Simpson collection of the Department (Simpson, 1948).

Cummins Range

Early reports of cassiterite from the Cummins Range (Chemical Branch, 1927) almost certainly refer to the Mount Dockrell deposit.

Halls Creek

A number of anomalously radioactive samples of fluorite-bearing latite and fine-grained tuffaceous sediment collected by Trend Exploration Pty Ltd from M.C.4110 near Halls Creek proved to have unusually high contents of tin (maximum 75 ppm), niobium and zinc. Mineralogical work showed the presence of cassiterite, ferroan-columbite and sphalerite. The volcanic rocks were considered to be part of the Olympio Formation. No plutonic igneous rocks were identified in the vicinity of the deposits (Dunn, 1974).

Collier Bay

Harris (1930), in a report on a prospecting expedition into the West Kimberley, mentioned the occurrence of cassiterite at Collier Bay.

Sunday Strait

In 1921 H. O'Grady applied for M.L.13 for tin on Kalganu Island in Cygnet Bay near Sunday Strait. The lease was surrendered in 1922. In 1928 the Mines Department received a sample of cassiterite with tourmaline and muscovite said to come from an island in Sunday Strait. Kalganu Island lies immediately west of Sunday Island at about lat.16°24′S, long.123°10′E.

GASCOYNE PROVINCE

As presently defined (Daniels, 1975), the Gascoyne Province of migmatite, granite and metamorphic rocks borders the northwestern corner of the Yilgarn Block (Fig. 2).

Cassiterite is recorded from two localities in the province, but there has been no commercial production.

YINNIETHARRA

Pegmatites mined at Yinnietharra have yielded a substantial part of the State's beryl and mica, and small quantities of columbite and bismutite. The geology of the field is described by Matheson (1944) and Johnson (1950).

Despite the abundance of mineralized pegmatites in the field, cassiterite has been recorded only once, in a sample submitted to the Department in 1961 (Government Chemical Laboratories, 1961).

GLOBE HILL

Alluvial cassiterite reported from Globe Hill in 1931 was later traced to an albite pegmatite where it was found associated with muscovite and ilmenorutile. Typical mineral associates of tin such as tourmaline, topaz, fluorite and garnet were also identified in the detrital ore (Simpson, 1948).

ALBANY-FRASER PROVINCE

The Albany-Fraser Province (Doepel, 1975) is an arcuate belt of high-grade metamorphic rocks and granites of Proterozoic age flanking the south and southeastern sides of the Yilgarn Block. The dominant rock types of the province are migmatite, gneissic granite, granite, and, in the Fraser Range area, basic granulite. Locally, remnants of folded clastic sedimentary rocks unconformably overlie the igneous and metamorphic rocks.

Uncommercial quantities of cassiterite have been reported from a number of localities between the Bremer Range and the Donnelly River.

BREMER RANGE, MID MOUNT BARREN

A specimen from the Bremer Range consisted of cassiterite with an external zonal growth of ainalite (Government Chemical Laboratories, 1961). The sample may be from the same locality as another submitted in 1967 from Mid Mount Barren (Government Chemical Laboratories, 1967).

BOW RIVER BRIDGE

In 1967, a sample of cassiterite was submitted to the Department from a locality given as 3.2 km north of the Bow River Bridge (Government Chemical Laboratories, 1967).

DONNELLY RIVER

A sample of concentrates reportedly coming from the left-hand branch of the Donnelly River, 38 km south of Nannup, contained cassiterite and appreciable quantities of platinum and osmiridium. Saint-Smith (1912) pointed out the sample's resemblance to platinum-bearing beach sands found on the northern coast of New South Wales.

PALLINUP, GARDNER AND WARREN RIVERS

A map given to the Department by Analex Pty Ltd shows tin occurrences in the Pallinup, Gardner and Warren Rivers. R. C. Horwitz (pers. comm., 1976) reported that the samples were panned concentrates in which cassiterite was determined mineralogically. No details of grades are available.

CHAPTER 5

Petrography and chemistry of granites associated with Western Australian tin deposits

INTRODUCTORY STATEMENT

Early in the present investigation it became apparent that little was known of the composition of granites associated with Western Australian tin deposits. The results presented in this chapter are an attempt to correct this situation, although owing to regional mapping carried out in tin-bearing areas since 1972, the deficiency of information is no longer as great as before.

It is likely that exploration for new tin fields, especially in the extensive granitic terrains of the Western Australian Shield, will be directed primarily at the search for favourable granites. Hence a knowledge of the features to be expected of a tin granite is of great importance to the prospector. Because of the lack of any Western Australian precedent (at the time), published information on tin granites in other parts of the world was reviewed to establish whether they had distinctive features capable of easy recognition in the field or laboratory. A summary is presented under the headings of tectonic setting, petrography and mineralogy, and chemical properties.

NOMENCLATURE

The word 'granite', from the Italian 'granito' (Latin 'granum') was originally a textural term meaning 'grainy rock'. Through long and diverse usage, the word has come to have several present meanings, of which the two most common are:

(1) as a broad term for 'holocrystalline coarse-grained rocks of plutonic aspect (but not necessarily of igneous origin), composed essentially of quartz, potash feldspar and/or sodic plagioclase, and subordinate biotite, hornblende, or pyroxene, and having a hypidiomorphic granular texture'. (Turner and Verhoogen, 1960, p.330).

(2) *as a more restricted name for granitic rocks in which potash feldspar, and/or albite, make up some stated proportion (usually 60 or 66 per cent) of the total feldspars present.*

In this chapter 'granite' without qualification is used in the first sense. Where a more precise term is required, granites with a high proportion (+60%) of potash feldspar to plagioclase are referred to as 'microcline granites' or 'potassic granites'. Names used for other compositional varieties of granite are adamellite, granodiorite and tonalite, sometimes with mineral qualifiers. K-feldspar/plagioclase ratios used to define the boundaries between these types are those of Nockolds (1954), although in most cases only estimates of the feldspar proportions were made.

The chemical scheme of Harpum (1963) was used to supplement the mineralogical one where the granites studied were either coarse-grained or banded, making estimation of mineral proportions from thin sections impracticable. In practice, little conflict was found between names given on the basis of petrographic examination, and those assigned from the chemistry. Where conflict did appear to exist, it was usually found that the thin section had been cut through an atypical part of the specimen, most commonly through a phenocryst or veinlet.

ANALYTICAL METHODS

Unless otherwise noted, all chemical analyses of Western Australian rocks were carried out by the writer using the facilities of the Geology Department of the University of Western Australia.

For whole rock analyses, SiO_2, Al_2O_3, total iron as Fe_2O_3 MgO, CaO, K_2O, TiO_2, P_2O_5 and MnO were determined by X-ray fluorescence spectrography (XRF) using the sample preparation technique (sample fused in lithium tetraborate/lithium carbonate glass) described by Norrish and Hutton (1969). The XRF output was calibrated against USGS standard rocks W-1, BCR-1, AGV-1, PCC-1, DTS-1, GSP-1 and G-2 (Fleischer, 1969; Flanagan, 1969) and synthetic standards. Matrix corrections given by Norrish and Hutton (1969) were applied with the aid of a computer.

FeO was determined by titration against a standard solution of ceric sulphate, and a correction applied to the figure for Fe_2O_3 obtained by XRF, Sodium was determined by atomic absorption spectrometry (AAS) using synthetic standards. Loss on ignition was obtained by heating to about 1 000°C and corrected for H_2O^-(where determined) and the oxidation of FeO.

The trace elements Ce, Nb, Rb, Sr, Sn, Th and Zr were determined by XRF on pressed powder discs using the USGS standard rocks and synthetic standards for calibration. Li, Be, Cu and Zn were found by AAS using synthetic standards, Be being determined in a nitrous oxide flame at the Government Chemical Laboratories.

Fluorine was determined by the method of Ficklin (1970) using an ion selective electrode. Solutions were prepared by the writer and the analyses carried out by Mr P. Wilson of the Government Chemical Laboratories.

For partial analyses, total iron, Mg, Ca, Na and K were determined by AAS using the method of Abbey (1968) with synthetic standards checked against several rocks previously analysed by XRF. Trace elements Rb, Sr and Sn were determined by XRF on pressed powder discs, and Li was found by AAS.

Uranium was determined by the Government Chemical Laboratories using a chromatographic method employing PAN (1-(2-Pyridylazo)-2-naphthol) as a reagent.

Twelve duplicate whole rock analyses showed the greatest error to lie in the determination of SiO_2.

PROPERTIES OF TIN GRANITES

The genetic relationship of tin deposits to granite is probably the earliest and least disputed ore to rock association known to Geologists. Over 150 years ago Jameson (1821) stated: "Tin, of all the metals, is that which is most peculiar to granite". Daubrée (1841) pointed out that all tin veins are close to granitic rocks, and postulated that the tin and other characteristic elements of tin veins were derived from granite magma. He carried out chemical experiments to indicate the processes involved, and concluded that tin was transported in vapour form as a fluoride (Daubrée, 1849). His theory was supported by observations of his contemporary, Elie de Beaumont (1847) and since that time the idea that tin deposits are related to granite has seldom been questioned.

It is not surprising then, that, with the rapid growth of economic geology in the early part of the 20th Century, attempts should be made to distinguish granites responsible for tin deposits from those which were evidently barren of tin. Prior to about 1950, such attempts were concerned mainly with the petrology and major-element chemistry of the tin granites. Two of the more systematic attempts, those by Ferguson and Bateman (1912) and Westerveldt (1936) demonstrated that tin granites did not differ essentially from tin-free biotite granites. However, Westerveldt pointed the way to further research by collating the then available information on trace elements, and showing that tin granites and, more particularly, their biotites, contain concentrations of rare elements commonly found in granite pegmatites.

The lead given by Westerveldt was not taken up seriously until the mid-1950s, by which time methods of trace-element analysis had improved sufficiently to allow the necessary research to be carried out.

The pioneering work of Jedwab (1955, 1958) was quickly followed by results from Barsukov (1958), Rattigan (1960, 1963), Beus and Sitnin (1968) and many others. In addition to research aimed specifically at distinguishing tin granites, a considerable body of chemical information has been built up by economic geologists investigating various mineral fields (e.g. Jacobson and others, 1958; Hawley and others, 1966) and by more general studies of granites (e.g. Ghosh, 1934; Exley and Stone, 1964).

Criteria to distinguish tin granites from gold-bearing granites were set up by Sattran and others (1964) and Klominsky and Groves (1970).

At the time of the First Technical Conference on Tin data on tin granites were sufficiently numerous to permit two contributors, Hosking (1968) and Sainsbury and Hamilton (1968) to review the subject. Two further papers dealing with properties of tin granites (Hesp, 1971; Flinter, 1971) were read to the 3rd International Geochemical Symposium in 1970, and Hunter and Lenthall (1971) offered a further review in a paper on tin mineralization in the Bushveld Complex. The most recent comprehensive review is by Davy (1972).

TECTONIC SETTING

Tin deposits are found in several tectonic settings. Most are related to granites intruded into linear fold belts during Phanerozoic orogenies. Some, like those of Bolivia, are associated with acid effusives and hypabyssal intrusives also occurring in fold belts. Deposits with a distinctly different setting are found in Precambrian shields associated with 'younger' post-tectonic granites, or with pegmatites emplaced in marginal mobile belts.

Tin granites in fold belts

Some of the most comprehensive accounts of the tectonic setting of tin deposits are given by Russian workers. Unfortunately much of their source material is unavailable in the West. Bilibin (1968) reviewed the different types of mineralization found in an evolving geosyncline. He postulated that although granitic rocks were formed at several different stages during this evolution, tin deposits are related to high-silica potassic granites formed in the middle-tectonic stage, and to granite and hypabyssal and volcanic derivatives intruded during the late-tectonic stage. He noted that the tin deposits formed in the middle tectonic stage contain W, Mo, Bi, F, Li, Be, Ta, and Nb minerals, while those in the later stage have associated ores of Pb, Zn, Ag, As, and possibly W and Mo.

Itsikson (1968) considered the distribution of tin in folded belts aand reached conclusions similar to those of Bilibin, but elaborated on the tectonic controls. He regarded the middle stages of development, corresponding to the period of transformation of a geosyncline into a folded belt, as being highly productive of tin ores. Tin accumulations are associated with syntectonic batholiths of acid and ultra-acid potassic granites. Tin-bearing batholiths occur in linear belts controlled by regional ancient deep-seated fractures, confined either to the places of anticlinorium contact with the adjacent inner synclinoria or to the contact of downwarpings with consolidated geanticlinal zones.

The late stages of development of geosynclinal regions corresponding to the period of consolidation of the folded territory also produced considerable tin concentrations. These may be either hypabyssal or subvolcanic, depending on the depth of the controlling intrusion, and follow contacts of mobilized parts of the fold belt with stable blocks or with downwarps or grabens superimposed at a late stage in the orogeny.

Many workers in the Western World (and in Czechoslovakia) would appear to disagree with the Russians' conclusions that major amounts of tin are related to syntectonic granites. Rattigan (1963) for example stated that tin granites are emplaced at relatively high levels in the crust and often as a late magmatic phase. Raguin (1965) cited the tin granites of Malaysia and Cornwall as examples of post-tectonic granites.

Descriptions of fold-belt granites related to tin fields in Southeast Asia (Hosking, 1970a,b), southwest England (Hosking, 1970c), the Erzgebirge region of Czechoslovakia (Janecka and Stemprok, 1968; Tischendorf, 1973), North Queensland (de Keyser and Lucas, 1968), Stanthorpe (Richards and Bryan, 1924), New England (Wilkinson, 1969), Tasmania (Spry, 1962; Gee and Groves, 1971) showed the intrusions to have several common features. The tin granites are mostly described as late or post-tectonic, are among the younger granites in any field where multiple intrusion of granite took place, and were intruded at a relatively high level in the crust. Usually they either occupy cusps (or high points) on the upper parts of larger batholiths (e.g. Cornwall), or form small, relatively late stocks cutting earlier granites (e.g. Erzgebirge). The tin granites of the Blue Tier field in Tasmania (Gee and Groves, 1971) form flat-lying sheets at the top of the Blue Tier Batholith.

Tin granites in Precambrian shields

Commercial tin deposits are comparatively rare in the Precambrian shield areas of the World, and, where present, are generally smaller than those in the fold belts. However, they make locally important contributions to the economies of their host countries, and at least one of them, the Manôna pegmatite in the Congo, may contain very large reserves of low grade tin ore (Sainsbury, 1969b).

The Nigerian tin fields, with a production of over 635 000 tonnes of cassiterite and about 50 000 tonnes of associated columbite, are the most important worked in a shield area. The primary deposits are greisens and disseminations within or adjacent to intrusions of 'Younger Granite'. These are described by Jacobson and others (1958) as high level, magmatic granites with sharply cross-cutting contacts against the Precambrian basement complex. Many exposures of 'Younger Granite' have been identified as complex ring structures.

The emplacement of the 'Younger Granite' was preceded by the extrusion of great quantities of rhyolitic lavas which in many places are still preserved as the result of subsidence along concentric faults. The close association of the lavas and the high-level granites is one of the most important features of the province.

Two types of granite are recognized in the younger suite—biotite granite and riebeckite granite. Only the former is associated with the tin and niobium deposits. The biotite granite occasionally occurs as ring dykes, but more often is found as circular or crescentic plutons and small stocks. Although formerly regarded as late Precambrian, the 'Younger Granites' have since been dated at about 160 m.y. (Jacobson and others, 1964).

A tin province of the Nigerian type in the Brazilian Federal Territory of Rondônia is described by Kloosterman (1967, 1970). Greisens, and quartz veins carrying topaz, cassiterite and, in places, associated wolframite, tantalite and columbite are found within complex intrusions of younger granite which cut a basement of migmatitic and gneissic granite. The younger granite is exposed as relatively small stocks, mainly following distinct, north-trending lines, suggesting a control by deep-seated structures. Priem and others (1971) dated the younger granite at 980 m.y., and the basement complex at 2 000 m.y.

The Maniema tin fields in the Democratic Republic of the Congo are described by Anthoine and others (1968). The deposits comprise aplite veins, pegmatites, quartz veins and quartz-filled breccia veins containing cassiterite, wolframite, tantalite and columbite. They are located about the apices of granite stocks which have sharp contacts with the intruded quartzite and schist. The authors regard the granites as having been emplaced into comparatively cold zones.

The Potgietersrus tin fields of South Africa (Strauss, 1954; Hunter and Lenthall, 1971) appear to be unique in their tectonic setting. They are related to sheets of granite, granophyric granite and granophyre intruded during the Late Plutonic Phase of the Bushveld Complex. The granitic rocks form concordant sheets structurally overlying the basic and ultrabasic rocks of the complex, and underlying the acid volcanics of the Rooiberg Felsite.

The primary tin deposits are typically pipes in or near the youngest granite phase. In addition to cassiterite, they contain fluorite, wolframite, scheelite, arsenopyrite, ores of copper and zinc, and rare earth minerals.

Not all tin deposits within shield areas can be attributed directly to the intrusion of granite. Isotopic age determinations by Priem and others (1971) on the tin-bearing pegmatites of the Kamativi tin belt in Rhodesia show them to be about 1 000 m.y. younger than the known granitic rocks of the area. The pegmatites are attributed to a later metamorphic event affecting the margin of the shield.

PETROGRAPHY AND MINERALOGY

Essential minerals

Many workers (e.g. Ferguson and Bateman, 1912; Westerveldt, 1936; Rattigan, 1963; Flinter, 1971) made the point that tin deposits are associated with biotite, or biotite-muscovite granite containing more potash feldspar than plagioclase. Amphibole is normally absent, or present only in accessory amounts, and there appears to be no record of tin being related to pyroxene granite.

These general statements are supported by descriptions of tin granite from Cornwall (Exley and Stone, 1964), Malaysia (Ingham and Bradford, 1960), Czechoslovakia (Stemprok and Sulcek, 1969), Nigeria (Jacobson and others, 1958), South Africa (Strauss, 1954), northern Queensland (de Keyser and Lucas, 1968), northern New South Wales (Shaw, 1969), and Tasmania (Groves, 1972).

In all of these descriptions biotite is shown as being the principal ferromagnesian mineral. Where mineral compositions of the granites are given, potash feldspar is normally in excess of plagioclase (Table 36) in the main body of the granite, although greisens or late-stage differentiates (e.g. Groves, 1972) may show a high proportion of albite.

Potash feldspar may be present as orthoclase, microcline or perthite and all three varieties are recorded from some tin provinces (e.g. Nigeria). In some localities, the potash feldspar is replaced by albite formed during late-stage soda-metasomatism.

In tin granites unaffected by late-stage alteration, the most common plagioclase mineral is oligoclase, although andesine or primary albite are also recorded. Late-stage deuteric alteration may produce rims of albite around the oligoclase grains, or effect almost complete replacement of earlier plagioclase and potash feldspar by albite. Kaolinization of the plagioclase is common in Cornwall and Malaysia.

TABLE 36. MODAL COMPOSITIONS OF TIN GRANITES FROM VARIOUS PARTS OF THE WORLD (PERCENTAGES)

Mineral (%)	A	B	C	D	E	F	G	H
Quartz	34.2	35.1	36.3	30-40	32.1	38.5	35.2	40.6
Potash feldspar	31.0[1]	30.4	55.3	30-35	37.9	32.8	29.6	28.8
Plagioclase	23.2[1]	21.9	5.6	20-30	25.8	21.3	28.3[2]	24.4[2]
Biotite	5.7	3.9	2.3	1-5	3.4	7.5	3.0	4.0[3]
Muscovite	3.9	7.0[3]					1.3	
Amphibole						0.7		
Topaz	P	P						
Fluorite			0.2					
Tourmaline	0.9	1.0						
Others	0.3	0.2	0.1		0.1		2.5	1.9[4]

A. Average of ten coarse porphyritic biotite granites, South-west England (Exley and Stone, 1964, Table 3).

B. Average of five fine porphyritic biotite granites, South-west England (Exley and Stone, 1964, Table 5).

C. Average of two younger biotite granites, Nigeria (Jacobson and others, 1958).

D. Range of composition of Elizabeth Creek Granite, North Queensland (de Keyser and Lucas, 1968).

E. Stanthorpe "Adamellite", Northern New South Wales-Southern Queensland (Shaw, 1969).

F. Average of five calculated modes of porphyritic biotite granite/adamellite from Blue Tier Batholith, Northeast Tasmania (Groves, 1972, Table 1).

G. Average of six biotite-muscovite granites representing final phase of Blue Tier Batholith, Northeast Tasmania (Groves, 1972, Table 2).

H. Porphyritic medium-grained granite, Erzgebirge (Stemprok and Sulcek, 1969).

Notes

1. Includes secondary mica
2. Plagioclase is albite
3. Protolithionite
4. Includes 1.8% sericite and kaolinite

P. Present

Most tin granites are relatively leucocratic, with biotite altered to chlorite or muscovite. Where chemical or more detailed mineralogical work has been carried out on biotites from tin granites, they are shown to have a range of compositions and to include lithium-bearing varieties such as lithionite, zinnwaldite, or lepidomelane with a high fluorine content.

The muscovite contents of tin granite range from almost nothing to several per cent of the rock. It is recorded as both a primary and secondary constituent, the latter resulting from alteration of potash feldspar or biotite.

Accessory minerals

In addition to minerals such as apatite, zircon and rutile which are common to most granites, tin granites usually contain one or more of the pneumatolytic minerals topaz, fluorite and tourmaline. Other accessory minerals which are recorded, and probably have diagnostic value where present, are cassiterite, columbite, beryl, lepidolite and amblygonite. However, cassiterite does not appear to be as common an accessory as was previously believed. Rattigan (1963) noted: 'In many recent studies, cassiterite was not found as an orthomagmatic accessory in tin granites". Hosking (1970c) stated: 'That syngenetic cassiterite has locally contributed significantly to the development of placer deposits . . . perhaps still remains an open question, although the paucity of such cassiterite in the Malaysian granites examined to date by the writer and his colleagues makes this unlikely in his view'. Hosking attributed some of the better grade occurrences of cassiterite in granite (e.g. that at Haad-Som-Pan in Thailand, described by Aranyakanon, 1961) to late-stage mineralization by fluids trapped within the granite.

Flinter (1971) drew attention to the division of granitic rocks by some Russian workers into 'ilmenite-monazite' and 'sphene-allanite' types and concluded, from published information and his own studies, that granites of the sphene-allanite type are tin-free while most tin granites fall into the 'ilmenite-monazite' class.

Texture and grain size

The descriptions cited above, and others, indicate that tin granites may be of coarse, medium or fine grain size. However, the late-stage phases most directly associated with tin deposits are commonly fine grained. The main phases of many, but not all, tin granites are porphyritic.

One feature of tin granites which is implicit although not always stated in these descriptions, is that they are massive unfoliated rocks. Foliation or banding is seldom noted in tin granites, and, where reported, is restricted to the margins of the intrusions.

Alteration

Many tin granites show signs of deuteric alteration. Where slight, this may be evidenced by such features as alteration of feldspar to clay or sericite, the introduction of pneumatolytic minerals (topaz, tourmaline or fluorite) and alteration of biotite to chlorite, muscovite or a lithium mica. Where more intense, these processes may form greisens, schorl rock or kaolin deposits.

Albite replacements of, or overgrowths on, earlier normal feldspars are noted in tin granites from Nigeria (Jacobson and others, 1958) and Czechoslovakia (Stemprok and Sulcek, 1969). In both cases albitization is associated with the introduction of lithium mica, and probably represents late-stage alkali metasomatism.

CHEMICAL PROPERTIES

Major components

Ferguson and Bateman (1912) made the first attempt to define tin granite chemically. They compared analyses of granites and quartz porphyries from tin-producing regions and concluded that: 'Granites associated with tin deposits are alkaline in type, the percentage of lime and magnesia being abnormally low and the content of the alkalies rather high'. They also noted that K_2O exceeded Na_2O in all but one analysis.

Another comparison of chemical analyses of tin granites from various parts of the world was made by Westerveldt (1936). He showed that in the analyses chosen, normative pyroxene (calculated by Niggli's method) was always low, falling in the range of 0.5 to 0.65. Normative feldspar was neither pronouncedly sodic nor potassic.

The conclusions of Ferguson and Bateman (1912) and Westerveldt (1936) were based on necessarily limited data; at the time of their writing chemical analyses of granite from tin provinces were comparatively few, and not always related to the economic aspects of the granite bodies. Hence some large multiphase intrusions, such as the New England Batholith (Ferguson and Bateman, 1912, analysis L) are represented by a single analysis which is not necessarily the tin-bearing phase. Other analyses are of rocks which are very late differentiates (e.g. Ferguson and Bateman's analysis M) or represent metasomatized granite (e.g. Westerveldt's analysis 5).

Sullivan (1948) noted the association of W, Ta, Nb, Bi, Mo and Sn with acid granites and ascribed it to the incompatibility of the ionic radii and charges of these metals with the principal elements (Na, K, Ca, Al and Si) making up the granites. He postulated that metals cannot be accommodated in the chief rock-forming minerals, and are expelled during granitization. On the other hand, ferromagnesian minerals can take up appreciable quantities of these metals in their crystal lattices, and will prevent them being concentrated into ore bodies. (Data accumulated since Sullivan wrote this, suggest that mineralizing granites have higher-than-normal initial concentrations of metals such as Sn, thereby to some extent invalidating his conclusions; these data are reviewed in the next section).

Edwards and Gaskin (1949), in replying to other points raised by Sullivan (1948), stated that tin granites are conspicuously silica-rich even among "acid" granites, and are abnormally low in Mg and Ca. They cite examples of Australian tin granites with silica contents ranging from 74 to 77.5 per cent.

Rattigan (1960) concluded from his work on tin granites in eastern Australia that a high SiO_2 content expresses the stage of differentiation of a granite. However, from the point of view of the genesis of tin deposits, the SiO_2 may not be as significant as the high alkali content relative to the cafemic constituents. He regarded a high ratio of Na + K to Ca + Mg as being an important feature of tin granites. Batholiths with tin deposits, he concluded, show a trend of differentiation through granodiorite, hornblende and biotite granite to alkaline silicic types which are the tin granites. Batholiths barren of tin are differentiated, but differentiation has not produced significant volumes of granite with a high ratio of K + Na to Ca + Mg.

Sattran and others (1964) compared igneous rocks associated with various metallic deposits in the Bohemian Massif. They found that tin granites fell within well-defined fields with respect to their contents of Na, K and Mg. The atomic proportions (X1 000) of Na and K were close to 100, while that of Mg was always below 20, and usually less than 10. A similar study carried out on Tasmanian tin granites (Klominsky and Groves, 1970) showed that these were generally of comparable composition to the Bohemian tin granites, falling in the same fields defined by Na, K and Mg. The few exceptions noted were granites associated with only minor tin mineralization.

Hosking (1968) reviewed published information on tin granites, complementing it with his own knowledge of Cornwall and Malaysia. He agreed with other workers that tin granites are rich in SiO_2 and low in CaO and MgO, but pointed out that many barren granites have the same features, and cited published analyses to support this contention.

Flinter and others (1972) plotted various oxides in granites of the New England Batholith against a differentiation index (D.I. = normative quartz + orthoclase + albite, corrected to 100 per cent) and obtained a good positive correlation for SiO_2 and good negative correlations for FeO, MgO, CaO and TiO_2. Al_2O_3 and K_2O were not so well correlated, and Na_2O they found to be uncorrelated. Their results show the more important tin granites to have high differentiation indices.

Apart from the early contributions of Ferguson and Bateman (1912) and Westerveldt (1936), the deficiencies of which have already been mentioned, the authors cited above base their conclusions on information from only a few tin fields. Table 37 was compiled in an attempt to test their conclusions on a wider basis. Analyses 1 to 12 were selected or compiled (by averaging selected analyses) from about 150 published analyses of tin granites from many parts of the world.

To avoid giving weight to unrepresentative samples, only analyses which are averages (or composites) of 3 or more samples have been used. Most of the analyses are from reports which clearly state the relationship of the granites to tin mineralization, or, if not, then this information is available elsewhere in the literature.

Analysis 13 is an estimated World average composition of tin granite calculated by Klominsky and Groves (1970), and analysis 19 is a beryllium granite from the U.S.A. The remaining analyses are of various "average" granites—from Daly (1933), Nockolds (1954) and Turekian and Wedepohl (1961)—presented to enable comparison between tin granite and "normal" granite.

Silica: As suggested by Edwards and Gaskin (1949) and others, the silica content of tin granites is mostly high, ranging from about 71 per cent in southwest England to over 76 percent in the Potgietersrus tin field of South Africa. All silica contents are higher than in Daly's average granite of all periods and several are greater than Nockolds' average alkalic granite.

Na_2O+K_2O : $CaO+MgO$ ratio: This ratio varies considerably in the tin granites listed, ranging from 3.59 to 17.76. It is always higher than in Daly's average granite and Nockolds' average adamellite but in several tin granites it is less than in Nockolds' average alkalic granite or Turekian and Wedepohl's average low-calcium granite.

SiO_2: Na_2O+K_2O: $CaO+MgO$ ratio: The three most commonly cited chemical features of tin granites, namely their high contents of silica and alkalies, and impoverishment in lime and magnesia, are conveniently shown on a triangular diagram having as its corners, $SiO_2/10$, Na_2O + K_2O, and CaO + MgO.

On this diagram (Fig. 13) Nockolds' average granodiorite, adamellite, calc-alkalic and alkalic granites plot on a curved line, reflecting the calc-alkali dif-

TABLE 37. MAJOR OXIDE COMPOSITIONS OF TIN GRANITES FROM VARIOUS PARTS OF THE WORLD COMPARED WITH AVERAGE GRANITES AND A BERYLLIUM GRANITE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
LOCALITY	Alaska - Western Seward Peninsula	Cornwall - St Austell	Cornwall - Carnmenellis	Czechoslovakia - Bohemian Massif	Northern Nigeria	Potgietersrus, S. Africa	New England, N.S.W.	New England, N.S.W.	Kinta Valley, West Malaysia	Heemskirk, West Tasmania	Blue Tier, N.E. Tasmania	Herberton, N. Qld	World average tin granite	Average alkalic granite	Average calc-alkalic, granite	Average adamellite	Average granodiorite	Granite of all periods	Lake George beryllium area, U.S.A.
MAJOR OXIDES (%)																			
SiO_2	74.1	71.30	72.28	73.67	75.86	76.40	74.0	75.8	74.02	74.71	74.98	76.76	73.44	73.38	72.08	69.15	66.88	69.92	74.28
Al_2O_3	13.7	14.80	15.08	13.36	12.52	12.00	13.0	13.0	12.93	13.11	13.57	12.47	13.61	13.75	13.86	14.63	15.66	14.78	13.36
Fe_2O_3	.31	.25	.37	.59	.56	1.53	} 1.75	} 1.2	.35	.46	.33	.50	.92	.75	.86	1.22	1.33	1.62	.77
FeO	1.01	1.82	1.49	1.24	.96	1.15			1.87	1.38	1.05	.79	1.38	1.13	1.67	2.27	2.59	1.67	.91
MgO	.42	.48	.40	.26	.12	.18	.60	.09	.32	.34	.06	.11	.47	.26	.52	.99	.57	.97	.06
CaO	.77	1.05	1.19	.75	.54	1.07	1.00	.57	.87	.78	.39	.75	1.30	.72	1.13	2.45	3.56	2.15	.69
Na_2O	3.8	3.20	2.76	3.17	4.03	3.00	3.50	3.71	3.32	2.83	3.33	3.53	3.13	3.51	3.08	3.35	3.84	3.28	4.03
K_2O	4.7	5.15	5.05	4.91	4.72	4.96	4.84	4.54	5.00	5.08	4.60	4.52	4.76	5.13	5.46	4.58	3.07	4.07	4.98
H_2O^+	.57	.63	} .77	.90	.30		} .8	} .8	.55	.64	.88	.45	.42	} .47	} .53	} .54	} .67	} .78	.27
H_2O^-	.16	.14		.23	.15				.12	.20	.00	.12	.16						.08
CO_2	.05								.09	.		.09							
TiO_2	.11	.34		.12	.10	.08	.23	.08	.25	.19	.01	.08	.22	.20	.37	.56	.57	.39	.12
P_2O_5	.02	.26		.21	.04	.01	.08	.04	.06	.07	.22	.04	.12	.14	.18	.20	.21	.24	.01
MnO	.04	.06		.05	.02		.06	.06	.04	.04	.04	.02	.06	.05	.06	.06	.07	.13	.03
Total	99.8	99.48	99.39	99.46	99.92	100.4	99.9	99.9	99.79	99.83	99.46	100.23	99.99	100.00	99.80	100.00	100.02	100.00	99.59
CIPW NORMS																			
Quartz (Q)	31.1	29.6	33.9	34.3	33.2	39.2	33.5	36.0	32.4	40.0	36.9	37.1	33.2	31.7	29.2	24.8	21.9	29.3	29.8
Corundum (C)	.92	2.3	3.7	2.0			.38	1.0	.82	1.7	2.9	.7	1.2	1.4	.8			1.6	1
Orthoclase (Or)	27.8	30.4	29.8	29.0	27.9	29.3	28.6	26.8	29.5	30.0	27.2	26.7	28.1	30.3	32.2	27.2	18.3	24.0	29.4
Albite (Ab)	32.0	27.0	23.3	26.8	34.1	25.4	29.6	31.3	28.1	23.9	28.2	29.3	26.5	29.7	26.2	28.3	32.5	27.7	34.1
Anorthite (An)	3.9	3.5	3.7	2.3	2.1	4.6	4.4	2.6	3.4	3.4	.50	2.9	5.7	2.6	5.6	11.1	16.4	9.1	3.4
Diopside (Di)					.26	.53													
Hypersthene (Hy)	2.6	3.9	3.1	2.3	1.3	.9	3.1	1.9	3.6	2.7	1.9	1.2	2.7	1.8	3.0	4.7	6.8	3.7	1.0
Magnetite (Mt)	.46	.37	.53	.85	.81	2.2	.72	.28	.51	.67	0.47	.7	1.3	1.1	1.4	1.9	1.9	2.3	1.1
Ilmenite (Il)	.21	.64		.22	.18	.15	.44	.15	.47	.36	.01	.15	.41	.37	.8	1.1	1.1	.7	.23
Apatite (Ap)	.05	.60		.49	.09	.02	.19	.09	.14	.16	.52	.09	.28	.33	.4	.5	.5	.6	.02
Calcite (Cc)									.20			.20							
RATIOS AND DIFFERENTIATION INDEX (D.I.)																			
K_2O/Na_2O	1.24	1.61	1.83	1.55	1.17	1.65	1.38	1.22	1.51	1.79	1.38	1.28	1.52	1.46	1.77	1.37	.80	1.24	1.23
$\frac{Na_2O + K_2O}{CaO + MgO}$	7.14	5.46	4.13	8.00	13.26	6.37	4.59	12.50	6.99	7.06	17.76	9.36	4.46	8.82	5.18	2.31	1.35	2.35	12.01
D.I.	91.7	88.1	88.2	91.6	95.7	93.5	92.5	94.9	90.8	94.9	93.6	93.4	88.3	92.1	88.2	80.7	73.2	81.6	94.0

(1) Average of 6 analyses of tin-beryllium granite (Sainsbury, 1969, Table 5). (2) Composite analysis of 6 samples of St Austell Granite (Harding and Hawkes, 1971). (3) Average of 5 analyses of Carnmenellis Granite (Ghosh, 1934, analyses 1-5). (4) Average of 46 analyses of tin granites from the Bohemian Massif (Klominsky and Groves, 1970, Table 1). (5) Average of 7 analyses of biotite-granite from younger Granites (Jacobson and others, 1958, Table 4). (6) Average of 5 analyses of Bobbejaankop Granite (quoted in Hunter and Lenthall, 1971, Table 1). (7) Average of 6 analyses of Stanthorpe Adamellite (Flinter and others, 1972, Table 1, analyses 70-75). (8) Average of 3 analyses of Ruby Creek Granite (Flinter and others, 1972, Table 1, analyses 76-78). (9) Average of 6 analyses of granites from the Kinta Valley (Ingham and Bradford, 1960, Table 6). (10) Average of 14 analyses of Heemskirk Granite (7 Red Granite 7 White Granite) (Klominsky and Groves, 1970, Table 1). (11) Average of 6 analyses of non-porphyritic granite, Blue Tier Batholith (Klominsky and Groves, 1970, Table 1). (12) Average of 10 analyses of Elizabeth Creek Granite (de Keyser and Lucas, 1968, analyses 13-22). (13) Average of 42 tin granites from the World (Klominsky and Groves, 1970, Table1). (14) Average alkalic granite (Nockolds, 1954). (15) Average calc-alkalic granite (Nockolds, 1954). (16) Average adamellite (Nockolds, 1954). (17) Average granodiorite (Nockolds, 1954). (18) Average granite of all periods (Daly, 1933). (19) Average of 3 analyses of Redskin Granite (Hawley and others, 1966).

ferentiation trend away from the CaO + MgO corner of the triangle. The tin granites (and the beryllium granite) from Table 37 show $Na_2O + K_2O$: CaO + MgO ratios between calc-alkalic and alkalic granite, or on the alkali side of the latter. Most lie on the silica side of a line joining the average granites, indicating that tin granites are richer in silica than normal granite.

A plot of the 150 analyses, from which columns 1 to 12 of Table 37 were selected, shows a similar clustering on the silica side of the average line, between calc-alkalic and alkalic granite, though there is a wider scatter of points.

K_2O:Na_2O ratio: All the tin granites listed in Table 37 contain more K_2O than Na_2O, but comparison with the average granites shows this excess to be a common feature of granites in general, by no means confined to tin granites. However, it may serve to distinguish possible tin granites within Archaean shields, where most of the granitic rocks contain more Na_2O than K_2O.

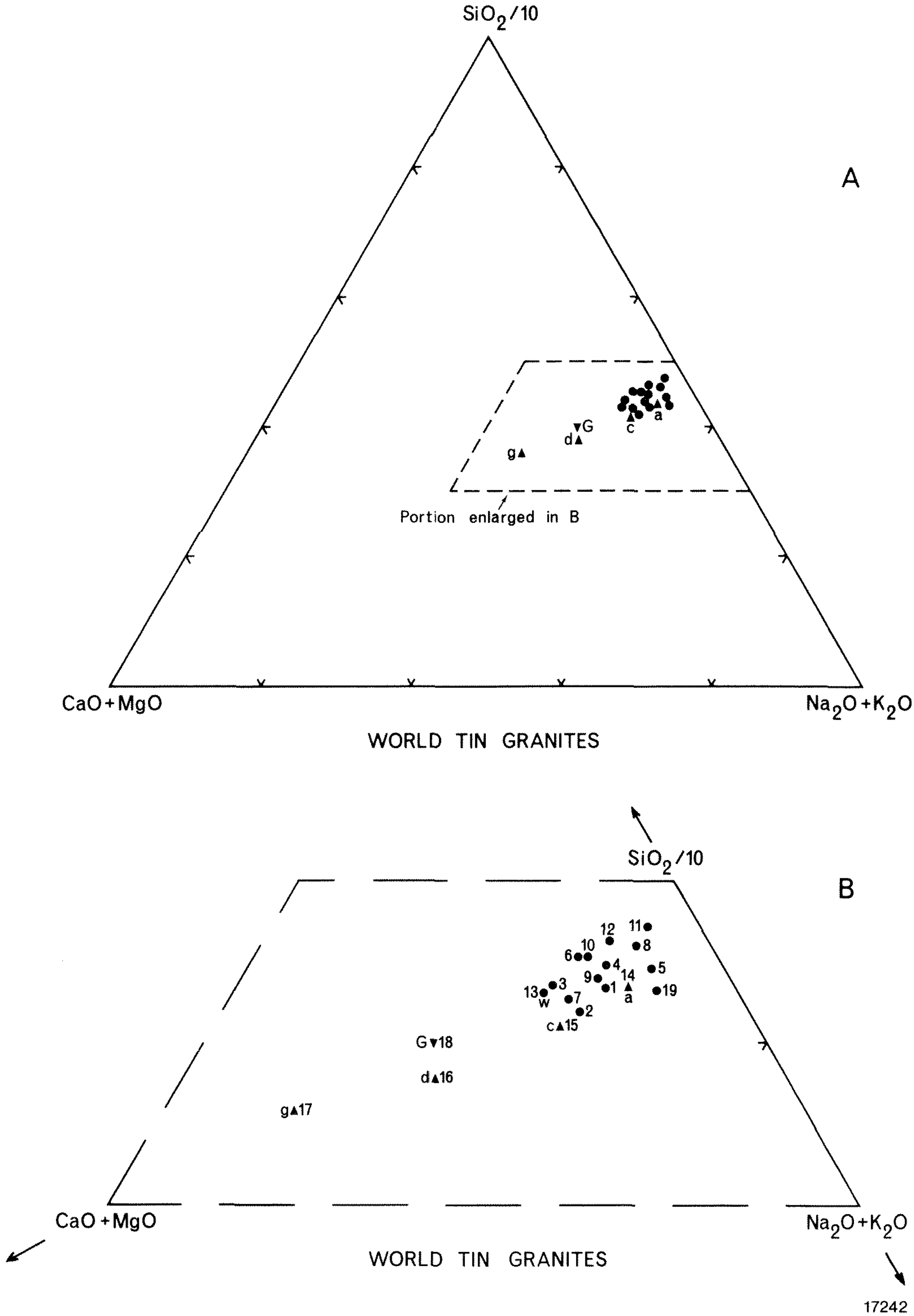


Figure 13. Triangular plot of $SiO_2/10$: $CaO + MgO$: $Na_2O + K_2O$ for World tin granites and average granites. Numbers in enlargement B refer to columns in Table 37. Lettered triangles refer to average granites: a = average alkali granite, c = calc-alkali granite, d = adamellite, g = granodiorite (Nockolds, 1954); G = average granite of all periods (Daly, 1933); w = World average tin granite (Klominsky and Groves 1970). The tin granites cluster towards the alkali side of the triangle and lie mainly on the silica side of a line joining Nockolds' averages.

$\sum FeO + MgO : CaO : Na_2O + K_2O$ ratio: The common association in tin granites of small amounts of ferromagnesian minerals and comparatively large amounts of alkali feldspars, is reflected in Figure 14—a triangular plot of the ratios $\sum FeO$ (total iron as $FeO) + MgO : CaO : Na_2O + K_2O$. In this figure Nockolds' averages for granodiorite, adamellite, calc-alkalic and alkalic granite plot on a curved line trending towards the alkali corner of the triangle. Again, all tin granites from Table 37 plot either between average calc-alkalic and alkalic granite or on the alkali side of the latter. All tin granites also fall close to the line joining the average granites, suggesting that they conform to the normal calc-alkali differentiation trend, at least prior to the formation of late-stage differentiates or metasomatic rocks, analyses of which have not been included in Table 37. Thus, the high proportion of alkalies to lime, magnesia and iron is a feature of differentiated granites in general, and not specifically of tin granites.

Differentiation Index: A number of indices designed to gauge the degree of differentiation of an igneous rock have been proposed from time to time. That used by Flinter and others (1972), and referred to earlier is one example. It was devised by Thornton and Tuttle (1960) and represents the sum of normative quartz + albite + orthoclase corrected to 100 per cent. In the following discussion it is designated simply D.I. Values of D.I. for the tin granites listed in Table 37 range from 88.1 to 95.7 compared with 88.2 and 92.1 for average calc-alkalic and alkalic granite respectively.

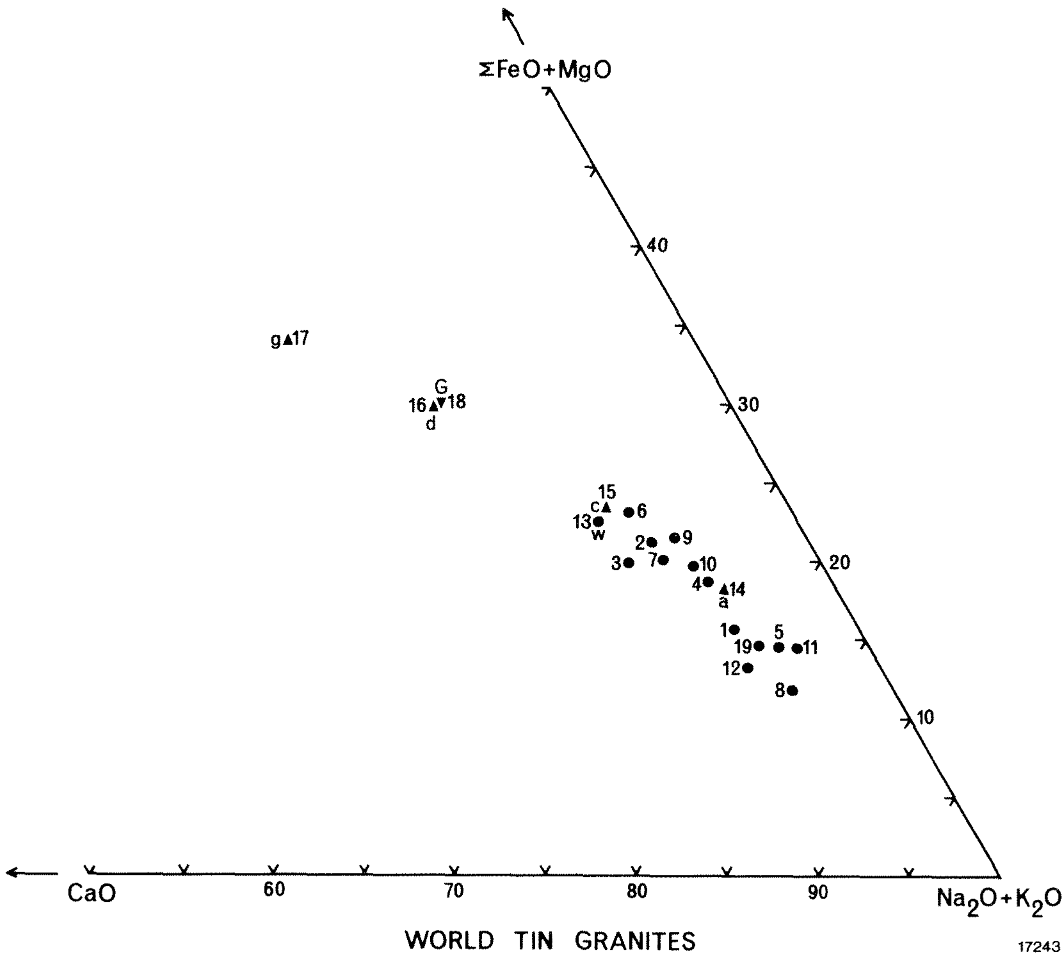


Figure 14. Portion of triangular plot of $\sum FeO + MgO : CaO : Na_2O + K_2O$ for World tin granites and average granites. Numbers and letters are as in Figure 13. Tin granites cluster towards the alkali corner of the triangle in the vicinity of average alkali and calc-alkali granite.

Discussion: Comparisons made between tin granite and 'average' granite on the bases of their major chemical components suggest:

1. tin granites are well differentiated members of the granite series;

2. many tin granites have a higher ratio of silica to alkalies than do 'average' granites; and

3. the frequently cited 'low' contents of lime and magnesia (and iron) in tin granites are due to normal differentiation processes and are not necessarily diagnostic of these granites.

Trace components

Although many studies of the trace element contents of tin granites have been made since 1955, the results are sometimes difficult to interpret because of the different ranges of elements determined and the varying stages of alteration of the granites sampled. The most commonly sought elements include tin itself and such rare and base metals as lithium, beryllium, uranium, thorium, niobium, tungsten, copper, lead and zinc, which are often associated with tin deposits. Some investigators have also determined indicators of magmatic fractionation such as rubidium, strontium and zirconium, and many include fluorine in the elements assessed.

The trace element contents of 14 better-documented tin granites are listed in Table 38. They can be compared with three tin-poor granites and two 'average granites' presented in Table 39.

Results of some investigations concerning only one or two elements are not listed in Table 38, but are referred to in the following discussion.

Tin in total rock: Onishi and Sandell (1957) estimated an average abundance of about 3 ppm Sn in granite, and concluded from the number of samples analyzed that the true average was probably between 2 and 4 ppm Sn. This range appears to be confirmed by additional data collated by Hamaguchi and Kuroda (1970).

Granites responsible for forming tin deposits almost always contain appreciably more than the clarke value of 3 ppm Sn in granitic rocks, and usually more than that noted in barren granites in the same region. Barsukov (1958) for example recorded 16 to 30 ppm Sn in tin granites from the U.S.S.R. compared with 3 to 5 ppm Sn in barren granites from the same region.

Rattigan (1963) found from 4 to 45 ppm Sn (average 20 ppm) in mineralizing granites from eastern and northern Australia, compared with only 2 to 5 ppm Sn (average 3.1 ppm) in tin-poor granite.

Investigations of single tin-bearing plutons show that the tin content can vary appreciably with depth

TABLE 38. CONTENTS OF SELECTED TRACE ELEMENTS IN GRANITES FROM VARIOUS TIN PROVINCES

Province	N.E. Queensland			New England		Tasmania			S.W. Europe		Erzgebirge	E. Transbaikalia		Alaska	Rooiberg	Nigeria
Element	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
								ppm								
Be	5.6	3.6	3.5							15	16	6.6	6.9	12		
Ce															153	
Cu	6	6	8	1.5	4				<10					37		
F	ca.2100			1 065	2 790	1 400	10 200		2 400	3 100	1 500	3 000	3 300		6 300	4 240
Li	31	69	94	101	147	93	370		300	497	280	70	84	177		102
Nb												22	44	41	48	
Pb	32	26	25	28	50						30	30	19	50		
Rb	427	356	389			365	1 035	330	460		730	342	372		523	341
Sr	26	88	43	<400	<400	75	5		78						6	
Sn	5	9	16	9	4.5	9	49			151	66	6.2	7.4	20	23	
Th	46	14	17					51.7							49.5	
W				<15	<15-20					42	13					
U								10.6			44					
Zn	33	50	32									61	42			
Zr				55	110											
								RATIOS								
K/Rb	92	99	102			108	37	136	94		56				80	93.5
Mg/Li	21	38	26	5.4	4.5	6.2	1.0									
Ca/Sr	195	114	128			140	740								1 800	
Rb/Sr	16.4	4.1	9.1				207								87	

(1) Elizabeth Creek Granite. (2) Mareeba Granite. (3) Finlayson Granite (1-3 from Sheraton and Black, 1973). (4) Ruby Creek Granite. (5) Mole Granite (4 and 5 from Flinter, Hesp and Rigby, 1972: 4 is average of analyses 76-78; 5 is average of analyses 84-87). (6) Porphyritic biotite granite/adamellite from Blue Tier Batholith. (7) Biotite-muscovite granite from Blue Tier Batholith (6 and 7 from Groves, 1972). (8) Red Granite phase of Heemskirk Granite (Heier and Brooks, 1966). (9) St Austell Granite, Cornwall (Data from Harding and Hawkes, 1971, Tables 2, 3 and 5). (10) Granite de Collette, France (Aubert, 1968). (11) Porphyritic medium-grained granite and microgranite, Cinovec (Stemprok and Sulcek, 1969). (12) and (13) Main apical portion and late differentiates respectively of the Soktuy Massif (Tauson and others, 1968). (14) Average biotite granite, W. Seward Peninsula (Sainsbury and others, 1968). (15) Bobbejaankop Granite (Hunter, 1973). (16) Younger granites (Bowden, 1966).

TABLE 39. CONTENTS OF SELECTED TRACE ELEMENTS IN SOME TIN-POOR GRANITES, AND "AVERAGE GRANITES"

Element	Tin-poor granites			Average granites	
	Snowy Mountains, N.S.W.		Albany, W.A.	High Ca	Low Ca
	1	2	3	4	5
		ppm			
Be		4.5		2	3
Ce				81	92
Cu	22	2	8	30	10
F				520	850
Li	29	ca.29	17	24	40
Nb				20	21
Pb	29	23	57	15	19
Rb	121	388	245	110	170
Sr	190	42	265	440	100
Sn	3.0	3.5		1.5	3.0
Th	17	17.2	74	8.5	17
W				1.3	2.2
U	3.8	8.0		3.0	3.0
Zn			62	60	39
Zr	195	88	236	140	175
		RATIOS			
K/Rb	217	99	168	230	250
Mg/Li	465	41	216	392	40
Ca/Sr	109	121	45	57	51
Rb/Sr	.64	9.2	0.9	.25	1.7

1. Average of 20 granodiorites and adamellites, Snowy Mountains area (Kolbe and Taylor, 1966).
2. Average of 8 leucogranites, Snowy Mountains area (Kolbe and Taylor, 1966).
3. Average of 10 massive adamellites, Mount Manypeaks Batholith (Stephenson, 1973).
4. and 5. Average high-calcium and low-calcium granites (Turekian and Wedepohl, 1961).

from the apex of the intrusion (e.g. Stemprok and Sulcek, 1969), and between different phases of the intrusion (e.g. Tauson and others, 1968; Groves, 1972).

Davy (1972, Table 1) listed results of 20 investigations of the tin contents of tin-bearing and tin-poor granites and concluded that the bulk analysis of a granitic rock for tin will indicate its possible tin-bearing potential. He considered that if the average tin content of five samples of granite, chosen to be as typical as possible of the sample site, is more than 10 ppm Sn, then there is a good possibility that tin mineralization is present. He also noted the importance of establishing a regional background value and of sampling sufficient localities to ensure that the apical parts of any pluton will be included.

Tin in mineral fractions: In tin-poor granites tin is concentrated mainly in sphene and amphibole where it replaces titanium and ferric iron (Petrova and Legeydo, 1965; Tauson and others, 1968). However, most studies of tin granite show that an appreciable proportion of the tin present is contained in biotite, or, if the granite is greisenized, in muscovite and/or cassiterite.

Many writers consider that the tin content of biotite in a granite is a useful indication of its mineralizing potential. Rattigan (1963) determined from 75 to 325 ppm Sn in biotites from tin granites in eastern and northern Australia, compared with 5 to 30 ppm Sn in biotites from barren granites. He regarded a concentration of greater than 50 ppm Sn in biotite as an indicator of associated tin deposits. He also noted that the comparatively low tin content of some tin granites is due to their small content of biotite. Pahn (1965) quoted 60 ppm Sn, 124 ppm Sn, and 155 ppm Sn respectively, in biotites from three tin granites in France, as against 17 ppm Sn in biotite from a barren granite. Davy (1972, Table 2) listed many more examples, most of which further illustrate the greater concentration of tin in biotites of tin-bearing granites.

Durasova (1967) found that the tin content of biotite could be related to the ratio $Fe^{3+}/Mg + Fe^{2+}$ in the mineral. Hesp (1971) claimed that a more satisfactory correlation is obtained by using the factor

$$\frac{Fe^{3+} + Li^{+}}{Fe^{2+} + Mg^{2+}} - \frac{Ti^{4+} + Mn^{2+}}{10}$$

He called this factor the "tin holding capacity" of the biotites.

The tin content of muscovite also seems to be a potential prospecting guide, although its use is limited by low contents of muscovite in many granites. Jedwab (1955) recorded 60 to 400 ppm Sn (average 120 ppm Sn) in muscovite from a French tin granite, and compared these to a range of from 10 to 130 ppm Sn (average 71 ppm Sn) in a tin-poor granite. In a similar study in Britain, Bradshaw and Stoyel (1968) found 52 ppm Sn in muscovite from tin-bearing granite, and 28 ppm Sn in barren granite. Pahn (1965) recorded respectively 77, 214 and 174 ppm tin in muscovite from three tin granites in France, and Stemprok and Sulcek (1969) found 470 ppm tin in white mica from a lithium-rich granite in Czechoslovakia.

Several investigators have determined the tin content of feldspars in tin granite, but although some high readings have been reported (e.g. Sainsbury and Hamilton, 1968), there appears to be no consistent pattern that could serve as a prospecting guide. Most of the results reported are listed by Davy (1972, Table 2).

Sainsbury and Hamilton (1968) found 250 to 5 000 ppm Sn (average 2 250 ppm Sn) in heavy mineral concentrates obtained from Alaskan tin granites. They recommend this approach as a useful prospecting tool.

Lithium: According to Heier and Billings (1969) lithium in igneous rocks substitutes for Mg and Fe^{2+}, and increases regularly, along with the Li/Mg ratio, in the series orthopyroxene-clinopyroxene-amphibole-mica. Feldspar contains only low amounts, generally less than 5 ppm Li. Lithium is concentrated in late phases of granitic intrusions, and may become sufficiently enriched in greisens, pegmatites and apogranites to form independent minerals.

Estimates of the average lithium contents of granites range from 24 ppm Li for high calcium granite to 40 ppm Li in low calcium varieties (Table 39). In tin granites the lithium content is rarely less than 50 ppm and in some stocks reaches 10 to 15 times the average quantities (Table 38). In altered or greisenized granite, the lithium content may reach 3 000 to 4 500 ppm (e.g. Aubert, 1968).

Most of the lithium in tin granites is held in micas. Jedwab (1958) reported biotite analyses of 380 and 3 654 ppm Li in two phases of the Montebras Granite, and 853 ppm Li in the Carnmenellis Granite. These figures are compared with 77, 121 and 165 ppm Li in some tin-poor granites in Europe. Sainsbury and others (1968) reported from 1 300 to 6 000 ppm Li in biotite from Alaskan tin-beryllium granites, and Groves (1972) determined averages of 1 440 ppm Li and 6 040 ppm Li in biotite from two phases of the Blue Tier Batholith. The substitution of Li^{+} for Mg^{2+} in biotite gives rise to low Mg/Li ratios in many tin granites.

Lithium is readily determined by emission spectrometry and atomic absorption methods, and seems to be a useful indicator of mineralizing granites.

Beryllium: The distribution of beryllium in granitic rocks is summarized by Hormann (1969). The metal is concentrated in the dark minerals and muscovite. Biotite and hornblende can contain up to 15 ppm Be, and muscovite 10 to 50 ppm Be. Plagioclase with up to 20 ppm Be exceeds potassic feldspar with about 4 ppm Be.

The average beryllium content of granitic rocks is put at 2 to 3 ppm, but the range is appreciable. Beus (1961), in a comprehensive study, found averages of 4.5 ppm Be in biotite granite and 10 ppm Be in muscovite granite. Limited data on tin granites (Table 38) show these to be mainly higher than average Be contents. Rare published analyses of biotite from tin granites show 4 to 16 ppm Be (Sainsbury and others, 1968) and 16 to 28 ppm Be (Jedwab, 1958). The highest content noted in dark mica is 39 ppm Be, in zinnwaldite, recorded by Stemprok and Sulcek (1969).

The analytical difficulties in determining beryllium probably restrict its use as a prospecting guide.

Rubidium: The geochemistry of rubidium is summarized by Heier and Billings (1970). Because of its ionic similarity to K^{+}, Rb^{+} is always incorporated in potassium minerals and never forms minerals of its own. It becomes preferentially concentrated in late-stage micas and K-feldspar to the extent of making up several per cent of the host mineral.

More recent estimates of the average content of granitic rocks are of the order of 100 ppm Rb (for high calcium granite) to 200 ppm Rb (for low calcium granite). Heier and Billings reported an average of 276 ppm Rb in 214 post-1961 analyses of granite.

Tin granites almost always contain above-average contents of rubidium. Those listed in Table 38 range from 330 ppm to 1 035 ppm Rb.

K/Rb ratio: Of possibly more significance than the absolute rubidium content, is the ratio K/Rb. The normal range of K/Rb in igneous rocks is 160 to 300, averaging about 230 (Shaw, 1968). Ratios of less than 160 indicate that magmatic fractionation has taken place. Tin granites almost always have K/Rb ratios of less than 160, and usually less than 100 (Table 38).

Strontium: In igneous rocks, Sr^{++} may substitute for Ca^{++} in plagioclase and K^{+} in potassic feldspar and mica (Rankama and Sahama, 1950). Sr^{++} is captured during the early stages of crystallization, and is consequently depleted in the residual fraction of a magma. Its average content in low calcium granite was determined by Turekian and Kulp (1956) as 100 ppm. Tin granites characteristically have appreciably less than 100 ppm Sr (Table 38).

Ca/Sr ratio: Turekian and Kulp (1956) showed a positive correlation between calcium and strontium in granitic rocks but it appears from their data that strontium is depleted at a greater rate than calcium. This results in increased Ca/Sr ratios in calcium-poor fractionated granites, including tin granites.

Rb/Sr ratio: This ratio appears to be a sensitive indicator of fractionation in granitic rocks. Normal granites have Rb/Sr ratios of less than 1, but in fractionated phases this ratio rises appreciably. Tin granites commonly have Rb/Sr ratios of between 5 and 10, and the ratio may rise to over 200 in extreme examples (e.g. Table 38, column 7).

Although not directly indicating the mineralizing potential of a granite, unusually high Ca/Sr and Rb/Sr ratios are characteristic of fractionated magmas in which rare elements, if present in the original melt, may be expected to concentrate.

Fluorine: The behaviour of fluorine in magmatic processes is summarized by Koritnig (1972). Because most early-formed minerals are unable to accept appreciable amounts of fluorine into their lattices the element accumulates during magmatic crystallization and fractionation. Only apatite among the early minerals contains fluorine as a main constituent.

During the later stages of crystallization, fluorine is able to substitute for the hydroxyl ion in mica. However, the amount accepted may be limited, and the residual magma is further enriched in fluorine. The comparatively high solubility of hydrofluoric acid in silicate melts also causes accumulation of fluorine.

Granties which have not been pneumatolytically altered contain an average of about 800 ppm F, held mainly in the micas and apatite. In greisenized granite, fluorine may comprise several per cent of the rock, forming fluorite and topaz, and replacing an appreciable part of the hydroxyl ion in lithionite and zinnwaldite.

Tin granites, have commonly undergone some greisenization and almost always contain above-average fluorine. In those listed in Table 38, the contents range from about 1 000 to 10 000 ppm F.

Fluorine has obvious potential as a geochemical indicator of tin granite, although accurate determinations can be time consuming. However, the method of Ficklin (1970) using an ion-selective electrode is sufficiently accurate for prospecting purposes, and has proved effective in distinguishing some Western Australian tin granites.

Anomalous fluorine contents in granite may also be indicated by fluorite and topaz in the heavy mineral suites.

SUMMARY

A consideration of published information indicates that tin granites have many of the following features:

1. They are usually late or post-tectonic, high-level intrusions with mainly undeformed textures;
2. they are biotite or biotite-muscovite granites, with a high proportion of alkali feldspar;
3. they are likely to have one or more of the minerals fluorite, topaz and tourmaline as accessories, and will probably contain no sphene;
4. they contain above-average silica, potash in excess of soda, a high ratio of alkalies to lime magnesia and iron, and high values of D.I.;
5. they contain anomalously high quantities of such "granitophile" elements as tin, lithium, beryllium, rubidium and fluorine, and below-normal amounts of strontium;
6. they have high Rb/Sr and Ca/Sr ratios and low ratios of K/Rb and Mg/Li;
7. their micas, particularly biotite, are anomalously rich in tin, lithium, beryllium, fluorine and probably other "granitophile" elements.

Of these features the trace element contents and ratios seem to be the most useful prospecting guides.

PILBARA BLOCK GRANITES

The distribution of the granitic rocks in the vicinity of the principal tin fields of the Pilbara Block is shown on Plates 2 (Moolyella), 4 (Shaw River), 5 (Wodgina) and Figure 7 (Coondina). Relationships of the various types of granite are given in the descriptions of these fields.

In summary, two broad groups of granitic rocks are recognized:

1. an older group, made up mainly of pre- or syn-tectonic migmatite and associated gneissic and foliated granite, but which also includes slightly later but still syntectonic plutons of homogeneous foliated granite;
2. a younger group of late or post-tectonic granites which include the tin granites of the Pilbara Block.

Age determinations, referred to in Chapter 2, date the older granites at about 2.9 to 3.1 b.y., and the younger granites at between 2.5 and 2.6 b.y. Emplacement of the older group of granites probably took place over a considerable period and possibly during more than one tectonic event (Hickman 1975b). The present scheme of grouping them together as 'older granites' is a simplification reflecting the economic bias of this investigation rather than the geological importance of the rocks. In other reports (e.g. Noldart and Wyatt, 1962; Blockley, 1973) the homogeneous plutons within the older complex are distinguished as 'magmatic granites of intermediate age'. This term is not used here, partly because it is cumbersome, but mainly because later geochronology (de Laeter and Blockley, 1972; de Laeter and others, 1975) showed samples of 'granites of intermediate age' to lie on or close to the same isochron as samples from the migmatite complex. It is recognized though that this isochron may reflect, at least in part, a metamorphic age.

PREVIOUS INVESTIGATIONS

Previous accounts of the geology of the Pilbara Block giving petrographic or chemical information on the granites are those of Noldart and Wyatt (1962—mineralogy of some samples and a few analyses for silica and tin only), Blockley (1970, 1971, 1973), de Laeter and Blockley (1972), Hickman and Lipple (1975), de Laeter and others (1975), and Oversby (1976).

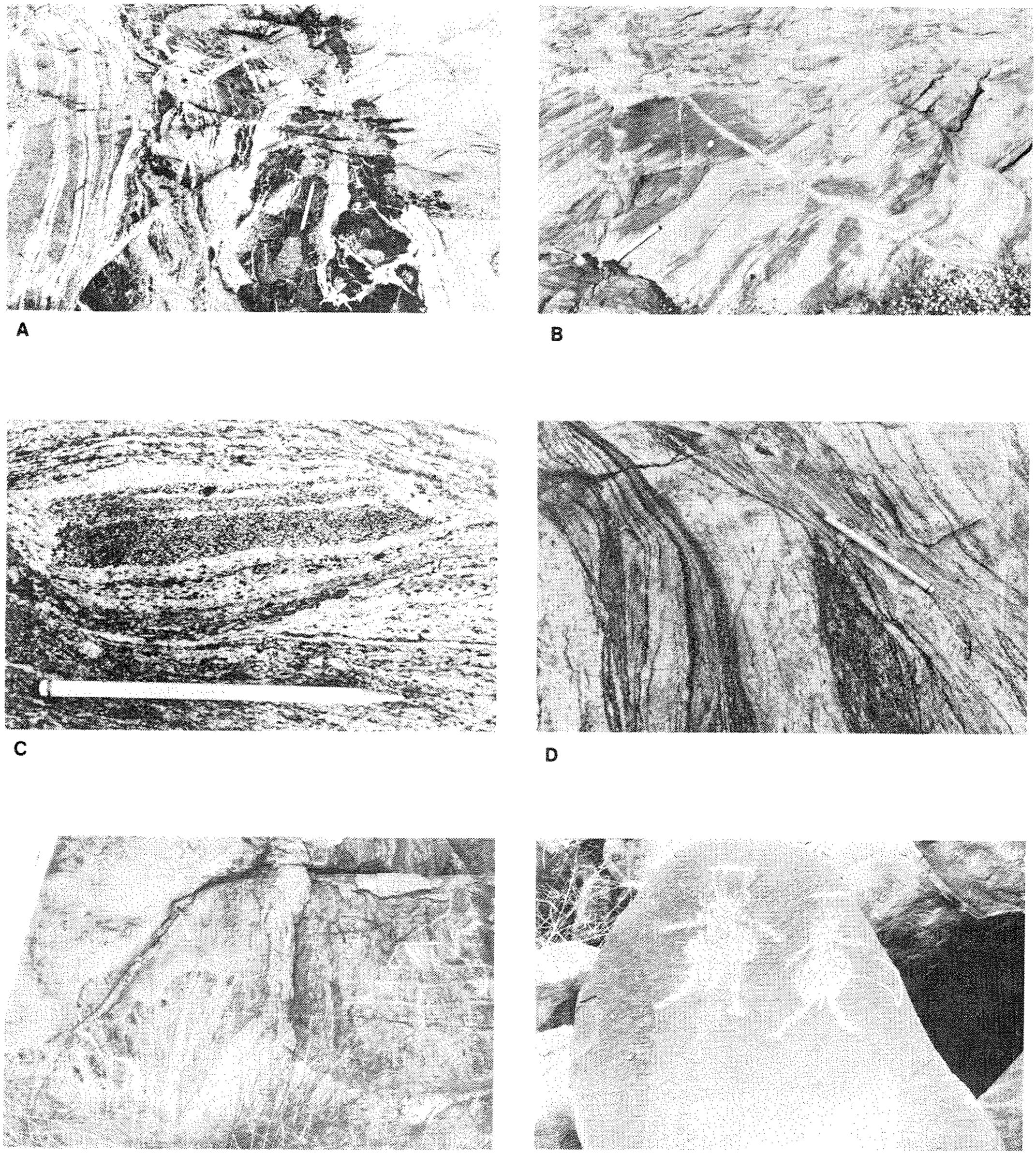


Figure 15. Photographs of exposures of older granite, Moolyella and Shaw River tin fields.

- **A. Stromatic, schollen (raft) and nebulitic structured migmatite exposed in the bed of the Shaw River west of Cooglegong.**
- **B. Stromatic and schlieren-structured migmatite cropping out near D.C. 585, Moolyella.**
- **C. Foliation in granitic neosome 'flows' about a rotated block of granitized amphibolitic palaeosome. Pegmatite segregations at either end of the block mark pressure shadows.**
- **D. Cross-cutting feature in migmatite outcrop is interpreted as a plastic shear formed at a relatively early stage in the history of the rocks. Exposure is in the bed of the Shaw River west of Shaw Patch.**
- **E. Contact between Mulgandinnah Adamellite (massive rock below hammer) and gneissic granite, north of Spear Hill.**
- **F. Fine-grained surface of Mulgandinnah Adamellite was favoured by Aboriginal artists for ceremonial petroglyphs. Mineral foliation characteristic of the granite type can be seen on the joint face immediately left of the left hand figure.**

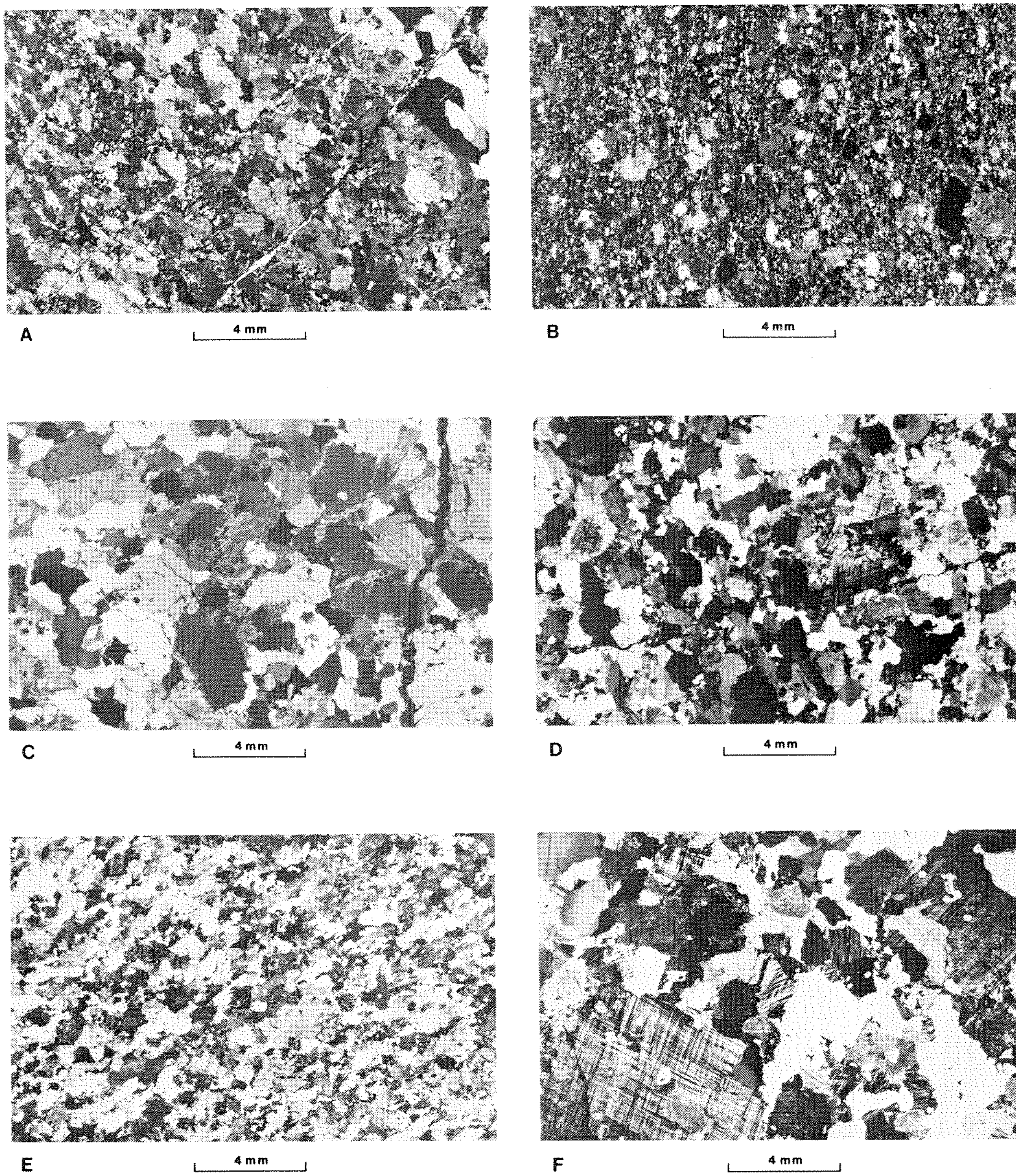


Figure 16. Photomicrographs showing textural features of older granites from the Pilbara Block.

A. Chloritized amphibolite palaeosome of migmatite from bed of Shaw River west of Spear Hill air strip (38027B).

B. Mylonitized granitic neosome from migmatite. Locality as for A (38026B).

C. Gneissic granite from near Eleys (15280).

D. Weakly foliated granodiorite from northwest of Pilbara Tin Pty Ltd's camp at Moolyella (12584).

E. Mulgandinnah Adamellite from Mulgandinnah Hill, Shaw River tin field (15221).

F. Kangan Adamellite from the western side of the Wodgina tin field. Some of the older porphyritic granites such as this one, have a strong petrographic resemblance to younger granites (15244).

(All viewed through crossed nicols)

FIELD RELATIONSHIPS AND PETROGRAPHY

Older migmatite complex

The migmatite complex, as exposed in the Moolyella and Shaw River tin fields, displays a distinct paragenetic sequence reflecting successive stages of assimilation of pre-existing greenstone material by granitic magma, and the mobilization of migmatite to form more-or-less homogeneous granite. The most primitive rocks in this sequence are stromatic migmatites made up of amphibole-rich or biotite-rich palaeosomes intruded lit-par-lit fashion by various types of granite and pegmatite (Fig. 15A,B). These rocks show flowage features (with a pronounced metamorphic overprint) parallel to the boundaries of the batholith and to the layering of the intruded greenstones (Fig. 15C,D). Homogenization of the migmatite produced first gneissic granite and then foliated granite. In parts of the Shaw River tin field, a second period of migmatite generation produced agmatites in which angular blocks of gneissic granite are veined and surrounded by fine-grained or porphyritic granite. Local concentrations of the neosome material in the agmatites produced stocks of homogeneous granite, and extension of the process apparently gave rise to plutons of foliated granite such as the Mulgandinnah Adamellite (Plate 4).

Summarized petrographic descriptions of typical rocks from the migmatite complex are given in Table 40, and some microfabrics are shown in Figure 16A-C. Except for the amphibole-rich and biotite-rich palaeosomes, the most common rock type is foliated to gneissic biotite granodiorite or tonalite in which the main variations are in the proportion of femic minerals. Characteristically, biotite is partly replaced by chlorite.

Older homogeneous foliated granites

Older homogeneous foliated granites comprise five main types in the areas studied:

1. medium-grained foliated granodiorite/tonalite forming a stock in the northern part of the Moolyella tin field;
2. leucocratic granodiorite making up a stock west of Moolyella;
3. fine-grained, foliated, magnetite-bearing adamellite (the Mulgandinnah Adamellite) which forms several small stocks in the northern part of the Shaw River tin field (Fig.15D,E);
4. foliated porphyritic adamellite/granodiorite in small plutons near Eleys (Eley Adamellite) and a larger batholith (Kangan Adamellite) west of Wodgina;
5. fine-grained cataclastic granodiorite/tonalite found at the contact of the older granitic rocks and the Warrawoona Group near Wodgina.

The petrography of these plutons is summarized in Table 41. They are adamellite, granodiorite or tonalite bodies in which the principal ferromagnesian mineral is chloritized biotite. They are mineralogically similar to the gneissic and foliated granites of the migmatite complex, but generally have more microcline and less biotite. Some typical textures are shown in Figure 16D-F.

Younger granites

The younger, or post-tectonic, granites of the Pilbara Block form irregularly-shaped stocks and small batholiths which intrude the older granitic complexes and the rocks of the Warrawoona Group (Plate 1). They crop out mainly as low tors, exfoliation domes and boulder fields, contrasting with the generally more subdued topography of undulating scree-covered plains over the older granites (Fig.17A,B). Soil on the younger granites is typically coarse feldspar-bearing sand which can be distinguished from the more loamy soils over the older migmatites and gneissic granites.

The contacts of the younger granites are sharp and cut cleanly across the banding and foliation of the older complexes (Fig.17B,C). Near their margins they contain angular xenoliths of older material and the Moolyella Adamellite (Plate 2) has two roof pendants of gneissic granite. Veins of aplite and pegmatite associated with the younger granites cut the older complexes near the contacts.

The younger granites are the youngest granitic rocks in the various tin fields mapped, being cut only by associated pegmatite and aplite, and a later suite of dolerite dykes. Although normally massive, the younger granites have in places weak primary foliations and broad-scale compositional banding picked out respectively by alignment of phenocrysts and variations in the proportion of phenocrysts and matrix. Both of these features seem to reflect flow directions in the original magma. Other deformation structures in the younger granites are protoclastic to cataclastic foliation near some contacts, and shearing and alteration close to quartz-filled fault zones.

Small lenses of greisen were noted in the western part of the Moolyella Adamellite.

The younger granites are typically medium-grained to coarse-grained rocks ranging in texture from even-grained to porphyritic. Finer grained varieties appear at the edges of some plutons and both the Cooglegong Adamellite and Numbana Granite have leucocratic pegmatite or apogranite phases where they intrude greenstones.

TABLE 40. SUMMARIZED PETROGRAPHY OF TYPICAL PHASES OF OLDER MIGMATITIC, GNEISSIC AND FOLIATED GRANITES, PILBARA BLOCK

Granite type and typical specimens	Megascopic appearance and outcrop characteristics	Microfabric	Essential minerals	Minor and accessory minerals	Comments
Migmatite with amphibolite remnants	Irregularly-banded rock comprising dark amphibole-bearing palaeosomes, granitized in part, with paler neosomes of gneissic granite, fine-grained granite and pegmatite. Crops out sparsely as low exfoliation domes and as pavements in larger streams. Generally concealed by soil containing pegmatite and amphibolite scree				
(38027A, 38027C)	Amphibolite palaeosome: Black rock with typical amphibolitic aspect. Occurs as bands, lenses and boudins in migmatite	Lepidoblastic but modified by alteration and cross-cutting fractures. Some idioblastic chlorite cuts main foliation	Plagioclase, green hastingsitic hornblende, quartz and microcline	Chlorite, carbonate, sphene, epidote	Hornblende partly replaced by chlorite and carbonate; plagioclase is sericitized
(12592A, B)	Granitized palaeosome: Dark blue-grey rock with foliated or gneissic texture. Occurs as bands and lenses in migmatite	Granoblastic to lepidoblastic	Quartz, plagioclase (An_{20}) yellow-brown biotite, microcline	Chlorite, sphene, magnetite, apatite, epidote, muscovite	Chlorite replaces biotite; some sericitized plagioclase has fresh rims. Generally tonalitic
(38025A, 38025B, 12592D)	Gneissose neosome: Grey, generally medium-grained, foliated or banded granitic rock forming bands within the migmatite	Granoblastic to mylonitic	Quartz, plagioclase (An_{30}), microcline, hornblende and/or biotite (chlorite)	Chlorite, epidote, sphene, apatite, muscovite, magnetite, zircon, allanite	Hornblende replaced by chlorite and epidote. Biotite replaced by chlorite and muscovite. Generally adamellitic or granodioritic
(38026A, 38026B, 12592C)	Fine-grained granitic neosome: Grey, fine-grained foliated granite forming bands and dykes in migmatite	Granoblastic to mylonitic	Quartz, plagioclase microcline, biotite (chlorite)	Chlorite, epidote, sphene, hematite, calcite, muscovite	Chlorite has almost completely replaced biotite. Generally adamellitic or granodioritic
(38024A, 38024B)	Pegmatitic neosome: Forms conformable bands, cross-cutting veins and irregular segregations in migmatite	Coarse granitic to protoclastic	Quartz, microcline, oligoclase	Biotite, chlorite, muscovite	Essentially microcline pegmatites
Gneissic granite (15272, 15280, 15290, 26207, 26244, 26268, 26276, 26279)	Grey foliated granitic rock with more or less distinct banding due to mafic schlieren and thin pegmatites. Crops out as pavements or low exfoliation domes	Foliated (elongated quartz, aligned biotite) but with relic igneous textures. More rarely protoclastic or porphyritic. Banding may not be apparent in thin-section	Quartz, plagioclase (An_{20-25}), microcline, biotite, or, rarely, green hornblende	Sphene, epidote, apatite, zircon, opaques; rare allanite, secondary chlorite, muscovite, epidote, sericite	Samples come from Shaw and Mount Edgar Batholiths. Biotite more or less replaced by chlorite. Some zoned plagioclase. Some samples have myrmekite. Composition typically granodioritic or tonalitic with range from adamellite to tonalite
Foliated granite (15225, 26278)	Usually fine to medium-grained foliated rock with rare mafic schlieren. Grades into gneissic granite without distinct contacts. Forms rounded hills of nearly bare rock	Foliated (elongated quartz, aligned biotite) with relic igneous textures. Some samples have protoclastic or mylonitic texture	Quartz, plagioclase (An_{20-30}), microcline, biotite (chlorite)	Chlorite, epidote, sphene, muscovite, apatite, hornblende, zircon, opaques	Composition typically granodioritic or tonalitic. Biotite partly replaced by chlorite and muscovite; plagioclase is saussuritized in patches
Porphyritic granite (15234)	Forms bands and irregular patches in gneissic granite; also matrix of some agmatitic migmatite. Typically grey foliated granite with aligned microcline phenocrysts	Essentially granitic with weak biotite foliation. Altered plagioclase has clear overgrowths. Microcline phenocrysts are poikilitic	Quartz, plagioclase, microcline, biotite (chlorite)	Chlorite, sphene, magnetite, epidote, hematite	Rock is similar to older homogeneous porphyritic granites. Composition granodiorite to tonalite

TABLE 41. SUMMARIZED PETROGRAPHY OF TYPICAL PLUTONS OF OLDER HOMOGENEOUS GRANITES FROM THE PILBARA BLOCK

Pluton and typical samples	Megascopic appearance and outcrop characteristics	Microfabric	Essential minerals	Minor and accessory minerals	Comments
Foliated biotite granite (Plate 2) (12584, 15227)	Medium-grained foliated granite forming bare rounded hills. Has some mafic schlieren. Foliation is across banding in surrounding gneissic granite, but no definite intrusive contacts noted	Foliated, protoclastic texture; aligned biotite and stretched quartz	Quartz, oligoclase, microcline, biotite (chlorite)	Epidote, magnetite, zircon, apatite, sphene; secondary chlorite, muscovite, epidote, sericite	Resembles foliated granite from migmatite complex. Composition granodiorite to tonalite
Leucocratic granodiorite (Plate 2) (26265)	Pale, altered-looking quartz-plagioclase rock. Forms rough terrain		Quartz, oligoclase, chlorite, microcline	Secondary muscovite and epidote	Leucocratic. Composition granodiorite to tonalite
Fine-grained foliated granite with magnetite (Mulgandinnah Adamellite, Plate 4) (15219, 15220, 15221)	Fine-grained foliated granite with magnetite octahedra. Forms prominent tors (eg. Mulgandinnah Hill). Has both cross-cutting and gradational contacts with agmatitic migmatite	Foliated to protoclastic with aligned biotite, stretched quartz and plagioclase. Microcline surrounds plagioclase	Quartz, plagioclase (An_{20-30}), microcline biotite, (chlorite)	Allanite, epidote, magnetite, rare sphene, apatite. Secondary chlorite, epidote, sericite	Lithologically similar to matrix of intruded agmatite, and probably represents remobilized neosome material. Composition generally adamellitic and rather leucocratic
Medium to coarse-grained porphyritic granite (Eley Adamellite Plate 4) (15205, 15275)	Medium-grained, porphyritic, weakly foliated granite, even-grained in places. Intrudes agmatite and foliated granite as small tors near Eleys centre	Granitic to weakly foliated or protoclastic. Microcline phenocrysts one cm long enclose plagioclase	Quartz, oligoclase, microcline, biotite (chlorite); some myrmekite	Epidote, sphene, apatite, zircon, allanite, magnetite; secondary chlorite, epidote, sericite	Composition generally adamellitic. Lithologically similar to neosome of intruded agmatite
Porphyritic granite (Kangan Adamellite, Plate 5) (15244, 15245, 26206)	Typically a well foliated porphyritic granite, but poorly foliated to massive in places. Foliation often due to alignment of phenocrysts. Crops out as pavements and boulder fields	Granitic with microcline phenocrysts. Little metamorphism apparent	Quartz, oligoclase (An_{20-30}), microcline, biotite (chlorite)	Epidote, magnetite, apatite, zircon, rare sphene and allanite; secondary chlorite, epidote, muscovite and sericite	Composition is adamellite to microcline granite
Fine-grained foliated granite (Plate 5) (15240, 15247, 26228)	Grey leucocratic foliated granite in contact with Warrawoona Group rocks in Wodgina tin field	Cataclastic, strongly foliated	Quartz, plagioclase, subordinate microcline, biotite and/or chlorite	Epidote, opaques, sphene, magnetite; secondary chlorite, muscovite, carbonate	Foliation is parallel to layering in greenstones. Composition is granodiorite to tonalite

Most fresh surfaces of younger granite are pale grey or mottled white, but part of the Cooglegong Adamellite is pink. Minerals seen in hand specimen are colourless to amber quartz, translucent white to pale pink microcline, opaque white or pale green plagioclase, dark mica and muscovite. Megascopic fluorite is present in parts of the Cooglegong Adamellite and Cookes Creek Granite. Phenocrysts in the porphyritic varieties are microcline, commonly showing Carlsbad twins. Poikiloblastic microcline megacrysts, up to 30cm in diameter, were noted in the Cooglegong Adamellite near Coomba Creek.

Even-grained granite: In thin section the most typical variety of younger granite is a leucocratic, medium grained to coarse-grained directionless rock with a hypidiomorphic granular texture (Fig.18A-C). It consists essentially of quartz, microcline, plagioclase and altered biotite. Common accessory minerals are muscovite, epidote, magnetite, fluorite, zircon and apatite. Rarer minerals found only in some plutons or specimens are topaz, spessartine, sphene, tourmaline, allanite, carbonate, pumpellyite and stilpnomelane. Minor and accessory minerals found in each of the tin granites examined are listed in Table 42.

Quartz occurs as large, euhedral, often compound grains, and as smaller rounded inclusions in microcline. It is strained in some samples, and near faults or contacts is granulated and sutured. It contains inclusions of apatite, epidote, and, in some slides of Moolyella Adamellite, fine fibres with the optical properties of amphibole.

Microcline normally forms about one half to two thirds of the feldspar present. Its shape ranges from anhedral to almost euhedral and it is typically poikilitic, enclosing grains of rounded quartz and plagioclase. Some microcline grains contain crystallographically-aligned pieces of plagioclase and appear to have partly replaced this mineral (Fig.19A). Perthitic exsolution lamellae of albite are common, as are myrmekitic intergrowths near microcline-plagioclase boundaries, although myrmekite is never an abundant constituent (Fig.19B). Microcline normally shows only slight alteration, but it may be extensively saussuritized near dolerite dykes or quartz veins. Almost all grains have cross-twinning and Carlsbad twins are also common.

Plagioclase normally ranges in composition from oligoclase to sodic andesine (An_{20}-An_{30}) but in both the Moolyella Adamellite and the Numbana Granite, it is albite (An_{4-10}). Most is partly altered to epidote, sericite, and, more rarely, fluorite. Grains with altered cores surrounded by almost clear rims are common (Fig.19C) but in some grains this scheme is reversed.

The principal primary ferromagnesian mineral in the tin granites was originally biotite, but, in the plutons examined, most biotite is altered partly or completely to chlorite. Where preserved it is pleochroic from Z = deep greenish brown to X = pale yellow. The chlorite replacing it is also pleochroic varying from Z = emerald green to X = pale yellow. Commonly it has anomalous blue interference colours. Most biotite and chlorite grains contain small spindles or chains of epidote (Fig.19D).

The muscovite contents of the younger granites range from almost none to about 3 per cent; some muscovite occurs as isolated flakes but most is associated with chlorite or biotite and appears to replace the dark mineral (Fig. 19E). It is usually pleochroic from X = colourless to Y = Z = pale lilac brown. An X-ray diffraction determination shows the mineral to be normal muscovite (M1 polymorph) with some illite. However, its colour and lower 2V (about 40°) suggest that it contains ferri-muscovite.

TABLE 42. MINOR AND ACCESSORY MINERALS RECORDED FROM PLUTONS OF YOUNGER GRANITES, PILBARA BLOCK

Pluton	Common accessories(1)	Rarer accessories(2)
Moolyella Adamellite	Muscovite, epidote, apatite, zircon, fluorite, magnetite	Spessartine, sphene, ?actinolite, topaz, tourmaline, pumpellyite
Cooglegong Adamellite	Muscovite, epidote, apatite, zircon, fluorite, magnetite	Sphene, stilpnomelane, allanite, carbonate, hematite
Spear Hill Adamellite	Muscovite, epidote, clinozoisite, magnetite, fluorite	Stilpnomelane, amphibole, allanite, apatite, hematite
Coondina Adamellite	Muscovite, epidote, magnetite, fluorite	Sphene, allanite, hematite, carbonate
Numbana Granite		
Main phase	Muscovite, epidote, magnetite, apatite	Stilpnomelane, fluorite
Marginal phase	Muscovite, spessartine, epidote, magnetite	Pinite, zircon, allanite, fluorite, ?stilpnomelane
Bonney Downs Granite	Epidote, muscovite, zircon, fluorite, magnetite, zoisite, apatite	Stilpnomelane, allanite, hematite

(1) Chlorite replacing biotite omitted.
(2) As noted in thin sections and heavy mineral concentrates.

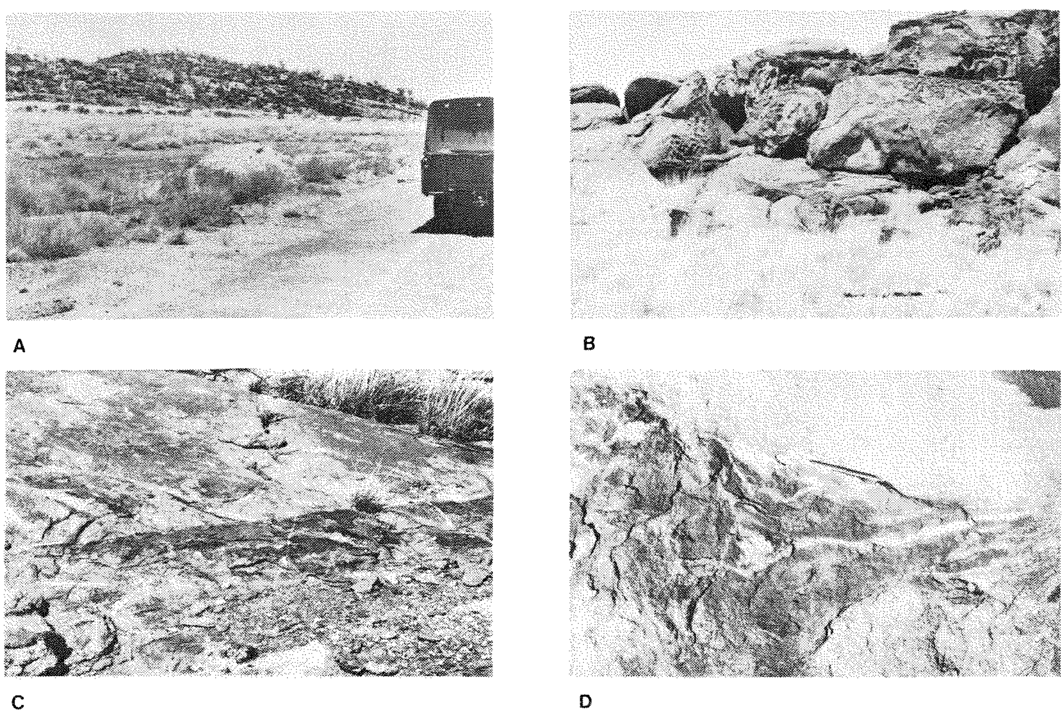


Figure 17. **Photographs of typical outcrops of younger granites from the Pilbara Block.**

A. **Spear Hill, Shaw River tin field. This tor of younger granite rises prominently above a plain underlain by migmatite and gneissic granite of the older complex.**

B. **Boulders of Cooglegong Adamellite show honeycomb structure due to silicification along a network of fine joints.**

C. **Contact of Moolyella Adamellite (light) and a roof pendant of older granite (dark).**

D. **Contact of Moolyella Adamellite and migmatite near D.C. 535, Moolyella tin field.**

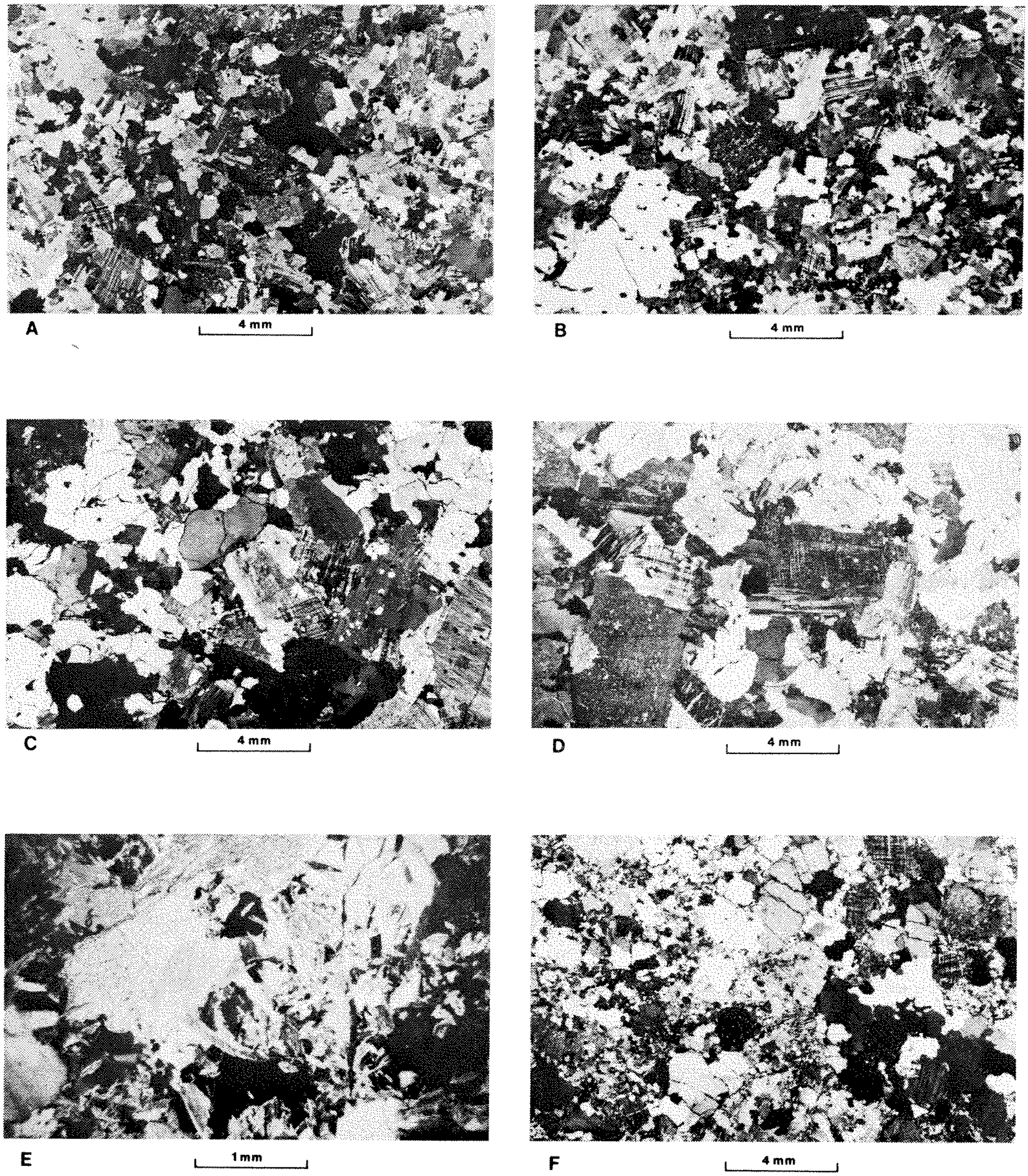


Figure 18. Photomicrographs showing textures of younger granites.

A. Typical even-grained hypidiomorphic texture of Moolyella Adamellite (12586).

B. Typical Coondina Adamellite (15287).

C. Typical Spear Hill Adamellite. Poikilitic microcline and zoned plagioclase feature in the central part of the picture (26303).

D. Porphyritic texture typical of southern part of the Cooglegong Adamellite (15207).

E. Greisen from lens in the Moolyella Adamellite consists mainly of muscovite and quartz. (21732).

F. Cataclastic texture in marginal phase of the Numbana Granite (26378).

(All viewed through crossed nicols)

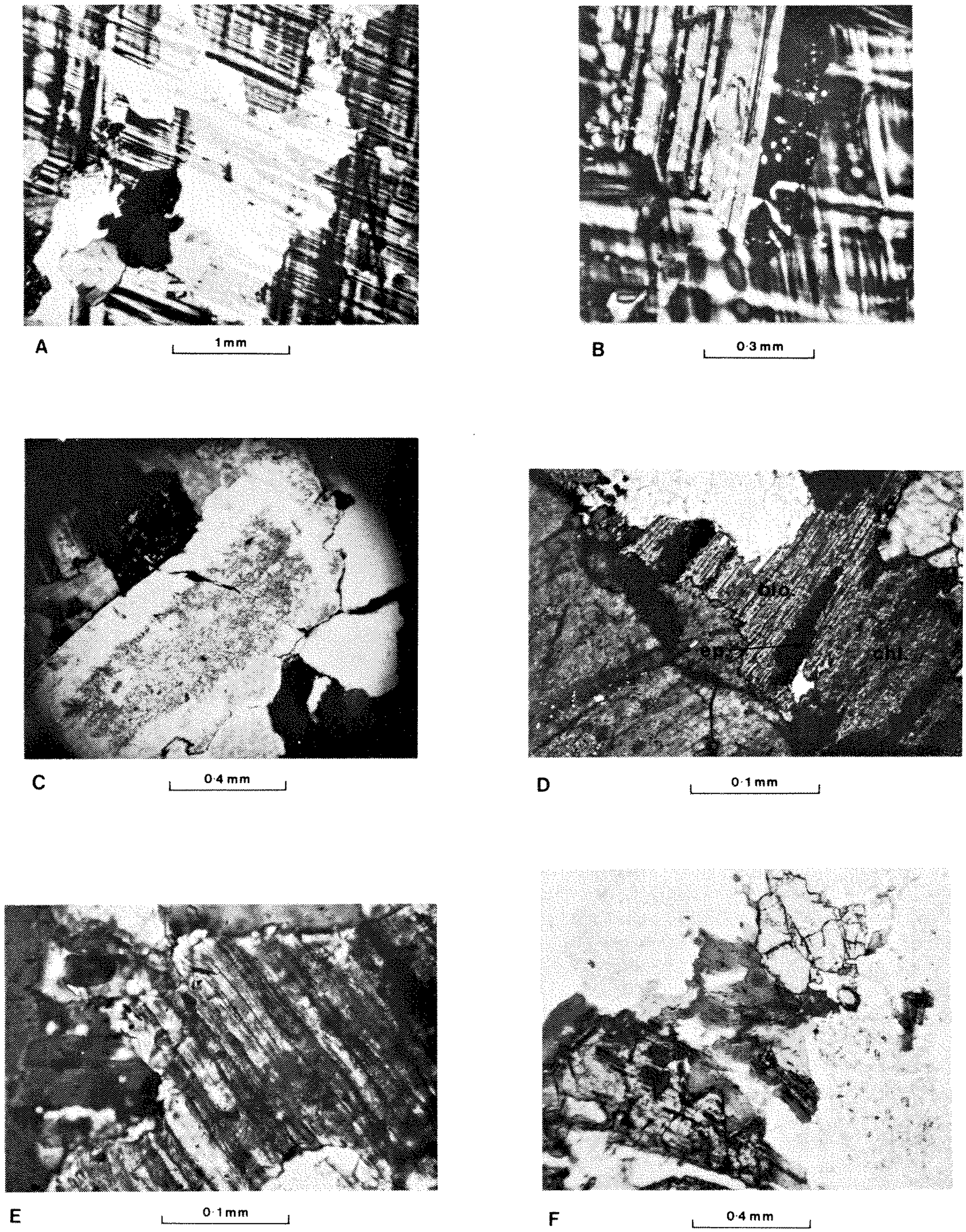


Figure 19. **Photomicrographs illustrating mineral relationships in younger granites.**

A. Microcline encloses and apparently replaces plagioclase with similar crystallographic orientation (26288).

B Myrmekitic intergrowths formed at margin of plagioclase enclosed in microcline (15226).

C. Plagioclase grain with altered core and clear rim. Sharp boundary suggests that the clear rim is due to later overgrowth rather than to zoning during crystallization (26266).

D. Chlorite (darker grey) replaces biotite (lighter grey) along cleavages. Epidote forms spindles lying in the cleavage direction (16367).

E. Muscovite (light) replaces biotite (dark) along cleavage planes (26270).

F. Spessartine garnet (high relief) associated with biotite and epidote in the Moolyella Adamellite (26234).

(A—E, crossed nicols; F, plane polarized light)

Traces of fluorite are present in most of the sections examined. Mostly it occurs as small grains in or alongside chlorite but it also forms as an alteration product of plagioclase. Where more abundant (e.g. specimens 16366, 26318) it forms aggregates in mafic minerals or skeletal grains in plagioclase. Small zircon grains are common, particularly in the chlorite and biotite, where they produce pleochroic haloes. Some are the poorly birefringent "degraded" variety. Magnetite is the only opaque mineral recognized, but some specimens also contain a little secondary hematite. Apatite, although present in most sections, is never common. Sphene is a prominent accessory in a few samples but is mostly rare or absent. A little allanite is present in some slides, and specimens from the western part of the Moolyella Adamellite and the pegmatitic phase of the Numbana Granite contain spessartine of apparently primary origin (Fig. 19F). Stilpnomelane appears in places as an alteration product of chlorite. It is most often seen in the Cooglegong Adamellite where it is pleochroic from Z = red-brown to X = golden yellow.

Pumpellyite, topaz and tourmaline (pleochroic from deep blue to pale yellow-green) were noted only in the Moolyella Adamellite.

Porphyritic granite: Where they are porphyritic the younger granites contain phenocrysts of subhedral to euhedral microcline, some showing Carlsbad twins (Fig. 18D). Phenocrysts commonly range from 1 to 3 cm long, although large megacrysts up to 30 cm across were noted locally. In thin section the phenocrysts are seen to be poikilitic, enclosing rounded quartz and plagioclase. Some phenocrysts, such as those in samples 15203 and 16366, are rimmed by plagioclase, suggesting that they are older than the groundmass microcline, which always appears to be later than the plagioclase. The matrix of the porphyritic granites is similar in composition and texture to the even-grained granites described above.

Greisen: Rocks composed largely of quartz and muscovite are conveniently grouped as greisen although some may have formed by cataclastic metamorphism near faults rather than by pneumatolysis.

Specimen 21732 from the Moolyella Adamellite is a well-developed pneumatolytic greisen (Fig. 18E). In outcrop it is a brown-weathering, pale silvery-brown rock in which can be distinguished quartz, pale-brown mica and fluorite. A thin section shows the rock to consist almost entirely of quartz and muscovite, with a little iron ore, fluorite and accessory zircon. Quartz forms anhedral grains ranging from 0.5 to 1.5 mm in diameter. It is strained and has sutured boundaries. Muscovite occurs as single or compound flakes 1 to 3 mm in diameter and as fine-grained interstitial aggregates separating the larger grains of rock. Small flakes of muscovite also appear as inclusions in quartz. The larger muscovite flakes are pleochroic from X = colourless to Z = very pale brown. Inclusions of zircon in the flakes have pleochroic haloes.

Where affected by shearing near quartz-filled faults, the younger granites are altered to a greenish granular rock with megascopically visible quartz and white mica set in a yellow-green matrix. Thin sections (e.g. 21739) show the rock to consist mainly of quartz and muscovite and to have a cataclastic texture. Quartz normally forms strained anhedral grains, 1 to 3 mm across, but in part of the section the mineral is present as cataclastically deformed grains with mutually sutured boundaries. Muscovite forms a few large flakes, but is present mainly as a fine groundmass, which, together with the crushed quartz, forms a greenish mortar to the larger grains. Similar alteration of older granitic rocks near quartz veins (e.g. 21744), has produced a mylonitic quartz-muscovite-chlorite-sericite rock.

Leucocratic apogranite: Muscovite-albite granites with textures ranging from pegmatitic to cataclastic form the marginal phases of some bodies of younger granite (Fig.18F). In the Wodgina tin field they probably represent the roof zone of the Numbana Granite, immediately underlying roof pendants of greenstone.

Typically, the rocks comprise quartz, albite, microcline and muscovite with accessory biotite, chlorite and spessartine. The proportions of the feldspars vary considerably, and albite appears to replace microcline in some samples.

The rocks appear to be partly formed by metasomatic alteration (assisted by cataclastic deformation) of original granites by late-stage magmatic fluids. This interpretation is supported by the chemical features discussed later.

Thermally altered granite: Thermal metamorphism of a younger granite by the intrusion of dolerite has been described by Lewis and others (1975). The granite was almost completely remelted for a distance of one metre from the dolerite contact. More widespread effects included alteration of microcline to orthoclase, increased sericitization of plagioclase, kaolinization of potassium feldspar, and the development of granophyric textures.

Granitic rocks of uncertain age

Most samples in this category were collected during brief field inspections which did not allow their field relationships to be established.

The exceptions are samples 15233 and 15242 from near Hillside Station (Plate 4). These come from small stocks clearly intruding the migmatite complex, but an attempt to date sample 15233 by the Rb-Sr method showed it to lie close to the intersection of the older and younger isochrons (de Laeter and others, 1975).

The petrography of the samples collected is summarized in Table 43. Specimens 15214 and 15297 resemble older granite while 15201, 15233 and 15296 are possibly younger granites despite foliation present in two of them.

Acid dykes

Two types of acid dykes were recognized during this study. The first, of dacitic composition, is well-exposed north of the Shaw River tin field near the north end of the Black Range dolerite dyke. A similar dyke occurs near the junction of Duffer Creek and the Coongan River, north of Marble Bar. These bodies intrude the older granite and are cut by the Proterozoic dolerite dyke suite.

Dykes of the second type have a *rhyolitic* composition and were noted only in or close to the Spear Hill, Cooglegong and Moolyella Adamellites, to which they are probably related.

Summarized petrographic descriptions of both types of acid dykes are given in Table 44.

Layered aplite-pegmatite dykes

Brief descriptions of the megascopic characteristics of various tin-bearing pegmatites in the Pilbara Block have been included in accounts of the various tin fields. This section gives some additional petrographic information on the layered aplite-pegmatites. It is by no means exhaustive and considerable scope remains for further studies of the rare-metal pegmatites in the Pilbara.

Dykes, consisting of alternating layers of aplitic and pegmatitic textured material, are the principal source of the secondary tin deposits of Moolyella, Shaw River, Coondina, Pinga Creek and Friendly Creek. Thinner dykes (less than 30 cm or so) consist of a central pegmatite core and narrow aplite margins. Thicker dykes contain rhythmically alternating layers of pegmatite and aplite usually in the order of 2 to 10 cm thick (Fig. 4C). The layering is always parallel to the walls of the dyke.

Individual layers are commonly internally banded due to variations in size or proportion of quartz and feldspar grains, or to concentrations of minerals such as spessartine, tourmaline, zinnwaldite and, more rarely, cassiterite. Contacts between aplite and pegmatite layers may be sharp or gradational.

A typical pegmatite-textured band (e.g. 21759) consists of perthitic microcline, albite (An_6), quartz, zinnwaldite after biotite, and spessartine with a little

TABLE 43. SUMMARIZED PETROGRAPHY OF GRANITES OF UNCERTAIN AGE FROM SOME SMALLER PILBARA TIN FIELDS

Locality and typical specimens	Megascopic appearance and outcrop characteristics	Microfabric	Essential minerals	Minor and accessory minerals	Comments
About 1.5 km west of Tabba *Tabba centre* (15201)	Medium-grained, leucocratic foliated granite. Forms bare ridges	Protoclastic. Foliation due to late shearing	Quartz, oligoclase, microcline; biotite almost all replaced by chlorite	Epidote, magnetite, fluorite, secondary muscovite, sericite, chlorite	Microcline ≫ oligoclase (adamellite). Mineralogy resembles "*younger granites*"—*possibly rock* is sheared Tabba Tabba Adamellite
Near Strelley centre (15214)	Fine-grained, strongly foliated granite. *Forms low hills*	Pronounced gneissose structure *with aligned* biotite and stretched quartz	Quartz, plagioclase, microcline; biotite partly replaced by chlorite	Epidote, apatite; secondary chlorite, and appreciable muscovite	Plagioclase ≫ microcline. Rock is a tonalite, probably belonging to "older granites"
Friendly Creek 1.5 km NE of plant (15297)	Foliated medium-grained rock. Forms rough rocky hills	Medium-grained cataclastic rock	Quartz, plagioclase, microcline; biotite partly replaced by chlorite	Epidote, opaques, colourless sphene	Plagioclase > microcline (adamellite). Probably an "older granite"
1 km NW of plant (15296)	Fine-grained, foliated granite	Fine-grained, protoclastic, weakly foliated. Some plagioclase phenocrysts	*Quartz, microcline, oligoclase* (An_{10}). Yellow to brown biotite partly replaced by chlorite	Apatite, epidote, allanite, fluorite; muscovite replacing chlorite and biotite	Possibly a sheared granite of the younger type (cf. chemistry in Table 51). Composition is adamellitic
Native Hill, near Mount Hall centre (26222).	Medium-grained foliated granite forming prominent tors	Marked cataclastic texture. Phenocrysts of feldspar are surrounded by granulated matrix with stretched quartz and aligned chlorite	Quartz, plagioclase, microcline, chlorite	Epidote, opaques, allanite; secondary *muscovite*	Composition is adamellite
Shaw River tin field, fine-grained leucocratic granite (Plate 4) (15233)	Pale grey, fine-grained massive granite. Forms small tors. Intrudes migmatite complex and has xenoliths of gneissic granite	Granitic texture. Some granophyric intergrowth	Quartz, *oligoclase* (An_{24}), *microcline*, chlorite after biotite	*Epidote, magnetite;* secondary muscovite	This rock may be a 'younger' granite. Composition is adamellite

fluorite, chlorite, magnetite, tourmaline and cassiterite (Lewis, 1972). Both microcline and quartz form large crystals up to 8mm across while albite occurs as medium-grained radiating aggregates or fine-grained mosaics. Microcline often encloses a number of albite laths and an occasional patch of mosaic albite, but there is no evidence for albite replacing microcline. Fluorite appears to replace biotite and also forms irregular patches along the cleavage planes of chlorite and muscovite flakes. In other samples (e.g. 16496), coarse albite laths (cleavelandite) are arranged perpendicularly to the layering of the pegmatite.

Typical aplite-textured bands (16496, 21766) comprise fine, even-grained granitic-textured mosaics of albite and quartz, or albite, microcline and quartz. Greenish muscovite, zinnwaldite and spessartine are common accessories, and cassiterite is most often found at the edges of the aplite layers. Large crystals of quartz, apparently growing from the pegmatite layers, may penetrate the aplite bands. One is present near the left-hand edge of the specimen shown in Figure 4C.

CHEMISTRY

Material analyzed

This section contains the results of 105 new analyses (68 complete and 37 partial) of various granites collected from the Pilbara Block, mainly from the vicinity of tin deposits. Results (some of which have been averaged) of 27 further analyses, either previously published, or carried out by the Western Australian Government Chemical Laboratories for other investigations, are also included, as are determinations for tin, niobium and lithium on biotite/chlorite concentrates.

The rock analyses are arranged into eight groups based on the type and age of the granite analysed:

1. Older migmatitic, gneissic, and foliated granites (Table 45: 44 analyses);
2. Older homogeneous plutons (Table 46: 16 analyses);
3. Moolyella Adamellite (Table 47: 11 analyses);
4. Cooglegong, Spear Hill and Coondina Adamellites (Table 48: 18 analyses);
5. Numbana Granite (Table 49: 14 analyses);
6. Miscellaneous younger granites (Table 50: 8 analyses);
7. Granites of uncertain age (Table 51: 12 analyses);
8. Pegmatites, acid dykes and greisens (Table 52: 9 analyses).

C.I.P.W. norms and differentiation indices (D.I.) are included in the same tables as the analyses where most of these are complete, but are collected separately (Tables 53 and 54) for groups where most analyses are partial only. To facilitate later discussion average compositions of some more important groups of analyses are listed in Table 55. Such averages are of all available determinations for each component (full and partial analyses) in each group. Results of tin, lithium and niobium determinations on biotite/chlorite concentrates are given in Table 56.

Comparison of older and younger granites

The analyses presented in Tables 45 to 50 reveal chemical differences between the granites of the older and younger groups. Some of the distinguishing features are very marked and allow a granite to be assigned to one or other group with some confidence on the basis of only one or two analyses. Other features show up where several analyses can be compared but cannot always be used to place a single sample within the older or younger category. This is due largely to the wide range of composition of rocks within the older complex, some samples of which have major oxide compositions very similar to that of younger granites.

Silica: The average silica contents of older granites are from 2 to 5 per cent less than the averages for individual plutons of younger granite. However, some samples from the older complex, especially of mobilized phases within the migmatites, have silica contents similar to those of many younger granites. Generally, silica contents of less than 72 per cent are diagnostic of older granites, and those greater than 75 per cent of younger granites, but granites of both ages commonly have silica contents between these amounts.

Iron and magnesia: The absolute amount of iron and magnesia are both appreciably higher in most older granites than in any of the younger granites analysed. But, as with silica, some of the homogeneous phases within the older complex also have low iron and magnesia. These relationships are shown clearly in Figures 20A and 20B in which ratios of $\sum$ FeO + MgO: CaO: Na_2O + K_2O for older and younger granites are plotted. The younger granites cluster within the alkali corner of the triangle, but the older granites extend from near this corner to beyond the centre of the diagram.

Lime, soda and potash: The ratio K_2O/Na_2O for each sample analysed is listed in the appropriate table. The fields in which they lie are shown in Figures 21A and 21B, for older and younger granites respectively. Most younger granites have K_2O/Na_2O ratios of between 1.0 and 1.5 making them adamellites by Harpum's (1963) classification. Those lying outside this range comprise

TABLE 44. SUMMARIZED PETROGRAPHY OF ACID DYKES FROM THE MOOLYELLA AND SHAW RIVER TIN FIELDS

Rock type and sample number	Megascopic features and outcrop characteristics	Microfabric	Essential minerals	Minor and accessory minerals	Comments
Dacite (26295)	Grey, fine-grained rock occurring as dykes cutting older granite. Flow-banded near contacts	Slightly foliated but generally aplitic	Quartz, calcic oligoclase, chlorite, biotite, microcline	Epidote, apatite, opaques, zircon	Plagioclase ≫microcline. Rock is of tonalitic composition
Rhyolite (15206, 15237)	Near-white to pale pink fine-grained rock forming narrow dykes *within or close to younger* granites. Fluorite can be seen in some samples	Aplitic in 15237. Cataclastic in 15206	Quartz, microcline, albite, biotite, pale green pleochroic muscovite	Epidote, opaques; fluorite common in 15206	Microcline > plagioclase. Composition adamellitic

TABLE 45. CHEMICAL ANALYSES OF OLDER MIGMATITIC, GNEISSIC, AND FOLIATED GRANITES, PILBARA BLOCK

	Mt Edgar Batholith		
GSWA No.	12585	26276	26278
MAJOR OXIDES (%)			
SiO_2	64.8	74.0	70.4
Al_2O_3	17.0	14.5	15.2
Fe_2O_3	1.78	.52	1.03
FeO	2.34	1.40	1.47
$\sum FeO$	3.94	1.85	2.40
MgO	1.08	.47	.74
CaO	4.35	2.39	2.73
Na_2O	4.41	4.48	4.75
K_2O	1.48	1.93	2.21
Loss	1.25	.85	.62
H_2O^-	.24	.13	.09
TiO_2	.50	.22	.31
P_2O_5	.08	.02	.03
MnO	.10	.04	.05
Total	99.4	100.9	99.6
TRACE ELEMENTS (ppm)			
Li	165	54	240
Be	2.5	1.9	3.6
F	860	800	1000
Cu	38	3	6
Zn	90	59	73
Rb	212	120	105
Sr	360	150	350
Zr	135	150	135
Nb	9	7	3
Sn	<3	<3	<3
Ce	54	56	38
Th	5	8	7
U	2	4	3
RATIOS			
K_2O/Na_2O	.34	.40	.47
K/Rb	58	124	175
Rb/Sr	.59	.80	.30

	Shaw Batholith															
GSWA No.	12592A	12592B	15225	26211	15255	15290	15234	26212	15238	26219	12592E	15208	26218	15235	A	B
MAJOR OXIDES (%)																
SiO_2			75.3		63.8		70.2			70.4				73.4	68.36	71.25
Al_2O_3			14.7		15.3		14.9			14.1				13.3	15.28	14.40
Fe_2O_3			.72		2.41		1.05			1.21				.68	1.18	.49
FeO			.95		2.30		2.05			1.16				.97	2.21	1.87
$\sum FeO$	3.90	4.90	1.60	1.75	4.47	2.85	2.99	1.12	2.25	2.25	2.15	1.16	1.05	1.58	3.27	2.31
MgO	1.07	1.70	.29	.48	1.79	.70	.76	.22	.50	.55	.48	.24	.28	.28	1.17	1.28
CaO	3.12	3.93	2.01	2.34	4.77	2.86	2.48	1.33	1.85	1.83	1.83	1.35	1.09	.66	2.33	1.96
Na_2O	4.60	5.20	4.93	4.70	4.74	4.45	4.56	3.85	4.15	4.11	3.95	4.10	3.10	3.27	4.45	4.36
K_2O	1.10	1.40	1.92	1.90	2.14	2.40	2.58	2.75	3.60	3.82	3.75	4.00	4.40	4.66	3.34	2.80
Loss			.63		.87		.83			.84				1.28 }	.90	1.17
H_2O^-			.08		.12		.08			.11				.07 }		
TiO_2			.20		.54		.49			.42				.14	.47	.26
P_2O_5			.02		.29		.10			.07				.03	.15	.07
MnO			.03		.09		.04			.03				.03	.06	.07
Total			101.8		99.1		100.1			99.0				98.8	99.9	100.0
TRACE ELEMENTS (ppm)																
Li	90	113	72	28	15	146	145	36	85	99	32	28	35	21		
Be			2.1		3.0		'1.7		2.8	0.5		1.4		0.7		
F			860		840					810						
Cu			19		11		12		2	63		12		4		
Zn			45		83		82		63	52		40				
Rb	70	100	100	110	80	120	105	320	90	175	135	135	170	195	170	
Sr	320	460	355	370	955	495	465	285	225	310	320		250	105	390	
Zr			160		200		255		240	265		170		145		
Nb			<3		3		4		3	4		<3		<3		
Sn	<3	<3	<3	5	<3		<3	<3	<3	<3	<3	<3	<3	<3		
Ce			42		76		1.18		1.50	137		70		53		
Th			4		14	25	12		25	28		5		12		
U					2	1	1					2			1.8	1.4
RATIOS																
K_2O/Na_2O	.24	.27	.39	.40	.45	.54	.56	.71	.87	.93	.95	.98	1.42	1.42	.75	
K/Rb	130	116	159	143	222	166	204	71	332	181	230	246	215	198	163	
Rb/Sr	.22	.22	.28	.30	.08	.24	.23	1.12	.40	.56	.42		.68	1.86	.44	

	Yule Batholith											
GSWA No.	15292	26207	15298	26226	16380	15299	16373	15293	16391	C	D	E
MAJOR OXIDES (%)												
SiO_2					74.0		74.3		73.75	71.67	70.30	71.72
Al_2O_3					14.3		13.7		13.6	14.24	14.27	13.90
Fe_2O_3					.19		.04		.52	.62	.36	.65
FeO					1.05		.59		1.06	1.51	2.43	1.72
$\sum FeO$	3.25	4.12	2.65	4.05		.80		.85	1.53	2.06	2.75	2.30
MgO	1.24	2.50	.52	2.95	.09	.12	.10	.15	.31	.74	1.27	.95
CaO	2.35	3.78	1.95	3.71	1.45	1.06	1.10	.64	1.43	1.26	2.29	1.89
Na_2O	4.15	4.25	4.00	3.85	4.67	4.15	4.50	3.80	3.80	3.98	4.49	3.93
K_2O	1.90	2.10	2.50	2.50	3.13	3.35	4.11	4.25	4.64	4.52	2.38	3.67
Loss					.26		.69		.67 }	.72	1.02	.81
H_2O^-					.07		.15		.09 }			
TiO_2					.06		.04		.24	.16	.35	.35
P_2O_5					.00		.00		.05	.06	.13	.11
MnO					.02		.01		.03	.08	.09	.06
Total					99.3		99.3		100.1	99.6	99.4	99.8
TRACE ELEMENTS (ppm)												
Li	200	144	21	114	46	37	11	27	33			
Be					0.1		0.0		2.1			
F					370				600			
Cu							11		1			
Zn							31		50			
Rb	290	220	165	190	100	290	120	290	215			
Sr	330	590	160	620	400	100	250	40	110			
Zr					120		105		150			
Nb					<3		<3		9			
Sn	<3	<3	<3	<3	<3	<3	<3	18	2			
Ce					13		12		108			
Th					<5		7		31			
U									5	7.4	3.0	2.1
RATIOS												
K_2O/Na_2O	.46	.49	.62	.65	.67	.81	.91	1.12	1.22	1.14	.53	.93
K/Rb	54	79	128	109	260	96	284	122	179			
Rb/Sr	.88	..37	1.03	.31	.25	2.90	.48	7.25	1.95			

Analyses A-E are averages from Oversby (1976)

A—Average of 4 samples from Tambourah Creek
B—Average of 5 samples from Cooglegong area
C—Average of 3 samples from Woodstock (vein omitted)
D—Average of 3 samples from 127-Mile Quarry (vein omitted)
E—Average of 3 samples from 70-Mile Quarry

Uranium determinations other than Oversby's, by Government Chemical Laboratories.

TABLE 46. CHEMICAL ANALYSES OF OLDER HOMOGENEOUS PLUTONS FROM VARIOUS PILBARA TIN FIELDS

Tin field	Moolyella			Shaw River							Wodgina					
Rock type	Foliated biotite granite		Leucocratic granodiorite	Fine-grained foliated granite with magnetite (Mulgandinnah Adamellite)					Porphyritic foliated granite (Eley Adamellite)		Fine-grained foliated granite			Weakly foliated porphyritic granite (Kangan Adamellite)		
GSWA No.	15227	12584	26265	15221	12591	15220	15219	15202	26217	15205	15240	15247	26228	26206	15244	15245
							MAJOR OXIDES (%)									
SiO_2	70.1	70.9		70.9		72.1	71.8	73.5		71.1	71.5	70.9	71.8	68.7	74.4	71.9
Al_2O_3	14.8	14.0		15.0		14.1	13.8	13.7		14.3	14.6	14.5	14.8	15.1	13.0	13.7
Fe_2O_3	1.03	0.96		0.59		0.96	0.85	0.81		0.88	1.12	0.70	1.08	1.30	0.81	1.14
FeO	2.58	1.80		1.39		1.01	1.17	0.52		1.20	1.02	1.23	0.82	1.50	0.82	1.05
$\sum$FeO	3.50	2.66	1.34	1.92	1.67	1.87	1.93	1.24	2.65	1.99	2.02	1.85	1.79	2.65	1.54	2.07
MgO	0.79	0.79	0.32	0.32	0.29	0.29	0.41	0.18	0.67	0.50	0.45	0.65	0.72	0.74	0.31	0.40
CaO	2.85	2.40	2.85	1.68	1.11	1.32	1.19	0.90	1.97	1.89	1.56	1.52	1.26	2.45	1.44	1.43
Na_2O	4.75	4.55	3.95	4.72	3.64	3.80	3.70	3.64	4.30	4.38	4.64	4.45	4.70	4.50	3.92	3.14
K_2O	1.66	2.54	1.40	3.52	3.95	4.75	4.97	5.16	2.75	3.39	2.50	3.81	4.21	3.12	3.51	5.83
Loss	0.76	0.87		1.08		0.85	0.88	0.57		0.70	0.98	1.09	0.75	0.70	0.57	1.12
H_2O^-	0.11			0.11		0.09	0.05	0.14		0.11	0.11	0.17	0.19	0.10	0.11	0.09
TiO_2	0.30	0.32		0.30		0.23	0.28	0.14		0.32	0.19	0.20	0.23	0.41	0.15	0.27
P_2O_5	0.06	0.08		0.03		0.05	0.10	0.06		0.07	0.04	0.09	0.11	0.12	0.07	0.03
MnO	0.05	0.03		0.03		0.03	0.04	0.03		0.03	0.04	0.03	0.06	0.05	0.03	0.03
Total	99.9	99.2		99.7		99.6	99.2	99.4		98.9	98.7	99.4	100.8	98.8	99.1	100.1
							TRACE ELEMENTS (ppm)									
Li	220	125	51	43	46	42	22	44	80	153	49	106	82	99	49	38
Be	1.0			1.7		1.1	1.6	2.7		1.3	2	3	3	1	3	1
F	400			620		490	370			440		1080	700	860		
Cu	20	18		4		2		3		3	7	5	9	20	6	2
Zn	73	74		60		67	66	59		64	79	47	42	83	51	57
Rb	110	140	115	155	215	230	185	220	140	115	100	270	220	200	150	230
Sr	410	355	150	175	150	105	125	100	260	375	315	485	440	310	125	135
Zr	135			210		190	205	140		220	175	210	190	190	115	195
Nb	4			3		4	5	7		<3	<3	3	5	11	4	7
Sn	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<2	<2	<2	3	<2	<2
Ce	24			94		101	160	112		96	87	56		130	74	155
Th	9	14		19	38	27	44	25		19	15	39	32	18	37	54
U						4	4	4		3	1					
							RATIOS									
K_2O/Na_2O	0.35	0.56	0.35	0.75	1.08	1.25	1.34	1.42	0.64	0.77	.54	.86	.90	.69	.90	1.86
K/Rb	125	150	100	188	152	171	223	194	88	244	207	117	159	146	194	210
Rb/Sr	0.25	0.39	0.77	0.88	1.43	2.19	1.48	2.20	0.54	0.31	.32	.56	.50	.64	1.20	1.70

TABLE 47. CHEMICAL ANALYSES OF THE MOOLYELLA ADAMELLITE

G.S.W.A. No.	26240	26247	12586	15266	26285	26270	26269	15267	15228	15249	15230	x̄	s
						MAJOR OXIDES (%)							
SiO_2	73.3	74.1	74.1	74.7	74.8	74.9	75.0	75.4	75.5	75.8	76.6	74.9	.91
Al_2O_3	14.0	13.4	13.4	13.4	12.8	13.6	13.7	13.5	13.2	13.2	12.9	13.4	.34
Fe_2O_3	.41	.42	.45	.39	.42	.42	.46	.16	.44	.35	.46	.40	.09
FeO	.73	.86	.75	.75	.76	.76	.73	.66	.71	.79	.70	.75	.05
MgO	.08	.10	.10	.13	.14	.12	.12	.10	.08	.10	.11	.11	.02
CaO	.78	.81	.82	.70	.93	.81	.74	.52	.74	.69	.99	.78	.12
Na_2O	4.41	4.05	4.05	4.13	4.25	3.92	4.05	4.05	3.97	4.10	3.93	4.08	.14
K_2O	4.54	4.94	4.73	4.65	4.16	4.97	5.01	4.28	4.41	4.62	3.99	4.57	.34
Loss	.50	.55	.52	.66	.63	.84	.58	.63	.46	.62	.43	.58	.11
H_2O^-	.07	.04	.11	.25	.12	.05	.04	.09	.06	.11	.06	09	.06
TiO_2	.07	.08	.09	.06	.09	.07	.07	.06	.06	.07	.08	.07	.01
P_2O_5	.00	.02	.02	.05	.03	.07	.00	.01	.04	.07	.00	.03	.03
MnO	.06	.04	.05	.07	.04	.04	.05	.05	.07	.04	.04	.05	.01
Total	98.9	99.4	99.2	99.9	99.1	100.6	100.5	99.6	99.8	100.5	100.3	99.8	
						TRACE ELEMENTS (ppm)							
Li	245	140	215	255	175	23	50	305	290	145	215	187	92
Be	9	5	5	1	5	1	2	7	11	7	8	5.5	3.3
F	1280	1300	1010			960	1000	1010		610	1240	1050	226
Cu	4	4	0		9	2	8		6	0	3	4	3
Zn	56	53	75	57	58	53	56	58	73	45	53	58	9
Rb	530	450	510	625	445	475	480	700	550	480	390	512	87
Sr	40	40	45	30	50	35	35	25	30	40	45	37.7	7.5
Zr	70	85	75	60	80	70	70	45	55	70	65	67	11
Nb	28	22	24	35	23	24	25	42	30	26	18	27	6.7
Sn	9	2	6	16	7	3	6	25	15	8	6	9.4	6.8
Ce	66		60	51	61	63	63	38	80	71	53	61	11.5
Th	37	26	59	27	36	44	44	16	35	29	31	35	11.4
U		24	18		8			12	21			15.1(1)	7.7
						C.I.P.W. NORMS							
Q	28.0	29.3	30.2	30.8	31.8	30.9	30.0	33.8	33.5	32.3	35.8		
C	.41	.00	.17	.41	.00	.48	.29	1.3	.63	.39	.29		
Or	26.8	29.2	27.9	27.5	24.6	29.4	29.6	25.3	26.1	27.3	23.6		
Ab	37.3	34.3	34.3	34.9	35.9	33.2	34.3	34.3	33.6	34.7	33.2		
An	3.9	3.8	3.9	3.1	3.4	3.6	3.7	2.5	3.4	3.0	4.9		
Di	.00	.07	.00	.00	.84	.00	.00	.00	.00	.00	.00		
Hy	1.2	1.4	1.2	1.4	.89	1.3	1.2	1.3	1.2	1.4	1.1		
Mt	.59	.60	.65	.56	.60	.60	.66	.23	.63	.50	.66		
Il	.13	.15	.17	.11	.17	.13	.13	.11	.11	.13	.15		
Ap	.00	.04	.04	.11	.07	.16	.00	.02	.00	.16	.00		
						RATIOS AND D.I.							
K_2O/Na_2O	1.03	1.22	1.17	1.13	.98	.27	1.24	1.06	1.11	1.13	1.02		
K/Rb	71	91	77	62	77	87	87	51	66	80	85		
Rb/Sr	13.2	11.2	11.3	20.8	8.9	12.1	13.7	28.0	18.3	12.0	8.7		
Mg/Li	2.0	4.3	2.8	3.1	4.8	3.1	14.4	2	1.6	4.1	3.1		
Ca/Sr	139	145	130	167	133	165	151	149	176	123	157		
D.I.	93.7	93.9	93.8	94.2	93.9	93.7	94.0	94.5	94.0	94.4	92.9		

(1) Includes unpublished data
x̄ Average
s Standard deviation

mainly marginal phases affected by late-stage alteration. The older granites show a much wider spread of K_2O/Na_2O but most are below one—in the fields of Harpum's granodiorite or tonalite. Lime contents of the younger granites are generally below one per cent while those of the older granites are commonly greater than this amount.

Titania: The principal tin granites have comparatively low titania contents when compared with the older granites; however, other plutons of younger granite, such as the Mondana Adamellite, have titania contents similar to the older rocks.

Lithium: The lithium contents of all groups of granites investigated are appreciably greater than those of average granites (Table 39). The younger granites, especially the Moolyella Adamellite, have higher lithium contents than the older granites in their immediate vicinity. But older granites of the Mount Edgar Batholith are richer in lithium than younger granites intruding the Shaw River and Yule Batholiths. The greater part of the lithium in the granites appears to be held in biotite.

Beryllium: Younger granites have an average beryllium content of two to three times that of the older granites. However beryllium contents of all granite types are low, and owing to the analytical difficulties in determining this metal, it is not considered a useful element for distinguishing between older and younger granites.

Fluorine: Contents of fluorine vary widely from sample to sample of the same granite type. Values in the older granites are generally below 1 000 ppm F with

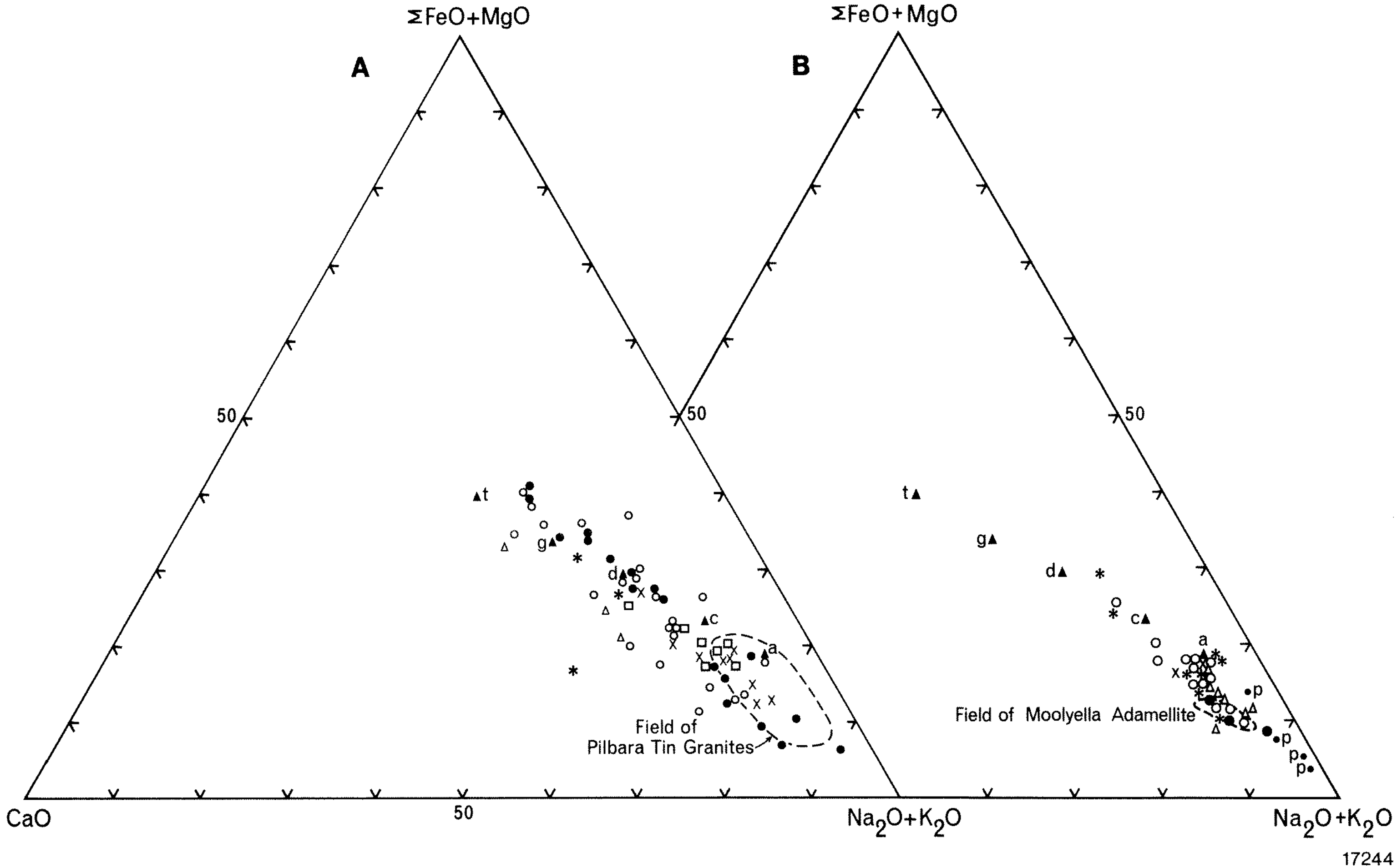


Figure 20. Triangular plots of the ratios $\sum FeO + MgO : CaO : Na_2O + K_2O$ for Pilbara Block granites.

A. Plot of older granites. Open triangles, open circles and filled circles are migmatites and gneissic granites from the Mount Edgar, Shaw and Yule Batholiths respectively. Asterisks, diagonal crosses and open squares respectively, are older homogeneous granites from these batholiths. Points for the Shaw and Yule Batholiths include the original analyses of Oversby (1976). Lettered solid triangles are average tonalite (t), granodiorite (g), adamellite (d), calc-alkali granite (c) and alkali granite (a) (Nockolds, 1954).

B. Plot of younger granites. Open circles=Cooglegong Adamellite; filled circles=Spear Hill Adamellite; open triangles=main phase of Numbana Granite; asterisks=marginal phase of Numbana Granite; diagonal crosses=Coondina Adamellite. The field of 11 samples of Moolyella Adamellite is enclosed by the dashed line. Small dots marked 'p' are tin-bearing pegmatites

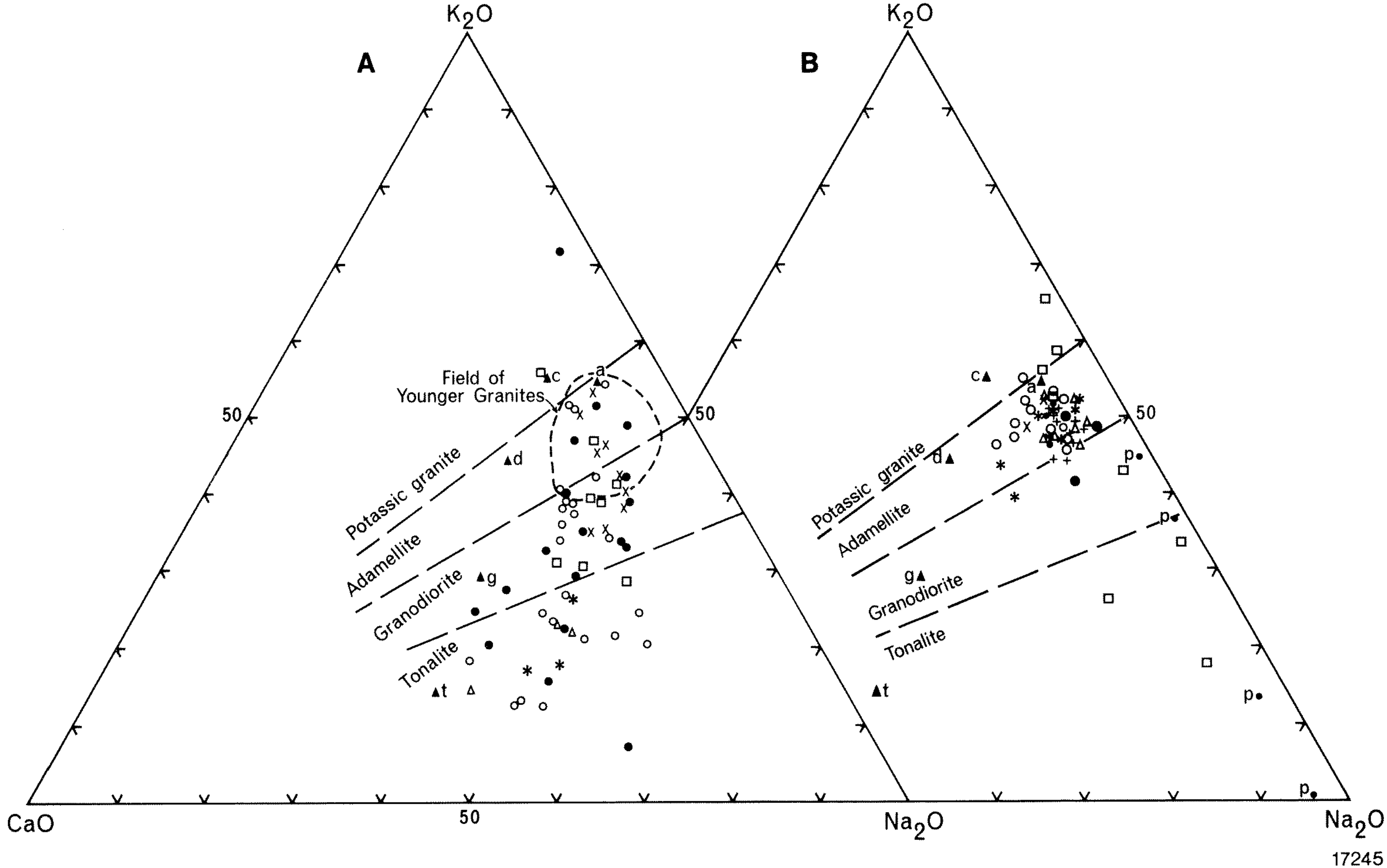


Figure 21. Triangular plot of the ratios K_2O : CaO : Na_2O for Pilbara Block granites.

A. Older granites. Symbols are the same as in Figure 20A. Lines separating varieties of granite are from Harpum (1963).

B. Younger granites. Upright crosses=Moolyella Adamellite; open circles=Cooglegong Adamellite; filled circles=Spear Hill Adamellite; open triangles=main phase of Numbana Granite; open squares=marginal phase of Numbana Granite; diagonal crosses=Coondina Adamellite; asterisks=other younger granites from Table 50. Small dots marked 'p' are tin-bearing pegmatites. Other symbols as for Figure 21A

TABLE 48. CHEMICAL ANALYSES OF COOGLEGONG, SPEAR HILL AND COONDINA ADAMELLITES

PLUTON	COOGLEGONG ADAMELLITE															SPEAR HILL ADAMELLITE			COONDINA ADAMELLITE	
GSWA No.	26318	26301	15207	15203	15204	15210	15209(1)	15135(1),(2)	15218	15141(2)	15236	15243	2/4839(2)	x̄	s	26303	26308	15216	15239	15287
MAJOR OXIDES (%)																				
SiO_2	71.4	73.0	73.3	73.5	73.6	73.9	74.4	74.6	74.6	74.8	74.8	75.1	75.8	74.1	1.13	75.5	76.7	78.6	73.2	73.7
Al_2O_3	14.2	12.8	13.5	13.1	13.3	13.6	13.0	13.6	12.9	13.7	13.1	12.6	12.3	13.2	.51	13.1	12.7	11.8	13.6	13.6
Fe_2O_3	.51	.69	.61	.94	.81	.54	.46	.07	.72	.16	.56	.19	.47	.52	.26	.55	.46	.34	.65	.65
FeO	1.35	2.06	.95	1.19	1.09	.99	.57	.99	1.17	.99	1.13	1.37	1.26	1.16	.34	.51	.40	.74	1.13	1.04
MgO	.31	.40	.25	.32	.34	.25	.05	.11	.12	.14	.27	.14	.10	.22	.11	.10	.02	.09	.31	.32
CaO	1.09	1.51	.88	1.23	1.40	1.04	.60	.72	.62	.77	.82	.75	.81	.94	.29	.80	.39	.86	.78	1.25
Na_2O	3.96	3.32	4.11	3.50	3.79	3.69	3.94	3.90	3.60	4.00	4.09	3.97	3.05	3.76	.32	4.20	4.26	3.90	3.77	3.96
K_2O	5.28	4.21	4.74	4.58	4.71	5.21	4.96	4.69	4.85	4.29	4.15	4.43	4.75	4.68	.35	4.93	4.44	3.38	4.89	4.91
Loss	.92	.48	.70	.68	.82	.67	.47	.72	.71	.47	.96	.84	1.04	.70	.17	.55	.97	.28	.94	.83
H_2O^-	.04	.14	.07	.11	.09	.08	.13	.11	.06	.03	.06	.11		.09	.04	.11	.04	.23	.08	.12
CO_2								.04		.01										
TiO_2	.22	.35	.16	.27	.24	.18	.10	.05	.14	.05	.15	.10	.19	.17	.09	.11	.04	.09	.23	.23
P_2O_5	.03	.09	.04	.02	.05	.01	.03	.02	.01	.03	.05	.06		.04	.02	.06	.00	.01	.06	.06
MnO	.05	.07	.04	.05	.04	.05	.04	.08	.07	.05	.08	.08	.02	.06	.02	.03	.05	.03	.04	.04
Total	99.4	99.1	99.4	99.5	100.3	100.3	98.8	99.4	99.6	99.5	100.2	99.7	99.8			100.5	100.5	100.3	99.7	100.7
TRACE ELEMENTS (ppm)																				
Li	40	70	88	106	110	52	15	25	56	120	72	20	460	95	115	70	108	103	85	80
Be	6	4	4	6	5	6	7		6		10	7		6.1	1.7	6	7	6	5	5
F	2360	7350	1120	2000	1760	1380	700	775	610	825			7300	2380	2510	940	450	820		1360
Cu	0	1	2	4	4	4	1	40	2	40	2	59		13	19	2	0	5	10	5
Zn	71	79	61	59	66	61	48	50	78	60	73	75		65	10	41	53	43	72	56
Rb	620	445	445	405	350	475	525	620	515	510	530	575	500	500	79	440	555	355	370	200
Sr	60	40	55	70	70	45	25	20	25	20	40	25	40	40	18	40	25	50	60	70
Zr	155	210	120	225	165	125	70	50	150	90	100	95		130	54	41	70	45	135	150
Nb	29	53	33	25	22	30	84		34		35	47		39	18	21	55	14	16	20
Sn	13	4	3	<2	5	6	10	<2	12	<2	19	19	10	7.7	6.7	5	8	4	3	3
Ce	124	190	95	145	157	81	46		73		88	58		106	47	260	41	35	107	135
U(2)							.17	6	19	2				(3)7.4	6.3		14			
Th	48	53	45	51	58	28	26		45		45	37		44	10.4	43	43	<5	27	51
C.I.P.W. NORMS																				
Q	24.7	32.7	28.6	32.0	30.0	29.4	30.9	31.6	33.0	32.6	32.5	32.4	37.3			30.6	33.9	40.6	30.0	28.6
C	.1	.3	.1	.2		.1	.1	.9	.6	1.2	.4		.7				.2	.2	.8	
Or	31.2	24.9	28.0	27.1	28.8	30.8	29.3	27.8	28.7	25.4	24.5	26.2	28.0			29.1	26.2	20.0	28.9	29.0
Ab	33.5	28.1	34.8	29.6	32.1	31.2	33.3	33.0	30.4	33.8	34.6	33.6	25.8			35.5	36.0	33.0	31.9	33.5
An	5.2	6.9	4.1	5.8	5.4	5.1	2.8	3.2	3.0	3.6	3.7	3.3	4.0			2.3	1.9	4.2	3.5	4.8
Di					1.0											1.1				
Hy	2.5	3.8	1.7	1.9	1.3	1.8	.7	2.0	1.7	1.9	2.2	2.7	1.9			.1	.4	1.2	2.0	1.5
Mt	.8	1.0	.9	1.4	1.2	.8	.7	.1	1.0	.3	.8	.3	.7			.8	.7	.5	.9	.9
Il	.4	.7	.3	.5	.4	.3	.2	.1	.3	.1	.3	.2	.4			.2	.1	.2	.4	.4
Ap	.1	.2	.1	.0	.1	.0	.1	.1	.0	.1	.1	.1				.1	.0	.0	.1	.1
Cc								.1	.0											
RATIOS AND D.I.																				
K_2O/Na_2O	1.33	1.27	1.15	1.31	1.24	1.41	1.26	1.20	1.35	1.07	1.01	1.12	1.56	1.25		1.17	1.04	.87	1.30	1.24
K/Rb	71	78	88	94	112	91	78	63	78	70	65	64	74	78		93	66	79	109	204
Rb/Sr	10.3	11.1	8.1	5.8	5.0	10.6	21.0	31.0	20.6	25.5	13.2	23.0	12.5	12.5		11.0	22.2	7.1	6.2	2.9
Mg/Li	46.7	34.5	17.1	18.2	18.6	30.0	20.1	26.5	12.9	7.0	22.6	42.2	1.3	14.0		8.6	1.1	5.3	220	24.1
Ca/Sr	130	270	114	126	143	165	172	257	177	275	146	214	145	168		143	111	123	93	128
D.I.	90.8	86.9	92.7	90.1	90.6	91.9	95.4	93.4	93.3	92.7	92.4	93.3	92.2			95.4	96.7	93.7	92.2	92.2

(1) Thermally metamorphosed by nearby dolerite
(2) Analysis by Government Chemical Laboratories
(3) Includes unpublished results

x̄ Average
s Standard deviation

TABLE 49. CHEMICAL ANALYSES OF NUMBANA GRANITE

	Porphyritic and even-grained phases							Marginal leucocratic and pegmatitic phases							
GSWA No.	26229	15291	26231	26230	15241	26203	15288	26377	26232	26233	26378	15246	26205	26204	26376
MAJOR OXIDES (%)															
SiO_2					78.4			72.9	75.6		75.7	75.9			76.5
Al_2O_3					12.5			14.8	13.0		13.7	13.1			12.5
Fe_2O_3					.33			.80	.39		.29	.58			.17
FeO					.52			2.03	.41		.27	.81			.23
$\sum FeO$	1.20	.88	1.35	1.05	.81	.98	1.30	2.74	.76	1.03	.53	1.33	1.35	1.02	.38
MgO	.20	.14	.34	.18	.03	.11	.20	.01	.04	.11	.06	.17	.24	.04	.01
CaO	.73	.50	.71	.66	.92	.42	.78	.56	1.23	.18	.37	.72	.64	.32	.15
Na_2O	3.65	3.95	3.70	3.70	3.67	3.60	3.70	5.75	5.00	4.60	4.67	3.64	3.40	3.35	2.96
K_2O	3.80	4.20	4.00	4.10	4.17	4.40	4.90	1.34	2.18	2.40	3.72	4.89	5.10	5.20	5.97
Loss					.58			.58	.52		.56	.68			.47
H_2O^-					.06			.24	.05		.19	.18			.14
TiO_2					.04			.00	.01		.01	.13			.01
P_2O_5					.06			.04	.00		.06	.02			.03
MnO					.01			1.75	.06		.06	.03			.07
Total					101.4			100.8	98.6		99.7	100.8			99.2
TRACE ELEMENTS (ppm)															
Li	74	99	77	67	31	67	63	27	88	75	84	70	87	15	54
Be					2			12	2		6	5			4
F															
Cu					2			6	30		3	1			2
Zn					42				58		40	58			20
Rb	330	460	330	335	230	390	305	175	530	610	515	360	370	540	785
Sr	65	30	100	60	35	35	55	10	5	15	10	40	55	15	10
Zr					40			60	5			100			
Nb					3			45	135		44	33			44
Sn	5	9	6	2	<2	5	3	2	5	7	14	5	3	<2	7
Ce					24			30	22		9	76			
Th		20			9			12	11		10	38			<5
U		6			6										
RATIOS															
K_2O/Na_2O	1.04	1.06	1.08	1.11	1.12	1.22	1.32	.23	.44	.52	.79	1.34	1.50	1.55	2.01
K/Rb	96	76	101	102	150	94	133	63	34	34	60	112	114	117	63
Rb/Sr	5.1	15.3	3.3	5.6	6.5	11.1	5.5	17.5	106	40.7	51.5	9.0	6.7	36.0	78.5
Mg/Li	16.3	8.5	26.6	16.2	5.8	9.9	19.1	2.2	2.7	8.8	4.3	14.6	16.6	16.1	1.1
Ca/Sr	80	119	51	79	187	86	101	400	800	86	264	129	83	152	107

TABLE 50. CHEMICAL ANALYSES OF SOME YOUNGER GRANITES OUTSIDE PRINCIPAL PILBARA TIN FIELDS

Pluton	Bonney Downs Granite		40 Mile Quarry(3)			Cookes Creek Granite		Mondana Adamellite
GSWA No.	15231	15232	A(1)	B(1)	26250	18418(2)	18417(2)	38031(2)
				MAJOR OXIDES (%)				
SiO_2	73.4	76.3	73.70	74.41	74.9	71.2	76.3	73.4
Al_2O_3	13.1	12.9	13.59	13.61	13.5	13.9	12.1	13.4
Fe_2O_3	.50	.54	.29	.30	.40	1.0	.4	.8
FeO	.98	1.07	.95	.87	.71	2.75	1.51	1.78
MgO	.31	.36	.63	.46	.12	.5	.0	.4
CaO	.85	.50	.96	.90	.85	1.79	.51	1.63
Na_2O	4.10	3.82	3.97	3.82	4.05	3.88	3.72	3.89
K_2O	4.38	4.52	4.43	4.75	4.98	4.4	4.3	3.6
Loss	.78	.83	.76	.68	.62	.80	.77	.49
H_2O^-	.08	.08			.01	.13	.10	.14
CO_2						.07	.19	.01
TiO_2	.17	.21	.12	.11	.11	.49	.17	.35
P_2O_5	.09	.08	.06	.05	.00	.11	.02	.06
MnO	.02	.04	.06	.05	.03	.06	.04	.07
SO_3			.01	.01				
Total	98.8	101.3	99.53	100.02	100.3	101.1	100.1	100.0
				TRACE ELEMENTS (ppm)				
Li	47	31			72	170	50	<10
Be	4	5			2			
F	690				420	1880	2240	
Cu	3	4			16			10
Zn	46	49			41			30
Rb	270	395		271.3	315	355	420	240
Sr	75	45		64.97	45	120	40	120
Zr	110	130			80	190	130	
Nb	18	21			8			
Ce	106	122			52			
Sn	<2	6			<2	5	10	10
Ba						580	170	600
Th	34	35			20			
U			8.58	9.72		4	3	
				C.I.P.W. NORMS				
Q	30.2	34.8	30.2	31.0	29.9	26.2	36.7	32.1
C	.3	1.0	.7	.7			.9	.3
Or	25.9	26.7	26.1	28.0	29.4	26.0	25.4	21.3
Ab	34.7	32.3	33.5	32.3	34.3	32.8	31.5	32.9
An	3.6	1.9	4.4	4.2	4.0	7.5	1.2	7.7
Di					.2	.2		
Hy	1.9	2.1	3.0	2.4	1.0	4.7	2.2	3.2
Mt	.7	.8	.4	.4	.6	1.4	.6	1.2
Il	.3	.4	.2	.2	.2	.9	.3	.7
Ap	.2	.2	.1	.1	.0	.3	.1	.1
Cc						.1	.4	
				RATIOS AND D.I.				
K_2O/Na_2O	1.07	1.18	1.12	1.24	1.23	1.13	1.16	.93
K/Rb	134	95		145	131	103	85.0	124
Rb/Sr	3.6	8.8		4.2	7	3.0	10.5	2.0
Mg/Li	39.8	70.0		10.0	71.2	17.7	0	>240
Ca/Sr	81	115		99	135	107	91	97
D.I.	92.8	93.6	91.1	91.9	94.0	85.0	94.6	86.7

(1) Oversby (1976)
(2) Analyses by Government Chemical Laboratories
(3) Oversby (1976) found "metamorphic" ages of 2245 ± 36m.y. (Pb-Pb) and 2207 ± 66 m.y. (Rb-Sr) for this rock.

a mean a little below that for average granite (Table 39). The younger granites have generally more than 1000 ppm F, but the Cooglegong Adamellite is the only one in which fluorine contents become abnormally high.

Copper and zinc: Copper is higher in older than younger granites but its distribution is erratic. Zinc contents of almost all granites fall close to the 60 ppm Zn level of average granites (Table 39).

Rubidium: Most of the granites analyzed have higher than average rubidium contents, with the figures for younger granites being two to four times those for the older complex. Except for pegmatites the highest readings were recorded from the Moolyella and Cooglegong Adamellites, and from the marginal phase of the Numbana Granite, each of which has an average of about 500 ppm Rb.

K/Rb ratios of each granite for which rubidium was determined are given beneath the analyses in the appropriate tables. Figure 22 is a plot of potassium against rubidium for the older and younger granites. The principal tin granites have K/Rb ratios of well under 100, the average readings for the Moolyella, Cooglegong and Spear Hill Adamellites being in the range of 75 to 80 and that of the marginal phase of the

TABLE 51. CHEMICAL ANALYSES OF GRANITES OF UNCERTAIN AGES FROM VARIOUS PILBARA TIN FIELDS

Tin field	Shaw River		Wodgina	Tabba Tabba			Strelley	Friendly Creek		Mount Hall		
Rock type	Fine-grained leucocratic granite		Fine-grained massive granite	Foliated granite			Foliated granite	Foliated granite		Foliated granite		Pegmatitic granite
GSWA No.	15233	15242	15300	15201	26251	26254	15214	15296	15297	15254	26222	15258
MAJOR OXIDES (%)												
SiO_2	76.1	73.5										
Al_2O_3	12.9	13.9										
Fe_2O_3	.44	.55										
FeO	.95	.68										
$\sum FeO$	1.34	1.17	1.45	1.20	1.16	1.09	1.60	1.75	2.30	1.80	1.20	.51
MgO	.25	.17	.24	.27	.23	.16	.50	.15	.33	.33	.16	.03
CaO	1.04	1.11	.98	1.01	.41	.78	2.15	.74	1.63	1.10	.57	.33
Na_2O	3.90	4.44	3.30	3.90	3.50	3.55	4.90	3.65	3.60	3.65	2.80	5.40
K_2O	4.25	4.05	3.80	4.30	3.85	3.75	2.10	4.20	3.30	4.30	3.40	2.10
Loss	.75	1.02										
H_2O^-	.09	.18										
TiO_2	.16	.13										
P_2O_5	.03	.00										
MnO	.04	.02										
Total	101.0	100.9										
TRACE ELEMENTS (ppm)												
Li	60	20	81	200	71	122	137	90	71	24	28	3000
Be	4	5		4			5					
Cu	4	4		12			12					
Zn	56	42		50			64					
Rb	340	305	340	290	280	365	180	540	290	245	400	2440
Sr	55	50	80	80	110	95	380	45	105	95	80	45
Zr	110	85		75			140					
Nb	15	10		15			5					
Sn	4	<2	<2	<2	<2	<2	<2	18	3	<2	<2	19
Ce	98	88		77			41					
Th	41	30		22			<5				50	
U		3									12	
RATIOS												
K_2O/Na_2O	1.09	.91	1.15	1.10	1.10	1.06	.43	1.15	.92	1.18	1.21	.39
K/Rb	103	110	93	123	114	85	97	65	94	146	71	71
Rb/Sr	6.2	6.1	4.2	3.6	2.5	3.8	.5	12.0	2.8	2.6	5.0	54

Numbana Granite about 65. Other younger granites have K/Rb ratios in the range of 100 to 150, figures normally taken to indicate appreciable amounts of magmatic fractionation. However the higher part of this range is close to the average K/Rb ratio found in the older granites, and suggests that the crustal abundance of rubidium with respect to potassium may be unusually high in granites of the Pilbara Block.

Strontium: Contents of strontium in younger granites are several times less than those of older granites, averaging about 40 ppm Sr in the principal tin granites. This compares with averages of 340 ppm Sr and 250 ppm Sr respectively in the migmatites and older homogeneous granites. Rb/Sr ratios in older granites fall mainly below one, averaging 0.5 and 0.7 in migmatite and homogeneous granite respectively. In contrast most younger granites have Rb/Sr ratios of more than five and the ratio exceeds 10 in the principal tin granites. The Rb/Sr ratio is one of the more useful criteria for distinguishing older from younger granites within the Pilbara Block.

Zirconium: For this element there is no consistent partition between older and younger granites. Some bodies of younger granite have zirconium contents two to three times lower than those of older granites but in others the zirconium contents are similar to those of the older complex.

Niobium: Contents of niobium in the younger and older granites are markedly different. The older granites have an average of about 4 or 5 ppm Nb, but the younger granites have average concentrations of from 18 to 60 ppm Nb. The highest readings are found in the marginal phase of the Numbana Granite near the well-known tantalite-columbite district of Wodgina.

Tin: This metal was below the limit of detection (about 2 ppm Sn) of the XRF method used, in almost all samples of older granite. By comparison, most samples of younger granite contain detectable quantities of tin although the amounts seldom exceed 20 ppm Sn. About one in four samples of Cooglegong Adamellite analysed had tin contents below the limit of detection. Although tin content is a useful guide to the age and mineralizing potential of Pilbara granites, several samples from each body may be required to ensure that a prospective pluton is not overlooked.

Uranium and thorium: After it was noted that tin granites were three to five times more radioactive than older granites about 40 samples were submitted to the

Government Chemical Laboratories for uranium determinations. Where thorium analyses were lacking, that metal was also determined. Uranium was found to be concentrated in the younger granites, with a highest average content of 15 ppm U in the Moolyella Adamellite. Th/U ratios range from an average of about two in the Moolyella Adamellite to 10 or more in the older granite, suggesting marked magmatic fractionation within the younger granites.

Granites of uncertain age

The available chemical analyses (mainly partial) assist in assigning only a few of these granites (Table 51) to the older or younger age groups. Sample 15214 from Strelley is clearly an older granite, and 15296 from Friendly Creek has close chemical affinities with the younger granites.

Sample 15258 from Mount Hall is probably the marginal phase of a younger granite, although some older granites may also yield lithium-rich pegmatites.

Most other samples have compositions between those diagnostic of younger and older granites, and cannot be assigned to either group on the basis of available chemistry.

Tin-bearing pegmatites

All samples analyzed were of layered aplite-pegmatite bodies. Analyses 16466 and 16467 (Table 52) were made on splits from two random grab samples of about 30kg each. They give a better approximation of the true composition of the layered aplite-pegmatites than the other samples which are single specimens of selected albite-rich material.

As expected from their petrography, the pegmatites comprise mainly silica, alumina and alkalies. They also have higher than average (for granitic rocks) amounts of lithium, rubidium and tin.

K/Rb ratios are low, at 14 to 18, and Rb/Sr ratios high, from about 30 to 160. The rocks appear to be formed from well-fractionated magmas.

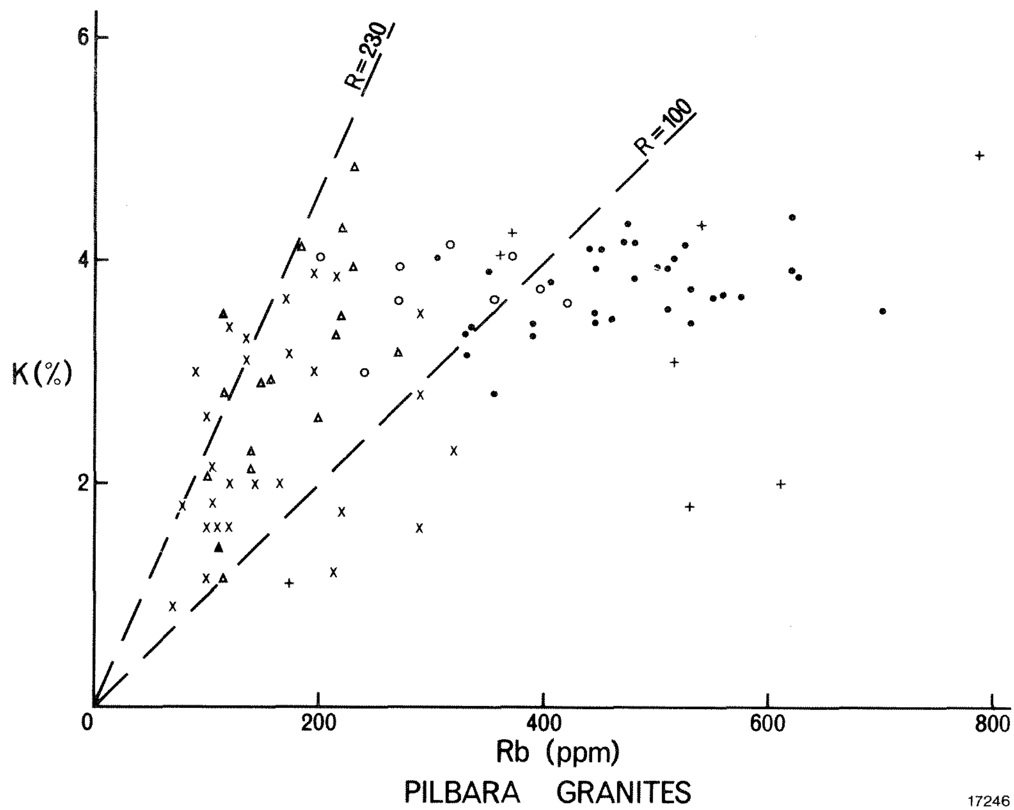


Figure 22. Plot of K against Rb for Pilbara Block granites. Filled circles = tin granites; open circles = other younger granites; diagonal crosses=older migmatite complex; triangles=older homogeneous granites; upright crosses=marginal phase of Numbana Granite. Dashed lines indicate K/Rb ratios of 230 (the crustal average of Shaw, 1968) and 100

TABLE 52. CHEMICAL ANALYSES OF TIN-BEARING PEGMATITE, ACID DYKES AND GREISEN, MOOLYELLA AND SHAW RIVER TIN FIELDS.

Rock type	Tin-bearing pegmatite				Acid dykes				Greisen
GSWA No.	(5397)(1)	15229	16467	16466	26295	(5392)(1)	15206	15237	21732(2)
MAJOR OXIDES (%)									
SiO_2	68.36	74.6	76.4	75.1	73.1	72.77	74.3		77.06
Al_2O_3	18.74	14.9	13.9	14.0	13.8	13.87	12.8		14.45
Fe_2O_3		.52	.18	.10	.96	Trace	1.10		.81
FeO	1.15	.16	.30	.27	1.34	2.79	.27		.06
$\sum FeO$	1.15	.63	.46	.36	2.20	2.79	1.26	.44	.79
MgO	.54	.00	.00	.00	.40	.40	.00	.01	.25
CaO	.39	.27	.10	.12	2.89	1.60	.65	.25	<.01
Na_2O	10.22	6.45	5.14	5.00	4.66	4.18	4.13	3.63	.09
K_2O	.07	1.04	3.03	4.15	1.43	2.81	4.55	5.20	4.53
Loss(3)	.03	.56	.45	.21		.29	.55		2.16
H_2O^-		.06	.06	.07		.02	.12		.12
TiO_2	.07	.01	.01	.00	.23	.55	.06		.11
P_2O_5		.11	.01	.05	.03		.01		.05
MnO	.45	.69	.18	.16	.04	.22	.02		.01
CO_2						.24			
Total	100.02	99.4	99.8	99.2		99.74	98.6		99.71
TRACE ELEMENTS (ppm)									
Li		265	245	125	28		95	6.	46
Be		6	16	10	1		4	2	12
F		1240		740	390		4880		860
Cu		3	0	0	1		1	12	
Zn		130	107	86	57		55	16	
Rb		630	1590	1870	70		745	595	560
Sr		20	10	25	185		5	30	30
Zr		10	5	10	185		130	55	
Nb		51	50	48	7		95	40	36
Sn		42	87	175	2		13	<2	39
Ce		0	14	9	60		98	17	
Th		3	0	0	18		98	8	
U(2)		2	3	5			23		
C.I.P.W. NORMS									
Q	5.72	32.4	34.4	29.7	33.5	31.36	31.6		58.7
C	1.14	2.9	2.0	1.2		1.02			9.4
Or	.41	6.2	17.9	24.5	8.4	16.68	26.9		26.8
Ab	86.47	54.6	43.5	42.3	39.4	35.63	34.9		.8
An	1.93	.6	.4	.3	12.5	8.06	2.8		.0
Di					1.4				
Hy	4.17	1.1	.7	.7	1.7	5.62			.6
Mt		.7	.3	.1	1.4		.8		.0
Il	.13	.0	.0	.0	.4	1.06	.1		.1
Ap		.3	.0	.1	.1		.0		.0
Hm									.8
RATIOS AND D.I.									
K_2O/Na_2O	.007	.16	.59	.83	.31	.67	1.10	1.43	50
K/Rb		14	16	18	170		51	73	67
Rb/Sr		31	159	73	.4		149	19.8	18.7
D.I.	92.6	94.3	96.6	97.6	83.5	91.4	96.2		88.8

NOTES:

(1) Numbers in brackets are 'old series' samples whose analyses are given by Maitland (1908, p.7). Sample (5397) is albite pegmatite from Moolyella. Sample (5392) is from a porphyry dyke at Duffer Creek (lat.21°07′, Long.119°45′).

(2) Analyses by Government Chemical Laboratories.

(3) Loss equals H_2O^+ in Maitland's samples.

Acid dykes

Only four analyses of acid dyke rocks are available (Table 52), and while certain compositional features are indicated, they cannot be substantiated statistically.

The dacite dykes contain more silica, and less alumina, total iron, magnesia, lime and potash than do Nockolds' (1954) average dacite and rhyodacite. One sample for which trace elements were determined, has normal K/Rb, low Rb/Sr, and low contents of lithium, beryllium, fluorine, rubidium, niobium and tin. It seems to have formed from an unfractionated magma.

Chemically the dacite dykes are similar to pillowed dacites within the Warrawoona Group (Hickman and Lipple, 1975, Table 13), but field relationships show them to be younger than these lavas. They do not resemble chemically any late Archaean or Proterozoic rocks for which analyses are available.

Of the two samples of rhyolite dyke rock, 15206 shows strong evidence of magmatic fractionation in its low K/Rb ratio, high Rb/Sr ratio, and high contents of lithium, fluorine, rubidium, niobium and tin. Fractionation in 15237 is less pronounced, but both rocks could be derived from the same magma that produced the younger granites.

TABLE 53. C.I.P.W. NORMS AND DIFFERENTIATION INDICES OF OLDER AND UNASSIGNED GRANITES FROM THE PILBARA BLOCK

	Migmatitic, gneissic and foliated granites										
GSWA No.	12585	26276	26278	15225	15255	15234	26219	15235	16380	16373	16391
Q	21.8	33.9	26.8	34.2	16.9	26.6	26.7	34.4	30.8	29.5	30.1
C	.4	.7	.1	.9		.3	.0	1.8	.6		
Or	8.7	11.4	13.1	11.3	12.6	15.2	22.6	27.5	18.5	24.3	27.4
Ab	37.3	37.9	40.2	41.7	40.1	38.6	34.8	27.7	39.5	38.1	32.1
An	21.0	11.7	13.3	9.8	14.2	11.7	8.6	3.1	7.2	5.0	6.2
Di					6.1						.5
Hy	4.9	3.0	3.2	1.6	3.0	4.1	2.6	1.7	1.9	1.1	1.7
Mt	2.6	.7	1.5	1.0	3.5	1.5	1.7	1.0	.3	.05	.7
Il	.9	.4	.6	.4	1.0	.9	.8	.3	.1	.1	.5
Ap	.2	.0	.1	.0	.7	.2	.2	.1	.0	.0	.1
D.I.	69.3	73.4	80.9	86.4	70.9	81.1	85.8	89.3	89.7	93.6	90.2

	Homogeneous plutons										Unassigned granites	
GSWA No.	15227	12584	15221	15220	15219	15202	15205	15240	15247	26228	15233	15242
Q	27.5	28.0	25.3	28.4	27.9	30.5	27.6	30.7	25.9	24.7	34.1	29.2
C	.2		.4	.4	.4	.7	.2	1.5	.5	.5	.1	.2
Or	9.8	15.0	20.8	28.1	29.4	30.5	20.0	14.8	22.5	24.9	25.1	23.9
Ab	40.2	38.5	39.9	32.1	31.3	30.8	37.1	39.2	37.6	39.8	33.0	37.6
An	13.7	10.2	8.1	6.2	5.2	4.1	8.9	7.5	7.0	5.5	5.0	5.5
Di		1.0										
Hy	5.4	3.5	2.4	1.5	2.1	.6	2.2	1.8	3.0	2.1	1.8	1.0
Mt	1.5	1.4	.8	1.4	1.2	1.2	1.3	1.6	1.0	1.6	.6	.8
Il	.6	.6	.6	.4	.5	.3	.6	.4	.4	.4	.3	.2
Ap	.1	.2	.1	.1	.2	.1	.2	.1	.2	.3	.1	.0
D.I.	78.2	82.8	87.3	89.8	90.2	92.9	85.6	86.7	87.6	89.5	92.1	92.1

Tin, lithium and niobium contents of biotite/chlorite fractions

To determine whether the trace element contents of biotite could be used to select potential tin granites in the Pilbara Block, biotite/chlorite concentrates were extracted from about fifty granite samples. The process comprised firstly passing the crushed granite through a heavy liquid, and then removing the biotite and associated chlorite from the heavy mineral concentrate by means of a Frantz isodynamic separator. Owing to the leucocratic composition of many of the granites, yields of biotite concentrates were often low and in many cases only small samples were obtained. The first attempt to determine tin was made using the colorimetric method of Stanton and McDonald (1961). This proved unsuccessful, the hot iodine vapour failing to extract tin from the silicate lattice of the biotite/chlorite assemblage. Unfortunately these attempts consumed a high proportion of many of the samples which limited further testing. Where more than 3g of sample remained, pressed discs were prepared and tin and niobium were determined by XRF. Remaining samples were sent to the Government Chemical Laboratories (some as composites) for determination of tin. Lithium was determined on 0.2g samples by AAS. Results of these analyses are shown in Table 56. They illustrate that biotite in tin granite has generally higher contents of tin, niobium and lithium than biotite in older granite, but there is a considerable field of overlap in the values obtained. Determination of tin, niobium and lithium on whole rock samples appears to be equally effective in distinguishing the tin granites and is considerably more convenient.

Two amphibole concentrates from a large raft of mafic and ultramafic rocks within the migmatites near Cooglegong contained no tin, niobium or lithium detectable by the analytical methods employed.

Chemical features of younger granites related to mineralization

Table 57 lists various ratios and trace element contents in the main plutons of younger granites, together with their associated mineral production.

The average ratios of $K_2O + Na_2O : FeO + MgO + CaO$ are included as an arithmetic method of expressing the grouping of the various granites in the triangular plot of Figure 22; the higher the ratio the closer the granite lies towards the $K_2O + Na_2O$ corner of the triangle. Other ratios and values are taken from Tables 47 to 50, and 54.

Although no separation can be made between mineral production related to the more fractionated Spear Hill Adamellite and that due to the Cooglegong Adamellite, the distribution of diggings suggests that

TABLE 54. C.I.P.W. NORMS AND DIFFERENTIATION INDICES OF NUMBANA GRANITE

GSWA No.	15241	26377	26232	26378	15246	26276
Q	39.0	30.4	35.3	33.4	33.9	36.0
C	.4	3.0	.2	1.5	.5	1.0
Or	24.6	7.9	12.9	22.0	28.9	35.3
Ab	31.1	48.6	42.3	39.5	30.8	25.0
An	4.2	2.5	6.1	1.4	3.4	.5
Di						
Hy	.7	6.3	.6	.5	1.3	.4
Mt	.5	1.2	.6	.4	.8	.2
Il	.1	.0	.0	.0	.2	.0
Ap	.1	.1	.0	.1	.0	.1
D.I.	94.0	86.9	92.3	96.0	95.1	97.8

mineralization was more intense about the former body. Again, most pegmatites in the Wodgina field seem to be associated with the more differentiated marginal phase of the Numbana Granite.

Examination of the results indicates that the greatest mineral production is associated with granites having higher concentrations of tin, lithium, rubidium and niobium, and higher Rb/Sr and lower K/Rb ratios. The mineralizing granites also have higher differentiation indices and higher $K_2O + Na_2O : FeO + MgO + CaO$ ratios but these functions seem less critical than the trace element concentrations and ratios referred to above. The association of tin mineralization with higher tin and lithium contents can be demonstrated within a single pluton. Figure 23 shows the western part of the Moolyella Adamellite with tin and lithium contents plotted. The higher contents of these elements are found in samples from the south-western tongue of the intrusion, that is from the part of the granite closest to the most prolific swarm of tin-bearing pegmatites in the Moolyella field (see Plates 2 and 3).

COMPARISON OF PILBARA TIN GRANITES WITH WORLD TIN GRANITES

The tin granites in the Pilbara Block have many features in common with their counterparts in other parts of the World. They are late-tectonic granites intruded after the main period of folding and are comparatively undeformed. Petrographically they are

TABLE 55. AVERAGED ANALYSES OF SOME OLDER AND YOUNGER GRANITES, PILBARA BLOCK

	Migmatites		Foliated granites		Moolyella Adamellite		Cooglegong Adamellite		Spear Hill Adamellite	Coondina Adamellite	Numbana Granite	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s			Main phase	Marginal phase
MAJOR OXIDES(%)												
SiO_2	70.8	2.8	71.5	1.4	74.9	.9	74.1	1.1	76.9	73.4	78.4(1)	75.3
Al_2O_3	14.5	.86	14.3	.6	13.4	.34	13.2	.51	12.5	13.6	12.5(1)	13.4
Fe_2O_3	.73	.56	.94	.19	.40	.09	.52	.26	.45	.65	.33(1)	.45
FeO	1.67	.75	1.24	.52	.75	.05	1.16	.34	.55	1.08	.52(1)	.75
$\sum FeO$	2.46	1.2	2.04	.57	1.11		1.63		.95	1.66	1.08	1.14
MgO	.92	.65	.49	.21	.11	.02	.22	.11	.07	.31	.17	.08
CaO	2.12	.10	1.74	.61	.78	.12	.94	.29	.68	1.01	.67	.52
Na_2O	4.25	.59	4.17	.49	4.08	.14	3.76	.32	4.12	3.87	3.28	4.17
K_2O	3.00	1.4	3.57	1.24	4.57	.34	4.68	.35	4.25	4.90	4.22	3.85
Loss	.94		.95	.19	.58	.11	.70	.17	.60	.88		
H_2O^-					.09	.06	.09	.04	.13	.10		
TiO_2	.31	.17	.26	.08	.07	.01	.17	.09	.08	.23	.04(1)	.03
P_2O_5	.10	.06	.07	.03	.03	.03	.04	.02	.02	.06	.06(1)	.03
MnO	.06	.03	.04	.01	.05	.03	.06	.02	.04	.04	.01(1)	.05(2)
TRACE ELEMENTS (ppm)												
Li	80	63	80	50	185	90	95	115	95	80	70	55
Be	2	1.1	2	.8	5.5	3.3	6.1	1.7	6	5	2(1)	6
F	765	195	620	250	1050	225	2380	2510	740	1360(1)		
Cu	15	18	8	7	4	3	13	19	2	7	1	8
Zn	60	20	63	12	60	9	65	10	45	65	42(1)	44
Rb	160	70	175	53	510	90	500	80	450	320	340	485
Sr	340	190	250	133	40	8	40	18	40	65	55	20
Zr	170	52	180	34	65	10	130	54	50	140	40(1)	55
Nb	±4		±5		27	7	39	18	30	18	3(1)	60
Sn	<3		<3		9.4	7	7.7	6.7	6	2.5	4.3	5.5
Ce	70	44	100	40	60	12	106	47	110	70	24(1)	35
Th	13	10	28	13	35	11	44	10	27	40	14	14
U	2.7	3	3		15(3)	8	7.4(3)	6.3	14(1)		6	
RATIOS												
K_2O/Na_2O	.7		.9		1.1		1.2		1.0	1.3	1.3	.9
K/Rb	155		170		75		78		78	127	103	66
Rb/Sr	.5		.7		12.7		12.5		11.2	4.9	6.2	24

(1) Only one analysis available
(2) Excludes one value of 1.75%
(3) Includes unpublished data
$\bar{x}$ Average
s Standard deviation

Number of analyses: migmatites—total and partial analyses from Table 45; foliated granites—total and partial analyses from Table 46; Moolyella Adamellite 11; Cooglegong Adamellite 13; Spear Hill Adamellite 3; Coondina Adamellite 2; Marginal phase Numbana Granite 8 (from Table 48).

TABLE 56. TIN, LITHIUM AND NIOBIUM CONTENTS OF BIOTITE/CHLORITE CONCENTRATES FROM PILBARA BLOCK GRANITES

Younger granites (Pluton and sample no.)	Sn (ppm)	Li (ppm)	Nb (ppm)
Moolyella Adamellite			
12586	55	2 120	225
15228	70	3 450	
15230	80	4 020	
15248	220		
15249	30	1 800	
15266[1]		2 000	
26240		2 230	
26247	120	3 070	
26266	80	1 580	
26269[1]		530	
26271[1]		1 350	
26273	50	330	190
26282	120	3 300	
26285		3 200	
26288	70	2 650	284
38090[2]	20		
Cooglegong Adamellite			
15203[1]		1 090	
15204[1]		1 300	
15207	50	860	235
15226	40	1 600	125
15236		820	
26209		2000	
26301	20	330	210
38091[2]	70		
Spear Hill Adamellite			
15216[1]		2 400	
26303[1]		1 500	
38089[2]	80		
Numbana Granite			
15246		1 280	
Coondina Adamellite			
15239	45	1 030	100
40-Mile Quarry			
15212	20	1 230	130
Bonney Downs Granite			
15232	45	460	150

Older and unassigned granites (Pluton and sample no.)	Sn (ppm)	Li (ppm)	Nb (ppm)
Migmatite			
12585	45	3 200	155
15208		280	
15225	<10	880	
15234	<10	1 370	20
16380		1 420	
Mulgandinnah Adamellite			
15202	15	500	105
15220		590	
15221	<10	130	
Eley Adamellite			
15205		2 100	
Stock north of Moolyella (Plate 2)			
12584	<10	1 320	20
15227	<10	1 890	5
Kangan Adamellite			
15244[1]		1 030	
15245[1]		480	
26206	40	800	
38092[2]	30		
Small stocks near Hillside (Plate 4)			
15233	45	650	215
15242		210	
Foliated granite near Strelley			
15214		1 870	
Foliated granite, Wodgina tin field			
15247		850	

(1) Samples included in composite
(2) Composite sample

leucocratic biotite or biotite-muscovite adamellites with low contents of accessory titanium minerals but common accessory fluorite, and, in some places, accessory topaz and tourmaline. Chemical analyses show high silica; comparatively high ratios of alkalis to lime, magnesia and iron-oxide; higher than average lithium, beryllium, rubidium, tin and uranium; and low concentrations of magnesium and strontium.

Comparison of Figures 13 and 24 shows that the $SiO_2/10$: $Na_2O + K_2O$: $CaO + MgO$ ratios of the Pilbara tin granites lie in the same field as the World tin granites listed in Table 37.

Like World tin granites, the Pilbara stocks have K/Rb ratios of less than 100 and Rb/Sr ratios greater than 5.

Even if the field relationships had been obscured, these chemical features alone (Tables 37 and 38 *cf.* Tables 47 to 49) would point to the Moolyella, Cooglegong and Spear Hill Adamellites being the ultimate source of the tin deposits in the Moolyella and Shaw River tin fields.

ORIGIN OF THE PILBARA GRANITES

Field and laboratory data collected during this investigation permit reasonably informed speculation on the emplacement of the younger granites, but throw little new light on the enigmatic origins of the older granitic complex.

Younger granites

Statements that can be made with more or less confidence about the history of the younger granites are listed here, and, with their supporting evidence, are discussed briefly below:

1. The younger granites are of magmatic origin;
2. The younger granites were formed by partial melting of pre-existing crust, probably the older granites;
3. The younger granites were emplaced by passive stoping in broad linear belts, possibly corresponding to directions of tensional crustal fracturing;

4. During emplacement the more volatile and less crystallographically compatible elements moved progressively to the tops of the plutons, causing increasing alteration of such minerals as biotite and plagioclase, and resulting eventually in residua of fluid, which, escaping into fractured country rock or trapped in joints within the cooling parent, gave birth to swarms of tin-bearing pegmatites;
5. The heat which produced the crustal remelting was derived from pools of basaltic magma gathering beneath the sialic crust.

In discussing the evidence for these conclusions it should be recalled that almost all features relating to the origins of granites have been subject to two or more interpretations.

1. A magmatic origin for the younger granites is supported by their intrusive contacts, their generally homogeneous lithology, and their chemical composition, which shows their normative quartz-albite-orthoclase ratios (Fig. 25a) to fall within the maximum frequency field for granites near the minimum melt

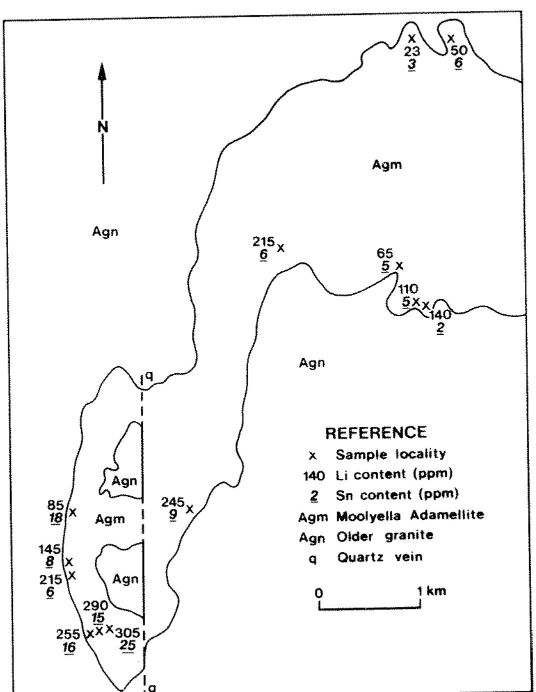


Figure 23. Map of western part of the Moolyella Adamellite (see Plates 2 and 3 for locality) showing distribution of tin and lithium

TABLE 57. COMPARISON OF CHEMICAL FEATURES OF YOUNGER GRANITES AND THEIR RELATED MINERAL PRODUCTION

Granite	Comparative chemical features (averages)									Associated mineral deposits
	$\frac{K_2O+Na_2O}{\sum FeO+MgO+CaO}$	D.I.	Rb	Li	Be	Sn	Nb	K:Rb	Rb:Sr	
Moolyella Adamellite	4.3	93.9	510	185	5.5	9	27	75	12.7	Production of 7 620 tonnes tin concentrate, 14 tonnes of tantalo/columbite and 12 tonnes of beryl
Cooglegong Adamellite	3.0	92.0	500	95	6	8	39	78	12.5	Production of 6 550 tonnes tin concentrate, 548 tonnes tantalo/columbite and 107 tonnes of beryl. Minor gadolinite and wolframite (Cooglegong and Spear Hill)
Spear Hill Adamellite	4.9	95.3	450	95	6	6	30	78	11.2	
Coondina Adamellite	2.9	92.2	320	80	5	2.5	18	127	4.9	Production of 610 tonnes of tin concentrate and 14 tonnes of tantalo/columbite
Numbana Granite (Main phase)	3.9	94	340	70	2	4	3	103	6.2	Production of 478 tonnes tin concentrate, 180 tonnes of tantalo/columbite, and 1 190 tonnes of beryl. Also significant unworked lithium deposits. Mineralization associated mainly with marginal phase (Main and Marginal phases)
Numbana Granite (Marginal phase)	4.6	93.6	485	55	6	5.5	60	66	24	
Tabba Tabba Adamellite	3.5	92.3	290	70	2	<2	8	138	5.6	Production of 130 tonnes of tin concentrate, 18 tonnes tantalo/columbite, and 52 tonnes of beryl. Some lepidolite
Bonney Downs Granite	3.4	93.2	330	40	4	3	19	115	6.2	Production of about 13 tonnes beryl, 3 tonnes of tantalo/columbite and minor cassiterite
Cookes Creek Granite	2.0	89.8	385	110				94	6.7	Minor production of wolframite. Small fluorite veins
Mondana Adamellite	1.6	86.7	240	<10				124	2.0	Possibly minor tin occurrences

composition (Winkler, 1967). Petrographic support is seen in the typically igneous hypidiomorphic-granular textures of most of the younger granite samples examined.

2. Derivation from pre-existing crust is strongly suggested by the high initial Sr^{87}/Sr^{86} ratios of both the Moolyella and Cooglegong Adamellites. These values, 0.74 and 0.73 respectively, are appreciably greater than would be expected for material derived directly from the earth's mantle. The identity of the pre-existing crustal material melted to form the younger granites cannot be established directly but the positions of the younger plutons in the regional geology (Plate 1) makes it most likely to be the older granite.

de Laeter and Blockley's (1972) comment on imprecision of the initial Sr^{87}/Sr^{86} ratios in the Moolyella Adamellite still applies to later work on the Cooglegong Adamellite, but the similar values obtained from both bodies makes it more credible that the true initial ratios in the younger granites are indeed greater than normal.

3. Emplacement of younger granites in linear belts is deduced from Plate 1 which shows these bodies to lie in belts; one belt trends west-northwesterly and takes in the Bonney Downs, Mondana, Cooglegong and Numbana plutons; a second, trending northeasterly, includes the Coondina, Cooglegong and Moolyella Adamellites; and a possible third, trending northwesterly, embraces the Cookes Creek Granite, Moolyella Adamellite and several small intervening stocks. The first two of these directions are those of Proterozoic dolerite dyke swarms, one member of which was dated by Lewis and others (1975) at 2 280 ± 87 m.y.

It seems likely that in the late Archaean there were already zones of crustal weakness and probable tension which allowed intrusion of firstly the younger granites, and later, the dolerite dykes. The swarms of tin-bearing pegmatites around some younger granites occupy typical tension fractures and give further indication of tensional forces operating at the time of intrusion of the younger granites. The evidence for passive emplacement by stoping is essentially negative; the younger granites had no apparent structural effect on

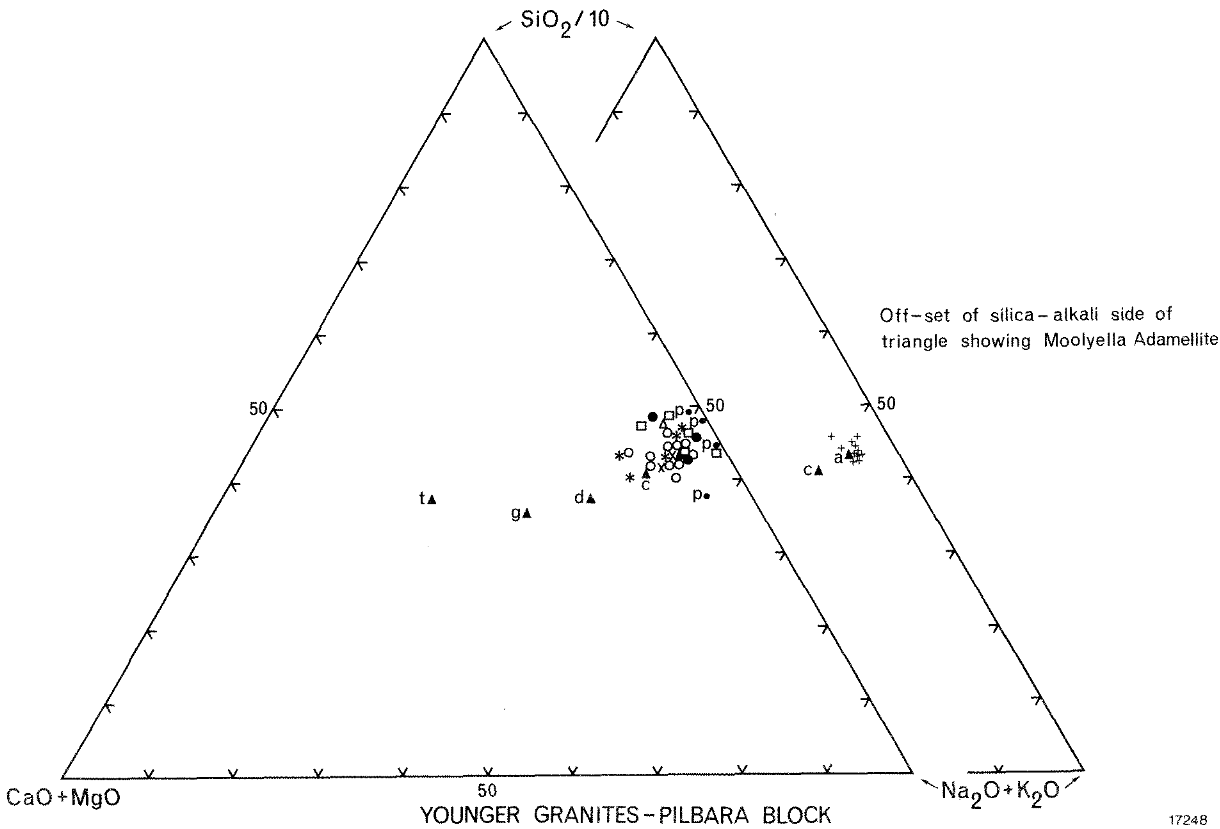


Figure 24. Triangular plot of $SiO_2/10$: $CaO + MgO$: $Na_2O + K_2O$ for younger granites in the Pilbara Block. Symbols are as in Figure 21B.

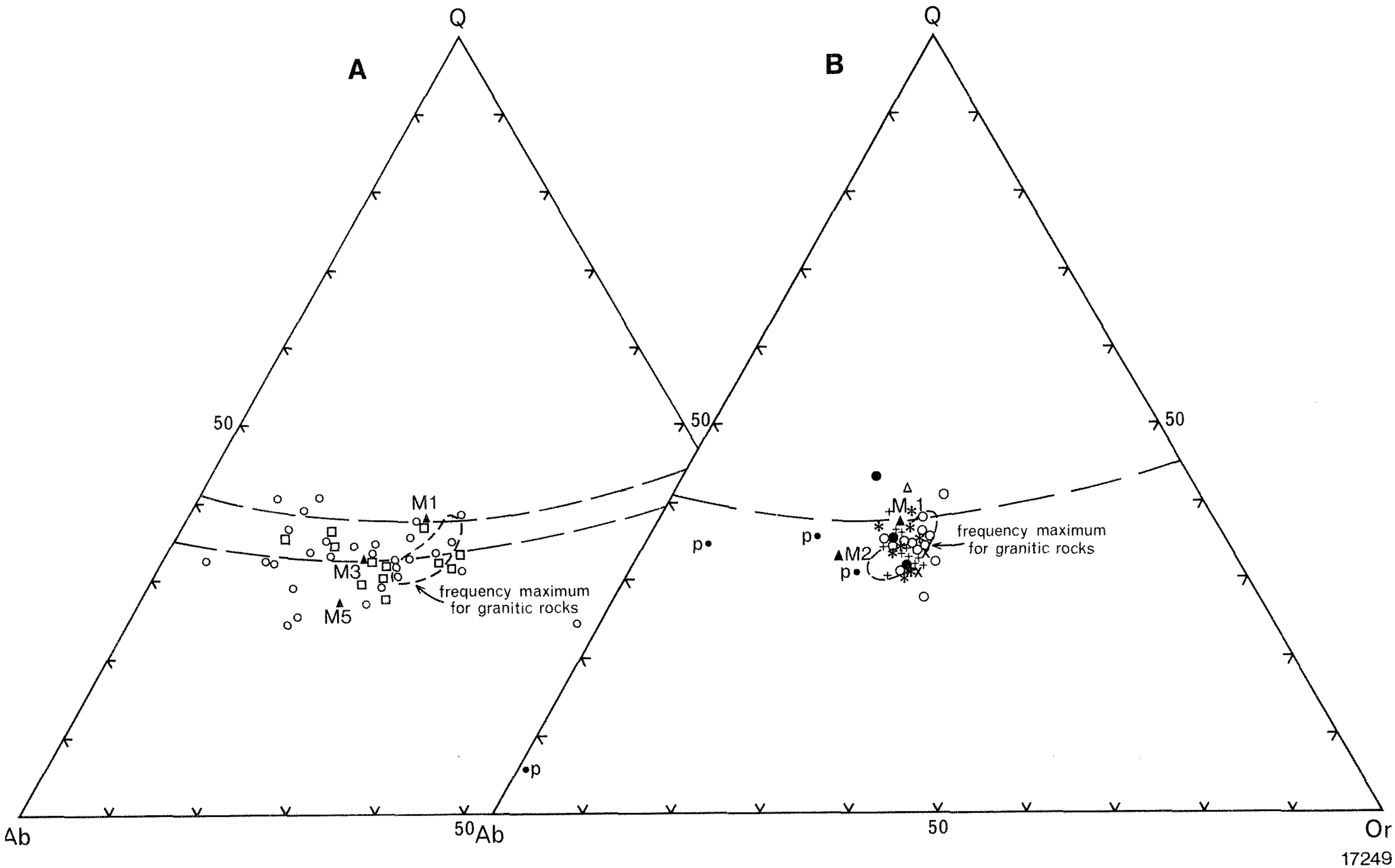


Figure 25. **Triangular plots of normative quartz (Q), albite (Ab) and orthoclase (Or) for Pilbara Block granites. (Data on silicate melts is from various sources, compiled by Mehnert (1968) and Winkler (1967)).**

A. Older granites. Open circles = gneissic and migmatitic granites; open squares = older homogeneous granites. Solid triangles M1, M3 and M5 are minimum melt compositions at 100 MPa, 300 MPa and 500MPa respectively. Two cotectic lines are shown.

B. Younger granites. Symbols are as in Figure 21B except that the marginal phase of the Numbana Granite is omitted, ***as these rocks probably have a metasomatic*** **component. Solid triangles M1 and M2 represent minimum melt compositions at 100 MPa and 200 MPa respectively. The dashed line marks the cotectic at 100 MPa.**

the rocks they intrude, and contain in places large blocks of older granite (Plate 2) or greenstone (Plate 5).

4. Upward fractionation of the younger granites is suggested by comparisons between the different plutons. All of the more fractionated bodies show signs of being exposed at levels near the roofs of their respective intrusions. The Moolyella Adamellite shows greatest fractionation at its western end where it is of finest grain size and where several roof pendants show the top of the body near at hand, the comparatively small Spear Hill Adamellite is best interpreted as an offshoot from the Cooglegong Adamellite; and the marginal phase of the Numbana Granite is in places the uppermost part of the main phase. In contrast the least fractionated younger granites are those exposed over large areas which most interpretations of original shape would place well below the roofs of the bodies. Contacts of the Bonney Downs Granite are more diffuse than those of more differentiated plutons, suggesting that it is exposed nearer to its anatectic root zone.

The abundance of tin-bearing pegmatites associated with some younger granites and their absence from other younger granites can be explained only partly by different levels of exposure. Some younger plutons such as the Cookes Creek Granite appear to be well fractionated and exposed near their roofs, but are lacking in associated mineralized pegmatites. Jahns and Burnham (1969) have shown that pegmatites form from an aqueous phase which separates from a magma during crystallization. Burnham (1967) pointed out that such an aqueous liquid separates from the silicate melt when the partial pressure of water in the magma exceeds the confining pressure, i.e. the magma must boil. Pegmatite-deficient younger granites may never have approached sufficiently close to the surface for these conditions to occur, and presumably the aqueous phase and associated volatiles were trapped within the main body of the rock. It may be significant that the Cookes Creek Granite has a high content of fluorite.

5. The source of the heat which remelted the older granites seems likely to have been the first upwellings of basaltic magma which, at the end of the Archaean era, erupted from a multitude of fissures to form the Lower Proterozoic Fortescue Group which covered the Archaean rocks and plated the floor of the Hamersley Basin—at that time subsiding to the south of the Pilbara Block. Evidence for this admittedly speculative statement comes from the coincidence of some of the younger granites with prominent swarms of dolerite (a coincidence which has led prospectors and some geologists to suppose that the source of the alluvial tin ore lay in the dolerites) and the isotopic indication for a thermal event culminating at about 2 200 m.y. found by Oversby (1976).

More recent work by de Laeter and Hickman (1977) indicated that the Fortescue Group may be as old as 2 550 m.y., and Richards (pers. comm.) has determined ages of about 2 700 m.y. for galena in veins cutting these rocks. These results indicate that the time interval between the intrusion of the younger granites and the extrusion of the Fortescue lavas may have been quite short.

Older granites

The origin of the large granitic complexes with high ratios of soda to potash, which make up appreciable parts of many Archaean terrains, has been the subject of much debate. Summaries of the various hypotheses extant, as well as two markedly contrasting interpretations of their own, have recently been presented by Glikson and Sheraton (1972) and Dougan (1976). These hypotheses discuss the origin of the oldest granites in terms such as direct derivation from the mantle, partial melting of oceanic crust, remobilization of primordial sial crust, and anatectic melting of greywacke.

Field evidence for the origin of the older granites of the Pilbara Block is contradictory. Many contacts of older granite with the Warrawoona Group can be seen in which an intrusive relationship is clear. However, Hickman (1975b) noted deformational features in the granites which he was unable to find in the greenstone. Other writers (e.g. Ryan, 1964) have suggested that older granites are in part a basement to the greenstone sequence, but are locally mobilized to form intrusive contacts. Recent age determinations on the Warrawoona Group (e.g. Sangster, 1977; Pidgeon, 1978) show that the greenstones are 300 or 400 m.y. older than the older granites.

A simple magmatic origin for the older granites seems to be ruled out by the complex mixtures of different granite types commonly present in single outcrops, and by examination of the ratios of normative quartz-albite-orthoclase (Fig. 25b) which rarely lie near the minimum melt composition.

Although the older granites have many features suggesting an origin by high grade metamorphism leading to local remelting, their high lithium contents and low K/Rb ratios argue against such an origin; mobile elements such as lithium and rubidium should be depleted during metamorphism, not enriched.

The very low initial Sr^{87}/Sr^{86} ratios of the older granites (p. 12) suggests that any crustal history prior to final setting of this ratio must have been quite short. Oversby (1976), using lead isotopes, concluded that the primary age for migmatite from the Shaw Batholith is

3 070 ± 12 m.y. whereas the Rb/Sr age for the older granites of this unit is 2 889 ± 81 m.y. (de Laeter and others, 1975). Structural features preserved in the migmatites (Fig. 15) suggest that at some stage the migmatites acted like viscous fluids, indicating emplacement or at least remobilization as crystal mushes.

What is known of the older granites is consistent with their being original sialic crust, appreciably modified by later tectonic reworking and incorporation of material from the greenstone sequence; from isotopic evidence, original formation and reworking of the material took place within a comparatively short duration.

GRANITIC ROCKS IN THE VICINITY OF THE GREENBUSHES TIN FIELD

Granitic rocks exposed in the vicinity of the Greenbushes tin field can be conveniently divided into three broad groups—the Darling Range-Wheat Belt granites; granitic and feldspathic gneisses within the Balingup Metamorphic Belt; and small bodies of generally concordant pegmatitic granites and aplites intruding the Balingup Belt rocks.

In the following discussion these are termed Groups 1, 2 and 3 respectively for ease of reference.

PREVIOUS INVESTIGATIONS

Wilson (1958) included petrographic descriptions and chemical analyses of some Darling Range-Wheat Belt granites in his review of the geology of Precambrian rocks in southwestern Australia.

Samples of granitic and feldspathic gneisses from Greenbushes and Ferndale respectively were described by Miles (1949) and Chung (1957).

Age determinations on various granitic rocks in the Greenbushes area were summarized earlier (p. 65).

FIELD RELATIONSHIPS AND PETROGRAPHY

Darling Range-Wheat Belt granites (Group 1)

Samples of the Darling Range-Wheat Belt granite were collected from the area shown in Plate 6, and on a reconnaissance traverse from Greenbushes, through Wilga to Boyup Brook, then returning through Bridgetown. The samples represent only a small part of the large extent of the Darling Range-Wheat Belt granite. During the field work, a subdivision of the granitic rocks into massive, foliated and gneissic types was made. However, gradations between the three types were commonly seen, and geological boundaries were difficult to establish. Later petrographic and chemical studies showed texture to have little effect on the composition of the rock, and the only subdivision retained on Plate 6 is into biotite-bearing and hornblende-bearing varieties (Groups 1A and 1B). All but two of the rocks examined are in the compositional range of adamellite or granodiorite. Of the exceptions, one (26327) is a tonalite and the other (36328) is a potassic granite. Texturally, most of the rocks are massive or foliated granites, but three samples (26324, 26330 and 26342) are gneisses.

Biotite granites (Group 1A): Massive to foliated adamellites and granodiorites are represented by samples 26329, 26332, 26333, 26327, 26361 and 26362. They are grey, medium-grained to slightly porphyritic rocks composed essentially of quartz, plagioclase, microcline and biotite. Minor and accessory minerals include muscovite, epidote, opaques, apatite, sphene and rare monazite.

Plagioclase, ranging from oligoclase to sodic andesine is normally slightly altered to sericite and epidote. Biotite is pleochroic from pale yellow-green to deep green-brown, is partly replaced by muscovite, and is commonly associated with epidote. Microcline is typically clear, perthitic and encloses plagioclase, often with myrmekitic intergrowths at the contacts.

Texturally the rocks range from granitic to protoclastic, depending upon the extent of the superimposed foliation. The protoclastic fabric (Fig. 26A) takes the form of finely granular quartz-feldspar mosaics between grains. The more obviously foliated specimens have aligned biotite flakes and stretched quartz grains.

Tonalite is represented only by sample 26327 (Fig. 26B). It is a medium-grey foliated rock made up predominantly of quartz, plagioclase and biotite. Microcline occurs both as small rare phenocrysts and interstitially to the other minerals. Plagioclase has the composition of calcic oligoclase and is partly altered to sericite. Biotite is pleochroic from pale yellow-green to deep green-brown. Minor and accessory minerals include muscovite, sphene, epidote, apatite and opaque iron minerals.

The texture as seen in thin sections is protoclastic with a foliation picked out by aligned biotites and slightly stretched quartz and feldspar grains.

Potassic granite comprises only one of the samples examined (26328). It is a coarse, even-grained, equigranular leucocratic rock with the same suite of essential minerals noted in the adamellite and granodiorite, but with microcline present well in excess of plagioclase (Fig. 26C). The potash feldspar is perthitic and has myrmekitic intergrowths with plagioclase, which it commonly encloses. The plagioclase is poorly twinned but has the optic sign and refractive index of oligoclase. Accessory minerals include epidote, zircon and opaque oxides.

Granitic gneiss samples from the western edge of the Darling Range-Wheat Belt granite are of contrasting types. Specimen 26324 is a medium-grained gneiss in which irregular black biotite-rich streaks alternate with thin quartz-feldspar bands containing microcline augen, and thicker bands of pale foliated granodiorite/adamellite. Sample 26342 is finer grained than 26324 and its banding is less pronounced, being due to comparatively small variations of biotite content between adjacent layers. In thin section it consists of a granoblastic aggregate of quartz, oligoclase, microcline, biotite and epidote with banding picked out mainly by streaks of aligned biotite flakes. There are signs of a latter protoclastic texture superimposed on the granoblastic fabric of the rock.

Fine-grained gneiss (26330) from Boyup Brook has an even banding due to thin (1 to 3mm) leucocratic layers spaced at intervals of 1 to 2cm in otherwise fairly uniform but strongly foliated granodiorite (Fig. 26D). The rock could be a metasediment but its composition is similar to that of other granodiorites of obvious igneous aspect.

Hornblende granites (Group 1B): Hornblende adamellite (26340) is a pink, granitic-textured rock with well-formed feldspar crystals and greenish-black grains and clots of ferromagnesian minerals. It consists essentially of plagioclase, microcline, quartz and amphibole with minor sphene and epidote and accessory magnetite, clinozoisite and apatite. The hornblende is strongly pleochroic from olive-green to colourless, and is altered to epidote at its margins. The epidote in turn is rimmed by clinozoisite. Perthitic microcline and plagioclase occur in about equal proportions. They have myrmekitic intergrowths where in mutual contact and the plagioclase has clear, well-twinned borders around poorly twinned, altered cores. The composition of the plagioclase is about calcic oligoclase. No biotite is present in the thin section.

Specimens 26338 and 26341 are generally similar to 26340, but have a lineation defined by oriented amphibole prisms.

Granitic and feldspathic gneisses (Group 2)

Granitic gneiss (Group 2A): The most common variety of granitic gneiss within the Balingup Metamorphic

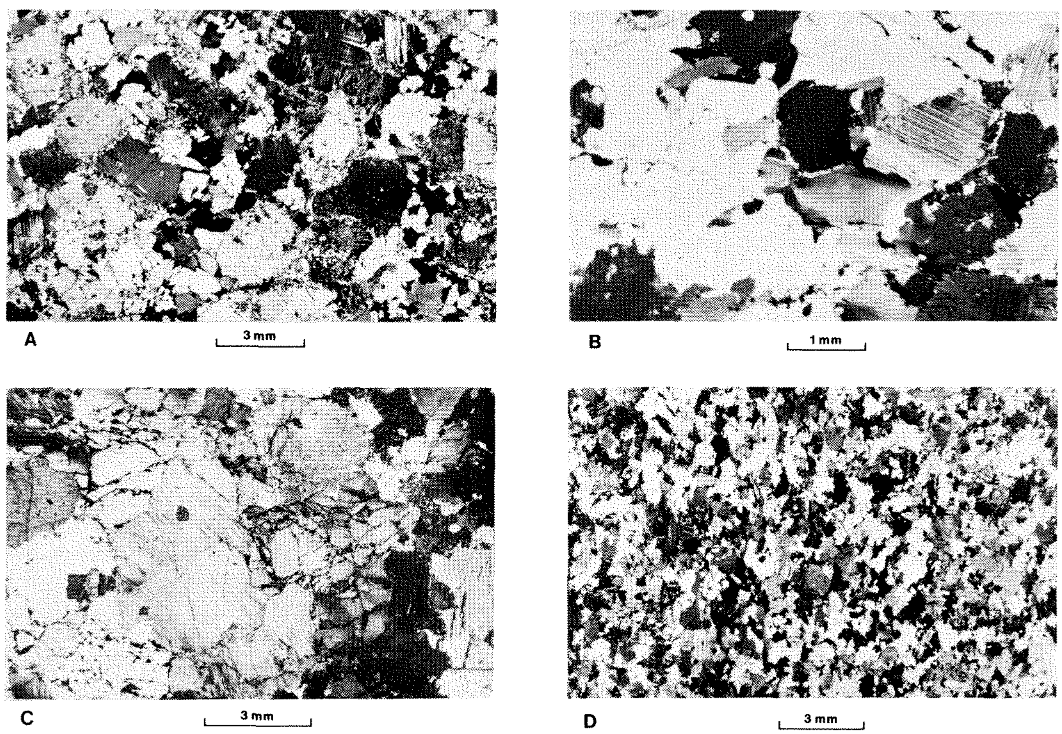


Figure 26. Photomicrographs of typical Darling Range-Wheat Belt granites.
A. *Protoclastic-textured adamellite/granodiorite* (26362).
B. Biotite tonalite (26327).
C. Potassic granite (26328).
D. *Fine-grained gneissic granite* (26330).
(All viewed through crossed nicols)

Belt is well exposed in cuttings on the Southwestern Highway, about 9km south of Greenbushes. It is a grey massive rock with gneissic structures picked out by thin leucocratic bands in an otherwise rather uniform granulose matrix. A foliation marked by aligned biotite flakes crosses the banding at a low angle. Pegmatite veins cutting the gneiss are ptygmatically folded. Microscopically, the rock (26357, Fig. 27A) consists of cataclastic-textured aggregates of quartz, oligoclase, microcline, biotite, epidote and rare fluorite and garnet. A weak banding due to variations in biotite content is evident but the main direction of deformation marked by lines of biotite and stretched quartz and feldspar grains is at about 25° to the banding. Accessory molybdenite is present in a sample from the same locality now in the collection of the Government Chemical Laboratories.

Feldspathic gneisses (Group 2B): Feldspathic gneisses (26344 and 26346) are more common in the valley of Balingup Brook. They differ from the granitic gneiss mainly in having a much higher proportion of leucocratic, often pegmatitic, bands which penetrate and disrupt the foliation of the rock. They are associated with fine-banded granite gneiss (26347) and augen gneiss (26345) in which eyes of microcline are set in a granitic matrix containing more biotite than usual. Another biotite-rich variety (2/2670) is described by Miles (1949).

Minor granitic rocks within the Balingup Metamorphic Belt (Group 3)

Pegmatitic and foliated granites (Group 3A): Pegmatitic granitic rocks form many concordant lenses (Fig. 27B) and a few stocks within the metamorphic rocks of the Balingup Belt. They vary greatly in texture and composition, but the most common type is a pink, coarse-grained to pegmatitic microcline granite, grading in places to graphic granite. The least deformed specimens (e.g.26349, 26352) are composed mainly of quartz, microcline, muscovite and/or biotite

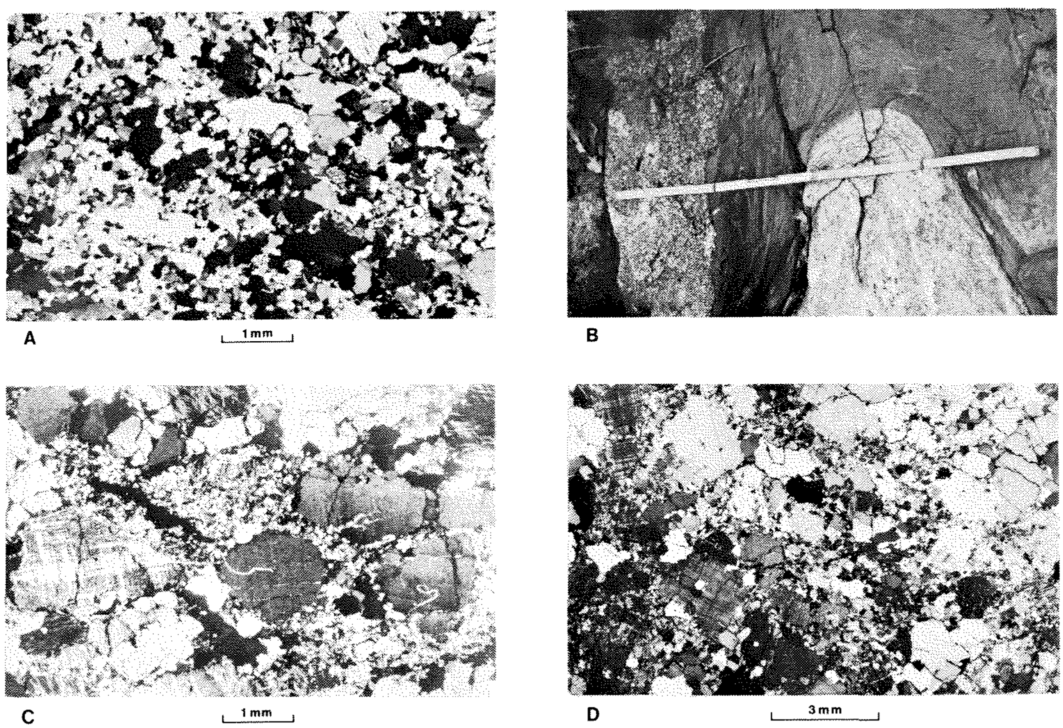


Figure 27. Photographs of granitic rocks from the Balingup Metamorphic Belt.

A. Photomicrograph of granitic gneiss (26357).

B. Concordant pegmatitic granite disrupted by later folding to form a series of en echelon lenses with foliation parallel to that in the enclosing granofels. Scale is 914 mm (36 inches) long and graduated in inches.

C. Photomicrograph of pegmatitic granite (26349).

D. Photomicrograph of granitic dyke rock (26373)

(All photomicrographs viewed through crossed nicols)

with plagioclase and accessory garnet (Fig. 27C). Plagioclase, which is subordinate to microcline, is poorly twinned and partly altered to sericite. Its composition is sodic. Microcline is perthitic and has reaction zones with adjoining plagioclase. Biotite is partly altered to stilpnomelane.

Even the least deformed pegmatitic granites show signs of cataclasis, marked by strained quartz and granulated aggregates of fine-grained quartz and feldspar at grain boundaries. Increased deformation of the pegmatitic granites has produced strongly foliated, cataclastic-textured rocks in which remnant quartz and feldspar grains are drawn out into eyes separated by a partly recrystallized quartz-feldspar mosaic and anastomosing streaks of muscovite (e.g.26363).

Although most of the pegmatitic granites are microcline-rich, some lenses have plagioclase equal to or greater than potash feldspar. An extreme example is 26371 which consists mainly of quartz and poorly twinned oligoclase with muscovite and only a minor amount of microcline. It is associated in the field with a tonalite gneiss.

Dyke rocks (Group 3B): A very few dykes of aplite were noted during the reconnaissance mapping. One (26373, Fig. 27D), immediately downstream from the dam on Cowan Brook is a pink, slightly porphyritic rock with a weak foliation. It consists of essential quartz, perthitic microcline and plagioclase, minor muscovite and biotite, and accessory garnet. The rock has a protoclastic texture and possibly the fine-grained groundmass is partly of cataclastic origin.

Another dyke exposed in a road cutting near Balingup (26384, 26385) is of similar composition but is more strongly foliated and generally coarser grained. One dyke of coarse pegmatitic granite comprises a coarse-grained protoclastic-textured aggregate of quartz, albite and microcline with minor muscovite.

CHEMISTRY

Material analyzed

In an attempt to identify granites which may have been the ultimate source of the Greenbushes tin deposits, 55 samples of granitic rocks (including some obvious gneisses) collected during the survey were analysed chemically in full or in part. Analyses of Groups 1, 2 and 3 are given in Tables 58 (22 analyses), 59 (11 analyses), and 60 (22 analyses) respectively and C.I.P.W. norms, Niggli values and Differentiation Indices of fully analysed samples are set out in Table 61.

TABLE 58. CHEMICAL ANALYSES OF DARLING RANGE–WHEAT BELT GRANITES (GROUP 1), GREENBUSHES AREA

	Biotite-bearing granitic rocks (Group 1A)																		Hornblende adamellite (Group 1B)		
GSWA No.	26327	26336	26333	26334	26330	26335	26325	26342	26337	26326	26324	26362	26329	26322	26361	26332	26331	26328	Average Group 1A	26340	26338	26341
OXIDES (%)																						
SiO_2	70.7							72.9	73.0			74.1	74.1	71.2	72.3	75.6		74.8	73.2			
Al_2O_3	14.3							14.2	14.5			14.1	14.2	14.3	14.8	13.2		13.1	14.1			
Fe_2O_3	1.27							.93	.60			1.16	1.02	1.01	1.96	1.28		.51	1.1			
FeO	2.41							.97	1.04			.68	1.11	2.12	.65	1.04		.47	1.1			
$\sum FeO$	3.55	1.55	2.60	1.55	1.95	1.55	2.65	1.81	1.58	3.10	3.65	1.72	2.03	3.03	2.41	2.19	2.60	.93	2.2(1)	3.40	1.95	2.25
MgO	1.30	.35	.53	.30	.49	.29	.26	.47	.55	.60	.55	.36	.28	.60	.43	.48	.43	.17	.5(1)	.85	.26	.60
CaO	3.30	1.85	2.09	1.64	1.80	1.65	1.38	1.73	2.09	2.60	2.35	1.48	2.34	2.21	1.81	1.30	1.95	1.09	1.9(1)	3.17	1.94	2.60
Na_2O	4.42	4.30	4.20	4.20	4.00	3.80	3.00	4.20	4.06	4.20	3.40	4.25	3.70	3.68	4.10	3.90	3.05	3.10	3.9(1)	4.15	4.35	4.10
K_2O	1.57	2.60	2.80	3.10	3.10	3.00	2.40	3.49	3.59	3.70	3.10	3.92	3.52	3.79	4.77	4.45	4.30	5.84	3.5(1)	5.25	5.40	5.20
Loss	.63							.66	.56			.42	.46	.83	.46	.64		.27	.55			
TiO_2	40							.21	.18			.21	.19	.37	.29	.21		.08	.24			
P_2O_5	.06							.00	.00			.01	.05	.08	.03	.03		.01	.03			
MnO	.04							.02	.01			.01	.02	.03	.03	.03		.01	.02			
Total	100.4							99.7	100.2			100.7	101.0	100.0	101.6	102.2		99.5				
TRACE ELEMENTS (ppm)																						
Li	15	8	21	13	11	11	8	11	5	8	13	14	3	12	11	9	8	4	10(1)	5	1	4
Cu	8							7	6			7	10	7	18	9		9	10			
Zn	88							58	50			54	56	70	61	52		30	60			
Rb	5(2)	110	110	110	130	130	95	150	100	90	135	115	115	130	100	185	100	165	120(1)	110	120	110
Sr	290	255	240	500	130	300	160	210	190	1080(2)	140	205	310	160	570	165	165	180	240(1)	970	1 000	1 100
Sn	<3	<3	4	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	3	<3	<3	<3	<3(1)	<3	3	<3
Th	27							23	65			42	22	60	9	28		25	30			
RATIOS																						
K_2O/Na_2O	.36	.60	.67	.74	.88	.79	.80	.83	.88	.88	.91	.92	.95	1.03	1.14	1.14	1.14	1.88		1.21	1.24	1.27
K/Rb	2600	195	210	235	200	190	210	193	298	340	190	283	253	214	396	199	355	293		295	375	390
Rb/Sr	.02	.4	.45	.2	1.0	.4	.6	.7	.5	.1	1.0	.6	.4	.8	.2	1.1	.6	.9		.1	.1	.1

(1) Includes all analyses except those marked (2)

(2) Omitted from average

TABLE 59. CHEMICAL ANALYSES OF GRANITIC AND FELDSPATHIC GNEISSES (GROUP 2), GREENBUSHES AREA .

	Granitic gneiss (Group 2A)								Feldspathic gneiss (Group 2B)		
GSWA No.	26347	26345	26346	26368	26357	26339	26375	26367	26370	26343	26344
					OXIDES (%)						
SiO_2					75.9		75.8				
Al_2O_3					12.2		13.4				
Fe_2O_3					.80		1.02				
FeO					1.76		1.81				
ΣFeO	1.08	2.05	1.02	2.70	2.56	2.40	2.65	1.30	.41	.62	1.08
MgO	.37	.48	.26	.16	.20	.16	.11	.30	.08	.07	.10
CaO	2.23	2.04	1.81	1.18	1.44	1.22	1.33	1.15	.62	.62	1.01
Na_2O	4.35	4.00	4.30	3.50	4.00	3.55	3.70	3.45	3.85	3.10	3.10
K_2O	2.40	2.70	3.15	3.30	3.63	3.35	3.95	3.90	.75	4.60	4.90
Loss					.27		.56				
TiO_2					.19		.20				
P_2O_5					.04		.03				
MnO					.04		.04				
Total					100.5		101.9				
					TRACE ELEMENTS (ppm)						
Li	13	24	15	11	18	15	15	7	2	2	4
Rb	75	150	100	130	160	130	165	165	25	155	170
Sr	445	220	310	70	100	55	95	100	60	60	40
Sn	<3	<3	<3	4	<3	<3	<3	<3	<3	<3	<3
					(1)		(2)				
					RATIOS						
K_2O/Na_2O	.55	.67	.73	.86	.92	.94	1.07	1.13	.19	1.48	1.58
K/Rb	265	150	260	210	188	215	198	195	250	245	240
Rb/Sr	.2	.7	.3	1.9	1.6	2.3	1.7	1.6	0.6	2.6	4.2

(1) Also 7 ppm Cu, 69 ppm Zn, 30 ppm Th

(2) Also 10 ppm Cu, 105 ppm Zn, 30 ppm Th

TABLE 60. CHEMICAL ANALYSES OF MINOR GRANITES IN THE BALINGUP METAMORPHIC BELT NEAR GREENBUSHES (GROUP 3)

	Pegmatitic and foliated granites in mainly concordant bodies (Group 3A)								Granite and aplite dykes (Group 3B)			Pegmatite dykes (Group 3C)		
GSWA No.	26371	26354	26353	26363	26355	26359	26352	26349	26384	26385	26373	26321	26369	26387
						OXIDES (%)								
SiO_2	76.8	77.0		73.8		77.2	74.0	74.9	77.7	75.1	77.5	74.0		75.1
Al_2O_3	12.4	14.4		14.0		13.2	13.8	13.9	12.7	13.9	12.5	16.0		12.7
Fe_2O_3	.56	.46		.50		.42	.51	.51	.27	.53	.35	.18		1.13
FeO	.25	.22		.25		.29	.43	.58	.07	.47	.55	.07		2.08
ΣFeO	.75	.63	.70	.70	.39	.67	.89	1.04	.31	.95	.86	.23	.47	3.10
MgO	.21	.14	.04	.12	.07	.09	.02	.24	.04	.03	.10	.03	.13	1.03
CaO	2.11	.19	1.04	1.12	.93	.79	.55	.87	.71	.64	.90	.27	.16	1.44
Na_2O	4.60	4.90	4.15	4.10	4.35	3.65	3.00	2.55	4.30	4.05	2.64	7.30	3.00	3.75
K_2O	.88	1.89	3.10	3.38	3.90	5.25	7.26	7.24	4.24	4.31	5.52	.28	3.00	2.57
Loss	.50	1.07		.73		.36	.51	.61	.37	.53	.46	.26		.68
TiO_2	.07	.01		.00		.03	.00	.10	.01	.00	.02	.00		.28
P_2O_5	.00	.07		.03		.10	.04	.01	.00	.00	.02	.22		.02
MnO	.00	.1		.01		.00	.03	.02	.00	.04	.03	.01		.02
Total	98.4	100.4		98.1		101.4	100.2	101.5	100.5	99.6	100.5	98.6		100.7
						TRACE ELEMENTS (ppm)								
Li	7	11	30	6	8	2	13	25	15	13	19	165	54	33
Cu	7	5		11		7	5	13	6	7	3	8		7
Zn	28	22		18		19	22	34	22	31	16	30		75
Rb	15	45	200	55	95	135	325	160	175	160	180	155	1460	130
Sr	125	10	25	75	60	65	25	165	35	40	70	20	10	40
Sn	<3	5	<3	<3	<3	<3	<3	<3	<3	3	<3	22	<3	4
Th	6	48		12		24	8	82	9	11	26	4		23
						RATIOS								
K_2O/Na_2O	.19	.38	.75	.82	.90	1.44	2.42	2.84	.99	1.06	2.09	0.4	1.0	.68
K/Rb	486	349	130	510	340	322	185	375	201	224	254	15	17	164
Rb/Sr	.1	4.5	.8	.7	1.6	2.1	13	1.0	5.0	4.0	2.6	7.7	146	2.6

TABLE 61. C.I.P.W. NORMS, NIGGLI VALUES AND DIFFERENTIATION INDICES OF GRANITES FROM THE GREENBUSHES AREA

	Group 1A									Group 2A		Group 3A						Group 3B			Group 3C	
GSWA No.	26327	26342	26337	26362	26329	26322	26361	·26332	26328	26357	26375	26371	26354	26363	26359	26352	26349	26384	26385	26378	26321	26387
										C.I.P.W. NORMS												
Q	29.1	30.3	29.9	30.7	33.4	28.8	25.9	32.4	31.8	34.8	35.2	41.8	40.8	34.5	34.2	27.5	29.9	35.0	33.4	38.6	30.3	37.7
C		.3	.1	.2	.2	.2					.7	.1	4.2	1.7	.4	.1	.3		1.4	.5	3.6	1.2
Or	9.3	20.6	21.2	23.2	20.8	22.4	28.2	26.3	34.5	21.4	23.4	5.2	11.2	20.0	31.0	42.9	42.8	25.0	25.4	32.6	1.7	15.2
Ab	37.4	35.5	34.3	35.9	31.3	31.1	34.7	33.0	26.2	33.8	31.3	38.9	41.4	34.7	30.9	25.4	21.6	36.4	34.3	22.3	61.8	31.7
An	14.6	8.6	10.4	7.3	11.3	10.4	8.0	5.6	4.6	4.7	6.3	10.5	.4	5.3	3.2	2.5	4.2	3.0	3.2	4.3		7.0
Di	1.1						.6	.5	.6	1.8								.2	.5			
Hy	5.5	1.9	2.5	.9	1.6	4.0	.8	1.5	.4	1.9	2.5	.5	.4	.3	.4	.5	1.1		.6	1.0	.1	5.0
Mt	1.8	1.3	.9	1.6	1.5	1.5	1.4	1.8	.7	1.2	1.5	.6	.7	.7	.6	.7	.7	.2	.8	.5	.2	1.6
Il	.8	.4	.3	.4	.4	.7	.5	.4	.1	.3	.4	.1			.1		.2					.5
Ap	.1				.1	.2	.1	.1		.3	.1		.2	.1	.2	.1					.5	
Hm												.1						.1				
										NIGGLI VALUES												
al	38.0	44.5	44.6	44.9	44.5	41.5	42.9	42.4	46.4	41.6	44.1	47.1	55.2	50.5	48.1	47.7	46.9	48.5	49.9	48.1	54.7	40.5
fm	22.2	11.9	11.2	10.7	11.3	17.1	13.2	14.0	6.2	13.8	13.8	6.1	4.8	4.7	4.3	4.7	7.1	2.1	5.3	5.9	1.4	22.5
c	15.9	9.9	11.7	8.6	13.3	11.7	9.5	7.6	7.0	8.9	7.9	14.5	1.3	7.3	5.2	3.4	5.3	4.9	4.2	6.3	1.7	8.4
alk	23.8	33.6	32.5	35.8	30.9	29.8	34.4	35.9	40.4	35.7	34.1	32.3	38.6	37.4	42.4	44.1	40.6	44.4	40.6	39.8	42.2	28.6
si	318	389	382	400	393	351	354	411	449	437	423	494	499	451	476	433	429	503	457	507	430	407
k	.18	.35	.36	.37	.38	.40	.42	.42	.55	.37	.41	.11	.20	.35	.48	.61	.65	.39	.41	.57	.02	.31
mg	.48	.45	.48	.48	.30	.26	.52	.44	.38	.16	.09	.59	.52	.45	.35	.07	.40	.50	.09	.23	.40	.46
q	123	155	152	157	169	132	117	167	187	194	187	265	245	201	206	157	167	225	194	248	161	193
										DIFFERENTIATION INDICES												
D.I.	76.0	87.4	85.6	89.6	85.0	82.9	88.6	90.2	93.5	90.0	88.6	87.8	94.0	91.7	95.1	96.1	93.5	96.5	93.5	93.7	95.5	84.7

Major components

Silica: Contents of silica in all fully analyzed samples exceed 70 per cent, and are consistently higher than mineralogically similar average granites (Nockolds, 1954). The lowest value, 70.6 per cent, was found in a tonalite, and the highest, 77.5 per cent, in a pegmatitic granite. The relatively high silica contents of Group 1A granites corresponds to those noted in similar Archaean granitic terrains of the Pilbara Block and elsewhere. The even higher silica contents in Group 3 granites from the Balingup Belt probably reflect the mainly pegmatitic character of these rocks. The different silica contents are brought out clearly in a Harker diagram using Niggli values (Fig. 28).

Lime-alkali ratios: Plotted on a $K_2O : Na_2O : CaO$ diagram, most samples of granites from the Greenbushes area lie on the alkali side of Nockolds' averages (Fig. 29), indicating the rocks to be comparatively lime-poor.

$K_2O : Na_2O$ ratios of all but two of the Darling Range-Wheat Belt granites (Group 1) fall in the range 0.6 to 1.5, confirming their petrographic determinations as adamellite or granodiorite. The two exceptions are the tonalite (26327) and potassic granite (26328) referred to previously. Most samples of granitic gneiss (Group 2A) from the Balingup Metamorphic Belt have $K_2O : Na_2O$ ratios in the granodiorite/adamellite range, but two feldspathic gneisses have appreciably more potash and one is distinctly soda-rich. The lime-alkali ratios of most granitic gniess (Group 2A) samples fall in the same field as those of the granites, but cluster on the lime-poor side of that field.

Group 3 granites fall into two distinct fields, although further samples may possibly close the intervening gap. One field corresponds to potassic granites and the other to granodiorites. Of two exceptional samples, one is soda-rich and the other lime-poor.

There appears to be almost complete separation between the fields of Groups 2 and 3, suggesting that the two groups of rocks are unrelated.

The hornblende-bearing members of the Darling Range-Wheat Belt granite (Group 1A) have higher total lime and alkalis than the biotite granites, but the ratios of these components are similar in both varieties.

Iron and magnesium oxides: The contents of $\sum FeO + MgO$ are lower in granites from the Greenbushes area than in comparable "average" granites. In a plot of $\sum FeO + MgO : CaO : Na_2O + K_2O$ (Fig. 30) all granites are displaced away from the femic corner with respect to their "average" counterparts.

Group 3 granites have appreciably less iron oxide and magnesia than those of Group 1 and cluster in a different part of the triangular plot. Most of the granitic gneisses from the Balingup Metamorphic Belt fall into the same field as Group 1 granites, but some of the more feldspathic varieties cluster with the granites of Group 3.

Titania: Contents of titania in the Darling Range-Wheat Belt granites are similar to those of the granite gneisses in the Balingup Metamorphic Belt, but appreciably greater than those found in granites of Group 3.

Trace components

Lithium: Contents of this element in all granitic rocks except pegmatites are lower than the published World averages (Table 39). Mean values are 10 ppm Li in Group 1, 13 ppm Li in Group 2A, 16 ppm Li in Group 2B and 11 ppm Li in the coarse-grained gneisses. The lowest lithium contents appear in hornblende adamellite.

Rubidium; Contents of rubidium are variable in all groups of granites. Mean values of 120 ppm Rb in Group 1, 130 ppm Rb in Group 2, 150 ppm Rb in Group 3A, and 170 ppm Rb in Group 3B are comparable to average granites (Table 39).

The one sample of albite-rich pegmatite from Greenbushes analyzed during this investigation contained only 155 ppm Rb. However, six samples reported on by Koon (1973) had from 730 to 8 600 ppm Rb. The sample of Ferndale pegmatite contains 1 460 ppm Rb.

K/Rb ratios of the granitic rocks lie mainly between 200 and 300, with the lowest value of 130 in a Group 3 granite. Ratios suggesting marked magmatic fractionation are present only in the mineralized pegmatites (Fig. 31). Koon's values of K/Rb ranging from 4 to 9 have been mentioned earlier.

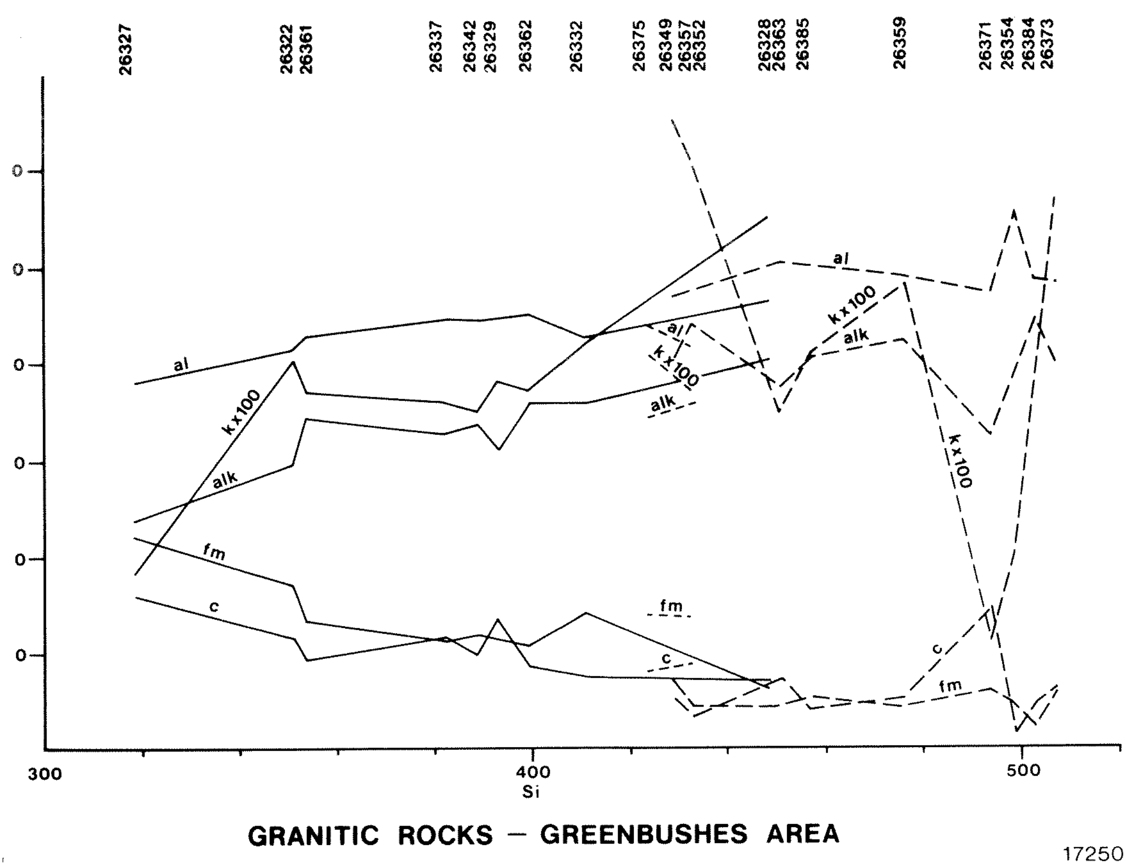


Figure 28. Plot of Niggli values for granitic rocks from the Greenbushes area. Solid line = Darling Range-Wheat Belt granites (Group 1); short-dashed lines =granitic gneisses from Balingup Metamorphic Belt (Group 2); and longer dashed lines =pegmatite granites from the Balingup Belt (Group 3)

Strontium: Contents of strontium are highest (mean 1 170 ppm Sr) in hornblende adamellite and lowest (mean 60 ppm Sr) in Group 3 granites. Rb/Sr ratios are low (range 0.1 to 1.1) in Group 1 granites but become greater (range 0.1 to 13) in some Group 3 rocks, and are highest in the Ferndale pegmatite (146).

DISCUSSION

Origin of the granitic rocks

The origins of most groups of granitic rocks sampled near Greenbushes are best considered in relation to a triangular plot of lime and alkalis (Fig. 29) and normative quartz, orthoclase and albite (Fig. 32).

Figure 32 also shows the cotectic line at 100 MPa pressure, the positions of the minimum temperature melts at 100 and 200MPa and the field of greatest concentration of 1 190 felsic rocks after Winkler (1967, Fig. 50).

The biotite granodiorites and adamellites of Group 1A plot close to the 100 MPa and 200 MPa minima. However, if allowance is made for the effect of anorthite shifting the minimum melting point towards the Q-Or side of the graph (Winkler 1967, Fig.

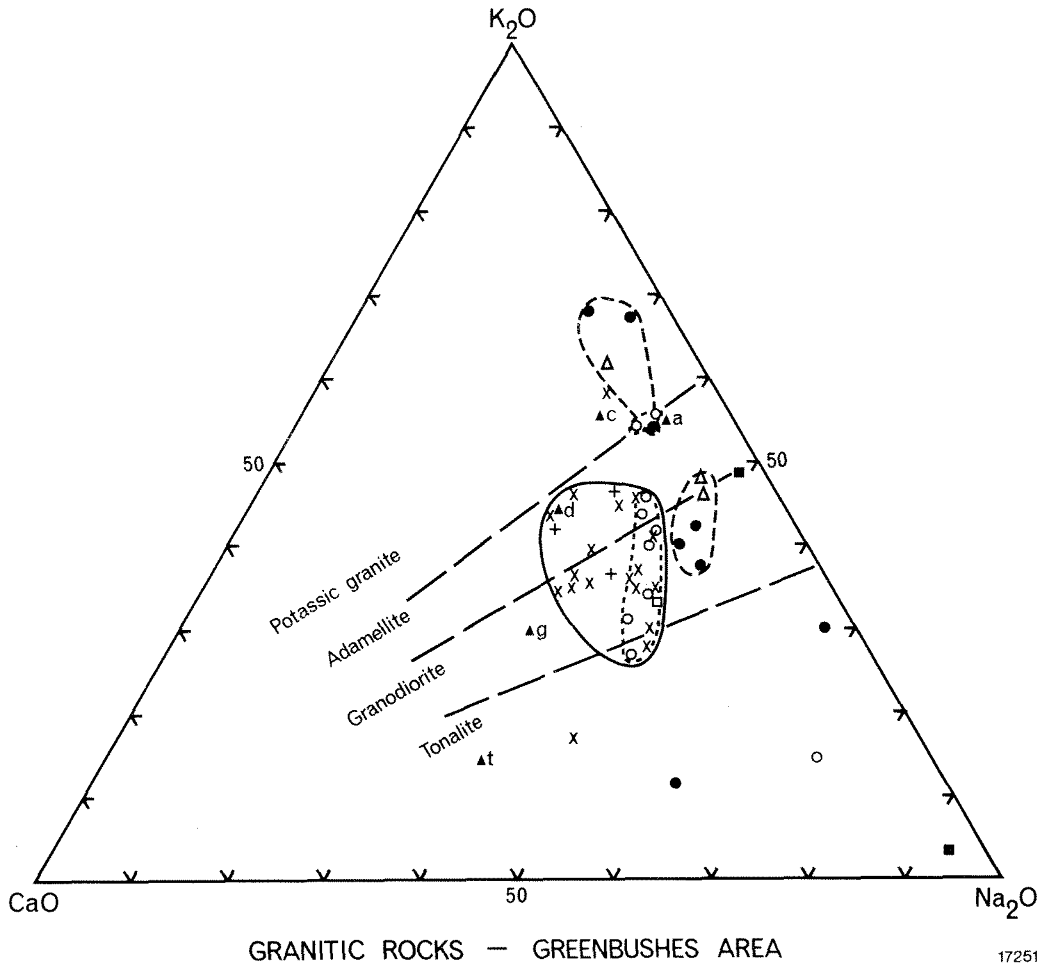


Figure 29. Triangular plot of K_2O : CaO : Na_2O for granitic rocks from the Greenbushes area. Upright crosses =hornblende granites; open circles = granitic and feldspathic gneisses; filled circles = pegmatitic granites; diagonal crosses = Darling Range-Wheat Belt biotite granites; open triangles = granitic dykes; open square = pegmatites (unmineralized); filled squares=pegmatites (mineralized). Solid triangles are Nockolds' average granites, and fields showing varieties of granite are from Harpum (see Figs. 20 and 21 for details). Fields of Group 1, 2 and 3 granites are shown by solid, short-dashed and long-dashed lines respectively

47) then the actual pressure during crystallization of the magma must have been appreciably greater than 200MPa.

Some probable differentiation during crystallization is indicated by samples 26327 and 26328 which lie outside the main field. The average composition of these samples is near that of the whole group, and they could have been produced from the typical rock by some mechanism, such as filter pressing, capable of segregating a plagioclase-rich crystal aggregate from a potash-rich melt at some intermediate stage during crystallization.

Most samples of Group 1A granites closely approach minimum temperature melts, and their uniform composition, over a sampled area of 500km^2, strongly suggests that the rocks are of magmatic origin.

A magmatic origin is also suggested for the hornblende adamellite, although the evidence is less clear. They appear to be part of the same complex as Group 1A granites, and have a similar composition to bodies of hornblende granite of undoubted intrusive origin mapped further to the east (Wilde and Walker, 1979).

Most granitic gneisses in Group 2A have a composition near that of the more alkali-rich members of Group 1A (see Figs 29 and 30). Two samples plotted on Figure 32 fall close to the composition of minimum temperature melts. These chemical features, together

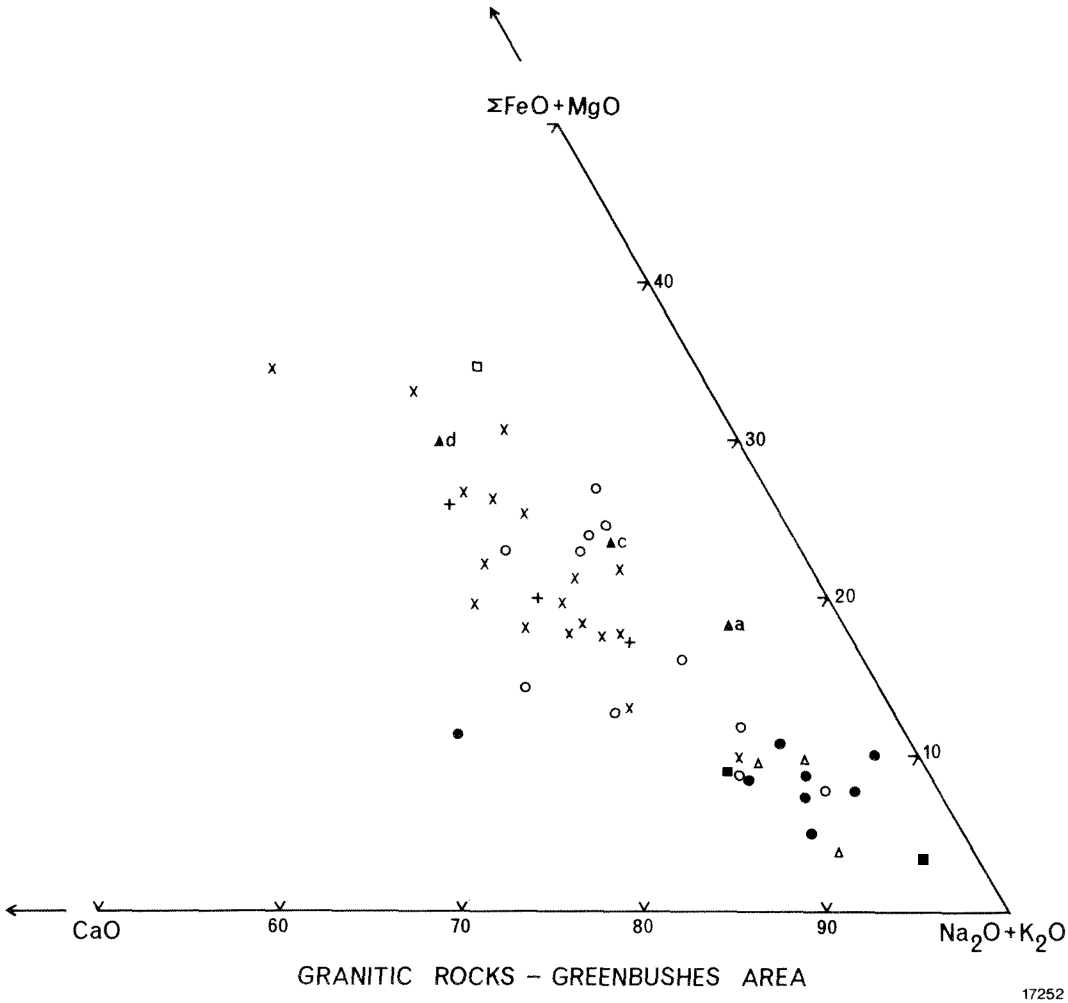


Figure 30. Portion of triangular plot of $\sum FeO + MgO : CaO : Na_2O + K_2O$ for granitic rocks from the Greenbushes area. Symbols are as in Figure 29

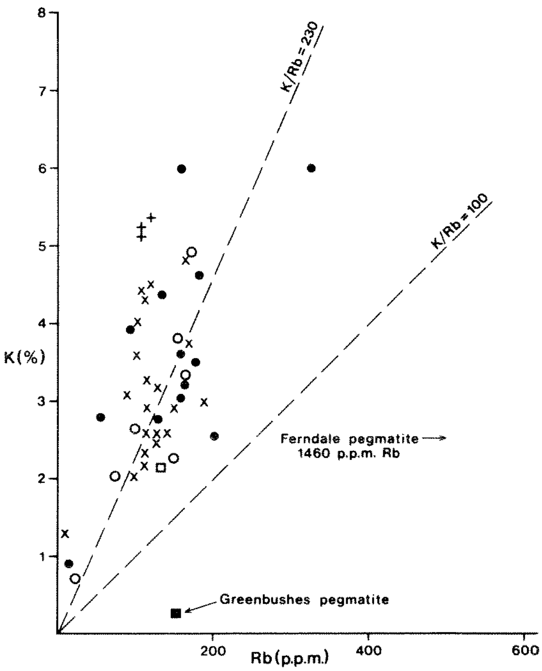


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Figure 31. Plot of K against Rb for granitic rocks from the Greenbushes area. Diagonal crosses = Darling Range-Wheat Belt granites; upright crosses = hornblende granites (Group 1); open circles = coarse-grained gneisses from the Balingup Metamorphic Belt (Group 2); filled circles = pegmatitic granites from the Balingup Belt (Group 3); filled square = mineralized pegmatite; and open square = unmineralized pegmatite. Dashed lines represent K/Rb of 230 and as indicated

with the general lack of relic sedimentary features, suggest that they are orthogneisses formed from igneous rocks (flows or sills?) related to the Darling Range-Wheat Belt granite.

No full analyses are available for the feldspathic gneisses (Group 2B). Partial analyses show a range in composition from tonalite to alkalic granite. From their field relationships these rocks are thought to be metamorphosed, possibly feldspathized, arkoses.

Group 3 rocks show a marked contrast in their normative Q-Or-Ab ratios. The dyke rocks of Group 3B all fall close to the 100 MPa cotectic line, a feature consistent with an igneous origin. However, Group 3A rocks, which were interpreted in the field as granite/pegmatite segregations formed during metamorphism, lie mainly some distance from the low temperature part of the normative quartz-albite-orthoclase diagram. Their distribution, on a line passing through the lowest temperature field towards the orthoclase corner of the plot, cannot be explained by experimental results on silicate melts (e.g. Winkler, 1967,

TABLE 62. COMPARISON BETWEEN GRANITIC ROCKS FROM THE GREENBUSHES AREA AND TYPICAL TIN GRANITES

FEATURE	TYPICAL TIN GRANITE	GROUP 1A	GROUP 1B	GROUP 2A	GROUP 2B	GROUP 3A	GROUP 3B
Emplacement relative to tectonism	Late or post-tectonic	Probably syntectonic	Probably syntectonic	Early or pretectonic	Probably metasediments	Syntectonic	Late tectonic
Texture	Massive	Massive to gneissic	Massive to gneissic	Gneissic	Gneissic	Foliated	Massive to foliated
Main ferromagnesian minerals	Biotite and/or mucovite—not hornblende	Biotite or biotite-muscovite	Hornblende	Biotite-muscovite	Biotite-muscovite	Muscovite-biotite	Muscovite-biotite
Diagnostic accessory minerals	Fluorite, tourmaline, topaz. Sphene is typically absent	Sphene present	Sphene present	Sphene present. Rare fluorite		No diagnostic accessories	No diagnostic accessories
SiO_2 content	+70%	70-76% (Av. 73%)	Probably 70%	+75%	Probably +70%	74-77%	75-78%
K_2O/Na_2O ratio	Usually >1	.36-1.88 (Av. 0.9)	1.2-1.3	0.5-1.1 (Av. 0.9)	0.2-1.6	0.2-2.8	1.0-2.1
$NaO+K_2O/CaO+MgO$	Usually >5	1.3-4.4	2.3-4.4	2.6-5.5	6.6-11.1	2.4-20.6	8.2-12.5
Differentiation Index	Range 88-95	75-93 (Av. 86)		88-90		88-96	93.5-96.5
Li content	30-500 (Usually >100)	3-21 (Av. 10)	1—5	7-24 (Av. 17)	2-4	2-30 (Av. 13)	13-19
Rb content	330-1 000	90-185* (Av. 120)	110-120	75-165 (Av. 135)	25-170	15-325 (Av. 130)	160-180
Sn content	5-150 (Usually 10-20)	<3-4 (Av. <3)	≮3	<3-4 (Av. 3)	<3	<3-5 (Av. <3)	≮3
K/Rb ratio	40-140 (commonly <100)	190-400*	3.75-400	150-265	240-250	130-510	200-255
Rb/Sr ratio	Usually>5	0.1*-1.1	0.1	0.2-2.3	0.6-4.2	0.1-13	2.6-5.0

*Excludes one exceptional sample

Fig. 51) and is therefore inconsistent with the rocks being formed simply by mobilization of eutectic fractions during metamorphism.

The samples analyzed were chosen to represent as wide a range of compositions as possible but those lying on the orthoclase side of the low temperature field are considered to be typical of the majority of exposures, that is, most rocks of this group are considered to be enriched in potash. Eskola (1957) discussed the origin of potash-rich granites in metamorphic terrains in Finland: and other examples of such granites, with alkali ratios differing appreciably from the minimum melt composition, are cited by Mehnert (1968, p.148-157). Both authors concluded that alkali metasomatism has been a factor in determining the final composition of such rocks, which seem to be characteristic of metamorphic terrains and not necessarily related to intrusion of magmatic granite.

Identity of the tin granites—the unresolved problem

Table 62 sets out a comparison between the various groups of granitic rocks exposed near Greenbushes and typical tin granites described earlier in this chapter. Although all groups, except 1B, have members

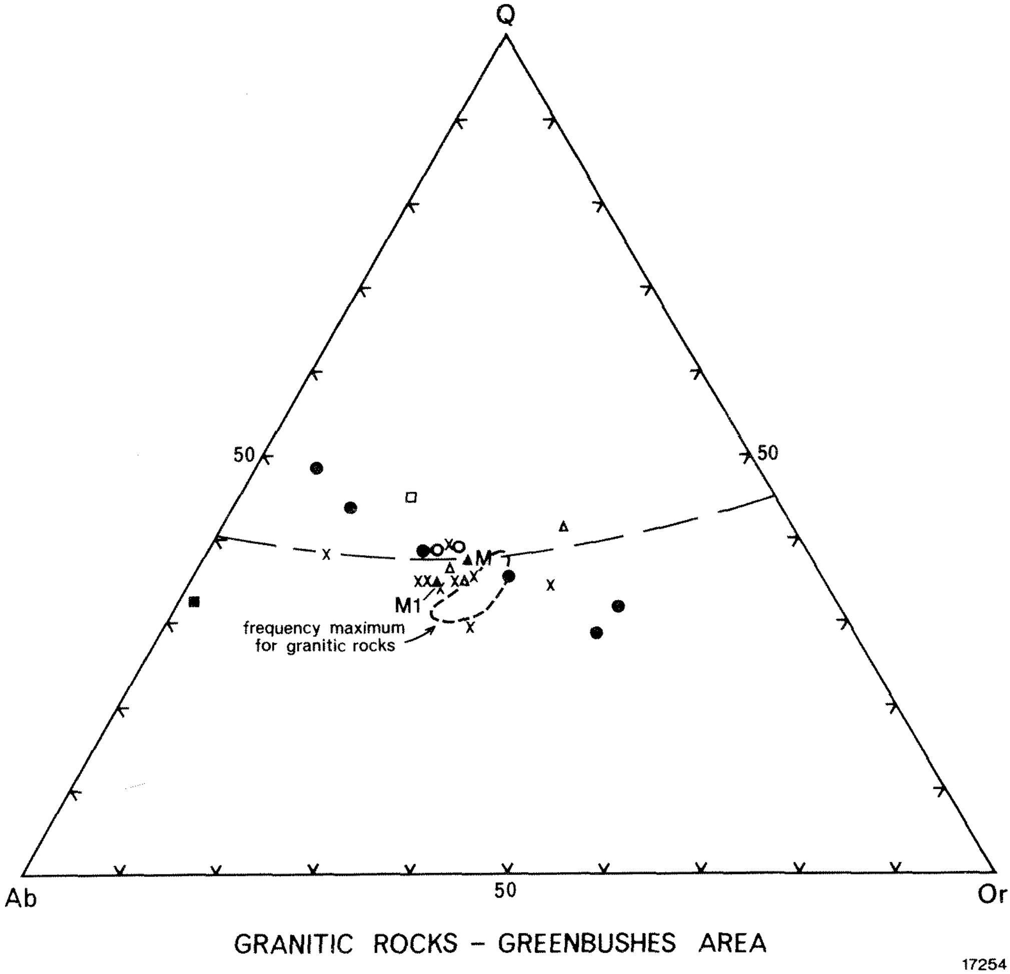

Figure 32. Triangular plot of normative quartz:orthoclase:albite for granite rocks from the Greenbushes area. Diagonal crosses=Darling Range-Wheat Belt granites; open circles=granitic gneisses from the Balingup Metamorphic Belt; filled circles=conformable pegmatitic granites from the Balingup Belt; open triangles=minor granitic dykes; open square=unmineralized pegmatite; filled square=mineralized pegmatite. The dashed line is the 100 MPa cotectic; triangles marked M and MI are the 100 and 200 MPa minimum melt compositions.

(Data from various sources collated by Mehnert (1968) and Winkler (1967)) with mineralogy and/or major oxide chemistry compatible with tin granites, none has comparable contents of Li, Rb, or Sn nor the typically low K/Rb ratio of mineralizing granites.

The only exposed body of granite which seems large enough to have produced the volume of tin-bearing pegmatites at Greenbushes is the Darling Range-Wheat Belt batholith. Although this body contains the least fractionated granites of the area, it is of similar age to the tin-bearing pegmatites (p. 65) and may possibly have more differentiated apophyses which were not located during the sampling programme.

While it is possible that some of the gneisses and granites of Groups 2 and 3 are of comparable age to the tin pegmatites, their low contents of Li, Rb, and Sn, and their small total volume, make them unlikely progenitors of the tin lodes.

From the results obtained by mapping, petrography and chemistry it is concluded that no tin granite is exposed in the vicinity of Greenbushes. This may be because:—

(a) the extensive lateritic and alluvial cover conceals any possible outcrop;

(b) the granite did not reach the present bedrock surface;

(c) the tin pegmatites have formed by some little understood mechanism of metamorphic concentration;

(d) the tin granite is present, but was not recognized because metamorphism has obscured the normal diagnostic petrographic and chemical features.

Of these alternatives, (b) seems to be the most probable.

GRANITES ASSOCIATED WITH MINOR DEPOSITS IN THE YILGARN BLOCK

Fourteen samples of granitic rocks were collected during inspections of small tin deposits in the Murchison and Eastern Goldfields Provinces of the Yilgarn Block. Summarized petrographic descriptions are given in Table 63 and chemical analyses are listed in Table 64.

The only clearly demonstrated relationship between tin deposits and an identified granite pluton is in the Murchison Province where the deposits of Poona, Coodardy and Dalgaranga lie at the edge of the Poona-Dalgaranga Batholith. This batholith has been

TABLE 63. BRIEF DESCRIPTIONS OF GRANITIC ROCKS ASSOCIATED WITH MINOR TIN DEPOSITS IN THE YILGARN BLOCK

GSWA No.	LOCALITY	DESCRIPTION
26390	Dalgaranga - near M.C.27	Fine-grained, foliated hornblende granodiorite with appreciable introduced quartz. Hornblende is partly altered to chlorite and muscovite. Accessory sphene and epidote. Secondary stilpnomelane and carbonate
26393	Poona - small tor about 1 km SW of Emerald mine	Medium-grained, porphyritic biotite adamellite with secondary chlorite (after biotite) and accessory epidote, fluorite, leucoxene, and retrograde zircon. Plagioclase is sodic oligoclase
26398	Kathleen Valley - near Jones Creek, approximately 3 km north of Kathleen Valley hotel, on track to Mount Mann	Arkosic matrix to Jones Creek Conglomerate which here is composed of granite fragments in a granite-derived matrix. Mineralogically the rock is a tonalite
26400	Kathleen Valley - "western granite", about 7 km north of Kathleen Valley (Sir Samuel 351595)	Massive, pink leucocratic granodiorite with chlorite, muscovite, myrmekitic microcline, sodic oligoclase and accessory magnetite
21701	Kathleen Valley - aplite cutting 26400	Fine, even-grained aplitic adamellite with poikilitic microcline, albite, pale-yellow biotite, a little muscovite and magnetite
21702	Binneringie - greisen vein in amphibolite near tin deposits (Bald Hill)	Slightly foliated quartz-muscovite rock with rather abundant apatite. Muscovite faintly pleochroic from pale green to colourless
21703	Binneringie - granitic vein cutting metasediments near Bald Hill	Essentially a porphyritic, foliated biotite dacite. Phenocrysts are zoned plagioclase. No K-feldspar seen
21704	Binyarinyinna Rock - about 5 km west of tin deposit	Weakly foliated, medium even-grained biotite tonalite. Zoned plagioclase has oligoclase rims. Myrmekite formed at microcline/plagioclase boundaries. Accessory sphene and magnetite
21705	Norseman - from outcrop of "western granite" at co-ordinates 473007, Norseman 1:250 000 geological sheet	Rock is a cataclastic-textured quartz-andesine-hornblende gneiss
21706 } 21707 }	Norseman - microgranite dyke at Mount Thirsty (co-ordinates 463003)	Fine-grained aplitic rock composed of quartz, albite, microcline, muscovite, and accessory spessartine. Resembles aplite phases of layered pegmatite
21708	Norseman - granite dyke from near Mount Thirsty deposits	Medium-grained, cataclastic-textured biotite-albite adamellite
21710	Ubini - from granite hill by dam on telegraph line (lat 30°56′S, long 120°58′E)	Porphyritic biotite adamellite with aligned phenocrysts of microcline and quartz. Plagioclase is sodic oligoclase. Greenish muscovite replaces biotite. Accessory opaques
21711	Holleton - on rabbit proof fence about 3.5 km west of tin deposit	Coarse-grained biotite-oligoclase granodiorite. Biotite partly altered to chlorite and muscovite. Accessory opaques and rare apatite

studied in detail by Muhling (1969, and in prep.) so only two samples were taken for the present investigation. The first, 26390, proved to be a much-altered gneissic rock probably not related to the main batholith or to the tin deposits. The second, 26393, is a fluorite adamellite with low K/Rb, relatively high Rb/Sr (3.1) and high lithium. It crops out close to Tin Creek at Poona, and is probably the ultimate source of the tin pegmatites in that area. Muhling (in prep.) reported that the main Poona-Dalgaranga batholith consists largely of potassic granite.

Newton-Smith (1970) suggested that the tin deposits at Mount Deans and Mount Thirsty were related to the "western granites". Specimen 21705 collected from a mapped outcrop of this granite proved to be a quartz-plagioclase-hornblende gneiss. Samples described by Trendall (1965) are mainly quartz-rich (30 to 50 per cent) adamellite or potassic granites with biotite, chlorite and muscovite as the most common femic minerals. A number of the samples contained accessory fluorite, and one has tourmaline. The samples were collected over a wide area, and may represent several distinct plutons within the western granite.

Of the samples collected from larger granite bodies at Kathleen Valley (26400), Binneringie (21704), Ubini (21710) and Holleton (21711), only the Ubini specimen shows any petrographic affinity to tin granite in that it contains appreciable muscovite. None of the samples contain diagnostic accessory minerals such as fluorite or tourmaline. The chemistry of the rocks (Table 64) shows little evidence for magmatic fractionation, although anomalous tin contents are present in the Ubini and Holleton samples.

In contrast, most granitic or aplitic dykes sampled show marked fractionation or alteration to greisen.

It appears from the limited sampling done that the minor tin deposits of the Eastern Goldfields Province are associated with small granitic dykes representing the fractionated residuum of larger, generally poorly differentiated granite plutons.

Large bodies of typical tin granite were not identified near any of the deposits.

GRANITES ASSOCIATED WITH MINOR DEPOSITS IN THE HALLS CREEK PROVINCE

MATERIAL COLLECTED

During the inspection of the King Sound and Mount Dockrell tin deposits, three samples were collected from each of the three bodies of granite (Mondooma, Lennard and Sophie Downs) possibly associated with the mineralization. Brief descriptions of

TABLE 64. CHEMICAL ANALYSES OF GRANITIC ROCKS ASSOCIATED WITH MINOR TIN DEPOSITS IN THE YILGARN BLOCK

Centre	Dalgaranga	Poona	Kathleen Valley			Binneringie			Norseman				Ubini	Holleton
GSWA No.	26390	26393	26398	26400	21701	21702*	21703	21704	21705	21706	21707	21708	21710	21711
MAJOR OXIDES (%)														
SiO_2	74.3	71.8	71.0	73.9	76.6	67.1	69.2	72.1	68.9	76.7	77.2	76.8	75.5	74.4
Al_2O_3	10.7	13.7	14.3	13.6	13.1	17.5	15.8	15.4	15.1	14.0	14.1	13.4	13.3	14.2
Fe_2O_3	1.30	1.28	1.24	.59	.38	.95	1.10	.02	1.32	.39	.32	.58	.74	.82
FeO	4.06	1.19	1.55	.40	.00	1.08	1.29	1.40	2.40	.29	.29	.07	.14	.47
MgO	.17	.46	.78	.25	.06	1.26	1.84	.51	.82	.15	.07	.10	.14	.29
CaO	2.98	1.45	2.64	1.11	.43	.77	2.24	1.80	4.73	.21	.09	.74	.93	1.56
Na_2O	2.65	3.53	4.30	4.60	4.44	.25	4.25	5.20	4.25	4.80	6.00	4.00	4.30	4.20
K_2O	1.89	4.96	2.52	3.59	4.22	5.82	2.42	2.35	1.36	3.15	.92	4.54	3.98	3.88
Loss	1.42	.57	.94	.75	.50	1.55	.97	.47	.88	.38	.47	.48	.42	.37
TiO_2	.31	.35	.42	.15	.06	.33	.51	.21	.49	.00	.00	.02	.10	.15
P_2O_5	.00	.09	.12	.07	.03	.84	.37	.11	.10	.00	.10	.06	.08	.00
MnO	.07	.04	.06	.01	.00	.11	.03	.02	.07	.10	.20	.02	.01	.01
Total	99.9	99.4	99.9	99.0	99.8	97.6	100.0	99.6	100.4	100.2	99.8	100.8	99.6	100.3
TRACE ELEMENTS (ppm)														
Li	85	315	27	10	2	1840	480	28	2	55	350	5	48	29
F	300	2640	1000	740									570	
Cu	5	11	47	5	2	6	25	6	12	4	3	5	7	5
Zn	92	67	80	25	7	157	90	74	80	40	75	38	51	37
Rb	65	405	125	120	205	5100	290	60	40	955	625	315	180	160
Sr	195	130	455	550	170	885	1500	1120	840	10	5	30	160	205
Sn	3	<2	<2	<2	<2	280	21	3	5	14	45	<2	10	11
Th	14	55	28		17	0	20	3	14	2	3	24	12	37
RATIOS AND DIFFERENTIATION INDICES														
K_2O/Na_2O	.71	1.40	.59	.78	.95	23.3	.57	.45	.32	.66	.15	1.13	.93	.92
K/Rb	241	102	167	248	171	9.5	69	325	282	27	12	120	184	201
Rb/Sr	.33	3.1	.27	.22	1.2	5.8	.19	.05	.05	95	125	10.5	1.1	.78
D.I.	77.7	88.7	81.4	92.6	96.8	80.1	79.4	86.1	72.0	95.1	95.3	94.9	93.9	89.8

*Another split analyzed by Government Chemical Laboratories contained 5.02% K_2O, 0.55% Rb, 0.30% Li, 0.03% Cs, 150 ppm Sn and 23 ppm W.

these samples are given in Table 65 and further information on the field relationships and lithology can be found in Gellatly and others (1968, 1969) and Dow and Gemuts (1969).

The Dyasons Granite, stated to be the source of the Dyasons Creek tin deposits, was not inspected by the writer. Descriptions of it are given by Gellatly and others (1968, 1969).

Chemical analyses of the samples collected during this investigation appear in Table 66 where they are compared with published analyses of the Bow River Granite and the Mabel Downs Granodiorite.

Of the three samples collected from an outcrop mapped as Lennard Granite east of the King Sound mine, the oldest on field relationships is a gneissic-textured, mafic-rich rock (12556) which seems out of character with the main body of the pluton. Probably it represents an earlier phase of igneous activity than the material normally mapped as Lennard Granite.

DISCUSSION

If, from the argument put forward at p. 98 it is accepted that the King Sound tin deposit is related to the Lennard rather than to the Mondooma Granite, then, of the granites presented in Table 66, only the Lennard and Sophie Downs bodies are responsible for tin mineralization. Plotted on a $\sum FeO + MgO : CaO:$

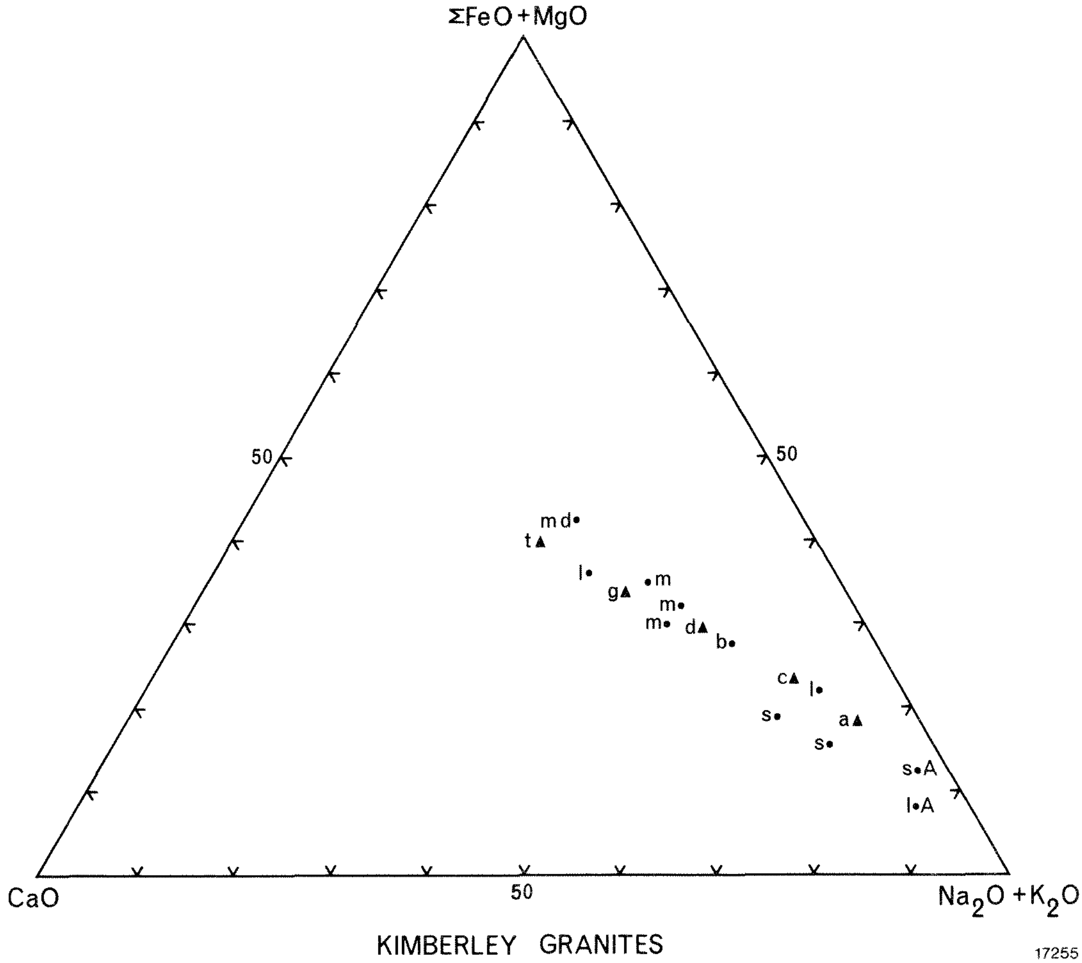

Figure 33. Triangular plot of $\sum FeO + MgO : CaO : Na_2O + K_2O$ for Halls Creek Province (Kimberley) granites l=Lennard Granite; m=Mondooma Granite; s=Sophie Downs Granite; b=Bow River Granite; md=Mabel Downs Granodiorite; A=aplite. Lettered triangles are average granites (Nockolds, 1954) as in Figure 13, with the addition of average tonalite, t

TABLE 65. SUMMARIZED PETROGRAPHY OF SOME GRANITES ASSOCIATED WITH TIN DEPOSITS IN THE HALLS CREEK PROVINCE

Pluton and sample no.	Field appearance and relationship	Microfabric	Essential minerals	Minor accessory and secondary minerals	Remarks
MONDOOMA GRANITE					
12550, 12552, 12553	Medium-grey to grey porphyritic rock with mafic xenoliths and rounded phenocrysts. Forms rounded hills	Porphyritic with protoclastic groundmass and rounded phenocrysts	Perthitic microcline with poikilitic rims, andesine altered to sericite and zoisite, quartz, yellow-green to deep green-brown biotite	Ilmenite rimmed by sphene, epidote, apatite, zircon, chlorite after biotite	Phenocrysts are quartz, microcline and plagioclase
LENNARD GRANITE					
"Older phase" (12556)	Gneissic-textured rock with large (2-3 cm) phenocrysts of feldspar. Biotite is abundant	Porphyritic with cataclastic groundmass and rounded phenocrysts	Quartz, orthoclase as phenocrysts, strongly zoned andesine/oligoclase, green-brown biotite, actinolitic amphibole	Apatite, ilmenite rimmed by sphene, zoisite	Probably wrongly included with Lennard Granite
Main phase (12557)	Pale grey, foliated, medium-grained biotite granite with small feldspar phenocrysts. Forms bare hills. Intrudes 12556	Porphyritic with weak cataclastic foliation superimposed on granitic textured groundmass	Phenocrysts are perthitic microcline and sodic oligoclase. Groundmass is mainly strained quartz, plagioclase, microcline, and pale yellow to red-brown biotite	Muscovite, zircon, apatite, garnet, chlorite replaces biotite	
Aplite phase (12558)	Pale fine-grained foliated rock forming dykes cutting 12557	Fine-grained, foliated microporphyritic rock	Ragged perthitic microcline and albite microphenocrysts. Quartz, feldspar and biotite in matrix	Garnet, pale yellow to blue pleochroic tourmaline, apatite, chlorite after biotite	
SOPHIE DOWNS GRANITE					
Main phase (12564, 12565)	Medium even-grained to slightly porphyritic buff-coloured granite with a typically bouldery outcrop	Protoclastic to foliated, one section is porphyritic	Quartz, oligoclase, perthitic microcline, some green biotite, pistacitic epidote	Chlorite, muscovite, apatite, zircon, opaque minerals, limonite	
Aplite phase (12566)	Pale leucocratic aplite forming dykes near edge of pluton	Aplitic texture with weak foliation	Quartz, microcline, albite, muscovite	Garnet, chlorite, limonite	

$Na_2O + K_2O$ diagram (Fig. 33) these granites lie towards the alkali corner in the field of tin granites (*cf.* Fig. 14).

Lithium and rubidium contents and, where available, K/Rb and Rb/Sr ratios show that the only well-fractionated rocks are the aplites. These also have comparatively high tin contents.

Although the Lennard and Sophie Downs Granites have major oxide compositions compatible with those of demonstrated tin granites, their trace element contents, except in the aplite phases, are deficient in components which indicate that appreciable magmatic fractionation has occurred. In these conditions, only small tin deposits of the type already located could be expected.

TABLE 66. CHEMICAL ANALYSES OF GRANITES FROM THE HALLS CREEK PROVINCE

Pluton	Mondooma Granite			Lennard Granite			Sophie Downs Granite			Bow River Granite [2]	Mabel Downs Gran-odiorite[3]
GSWA No.	12553	12552	12550	12556	12558[1]	12557	12565	12564	12566[1]		
					MAJOR OXIDES (%)						
SiO_2	69.1	69.4	71.7	65.3	73.8	75.5	73.8	75.7	76.1	71.90	66.60
Al_2O_3	14.3	14.0	14.0	16.0	14.1	12.0	12.9	13.2	15.0	13.40	15.20
Fe_2O_3	1.61	1.24	1.07	1.48	.30	.38	1.31	1.12	.97	.74	1.29
FeO	2.19	3.27	2.73	3.49	.67	1.07	.61	.54	.25	2.29	3.80
MgO	.69	.95	.73	1.07	.02	.09	.35	.20	.09	.50	1.96
CaO	2.92	3.01	2.43	4.12	.62	.93	1.64	1.22	.29	1.82	3.80
Na_2O	2.86	2.85	2.62	2.80	2.67	3.28	3.10	3.60	4.00	2.02	2.43
K_2O	4.37	4.06	4.31	3.50	7.51	4.57	4.51	4.70	4.18	5.18	3.18
Loss	.87	.95	.79	.81	.50	.37	1.35	.61	.74	1.17[4]	.64[4]
H_2O^-										.04	.20
CO_2										.11	.05
TiO_2	.44	.51	.41	.61	.04	.10	.16	.11	.01	.40	.58
P_2O_5	.10	.08	.09	.20	.13	.16	.00	.06	.00	.13	.13
MnO	.05	.06	.04	.07	.14	.03	.07	.03	.26	.04	.06
Total	99.5	100.4	100.9	99.6	100.6	98.6	99.8	101.1	101.9	99.7	99.9
					TRACE ELEMENTS (ppm)						
Li	16	23	21	40	5	46	20	8	3		
Be	1.9	1.4	.1	3.3	3.6	3.3					
F			1000	1120	220	460					
Cu	9	18	17				34	9	16		
Zn	58	91	76	81	21	81	56	32			
Rb	155	175	220	170	310	295	185	155	425		
Sr	255	240	210				110	90	10		
Nb				10	5	10					
Sn	2	<2	<2	9	4	17	<2	2	11		
Ce				80	37	80					
Th	13	24	22	17	9	14	35	20			
					RATIOS AND DIFFERENTIATION INDICES						
K_2O/Na_2O	1.53	1.42	1.64	1.25	2.81	1.39	1.45	1.30	1.04	2.56	1.30
K/Rb	234	193	162	171	201	128	202	252	82		
Rb/Sr	.60	.73	1.05				1.68	1.72	42.5		
D.I.	79.0	76.4	79.9	69.0	95.0	93.1	88.7	91.8	93.5	83.9	67.4

(1) Aplite dykes
(2) From Gemuts (1971, Table 7)
(3) From Gemuts (1971, Table 9)
(4) $=H_2O+$

APPENDIX

Locations of rock samples mentioned in this Bulletin

Additional information on the localities of these samples can be found in the specimen registers of the Geological Survey of Western Australia.

Sample No.	1: 250 000 Sheet	South Latitude °	'	East Longitude °	'
12550	Charnley	16	58	124	41
12552	Charnley	16	58	124	41
12553	Charnley	16	58	124	41
12556	Charnley	16	59	124	42
12557	Charnley	16	59	124	42
12558	Charnley	16	59	124	42
12564	Mt Ramsay	18	55	127	17
12565	Mt Ramsay	18	55	127	17
12566	Mt Ramsay	18	55	127	17
12584	Marble Bar	21	07	119	54
12585	Marble Bar	21	08	119	54
12586	Marble Bar	21	08	119	54
12591	Marble Bar	21	28	119	24
12592	Marble Bar	21	42	119	20
15201	Port Hedland	20	39	118	54
15202	Marble Bar	21	31	119	13
15203	Marble Bar	21	32	119	33
15204	Marble Bar	21	41	119	31
15205	Marble Bar	21	41	119	28
15206	Marble Bar	21	30	119	23
15207	Marble Bar	21	33	119	20
15208	Marble Bar	21	40	119	18
15209	Marble Bar	21	35	119	27
15210	Marble Bar	21	36	119	27
15212	Port Hedland	20	55	118	41
15214	Port Hedland	20	32	119	01
15216	Marble Bar	21	30	119	24
15218	Marble Bar	21	36	119	24
15219	Marble Bar	21	28	119	21
15220	Marble Bar	21	29	119	27
15221	Marble Bar	21	28	119	22
15225	Marble Bar	21	41	119	22
15226	Marble Bar	21	40	119	30
15227	Marble Bar	21	06	119	53
15228	Marble Bar	21	08	119	54
15229	Marble Bar	21	08	119	55
15230	Marble Bar	21	06	119	55
15231	Balfour Downs	22	07	120	03
15232	Balfour Downs	22	01	120	13
15233	Marble Bar	21	43	119	25
15234	Marble Bar	21	43	119	27
15235	Marble Bar	21	39	119	20
15236	Marble Bar	21	37	119	20
15237	Marble Bar	21	40	119	28
15238	Marble Bar	21	40	119	28
15239	Marble Bar	21	54	119	28
15240	Marble Bar	21	23	118	34
15241	Marble Bar	21	21	118	38
15242	Marble Bar	21	43	119	24
15243	Marble Bar	21	35	119	28
15244	Marble Bar	21	15	118	36
15245	Marble Bar	21	16	118	34
15246	Marble Bar	21	20	118	34
15247	Marble Bar	21	17	118	37
15248	Marble Bar	21	08	119	54
15249	Marble Bar	21	08	119	54
15254	Roebourne	20	51	117	12
15255	Marble Bar	21	29	119	25
15258	Roebourne	20	51	117	11
15266	Marble Bar	21	09	119	54
15267	Marble Bar	21	09	119	55
15272	Marble Bar	21	10	119	57
15275	Marble Bar	21	44	119	28
15280	Marble Bar	21	43	119	28
15287	Marble Bar	21	54	119	28
15288	Marble Bar	21	21	118	38
15290	Marble Bar	21	53	119	24
15291	Marble Bar	21	11	118	44
15292	Pyramid	21	14	118	24
15293	Pyramid	21	14	118	24
15296	Pyramid	21	14	118	20
15297	Pyramid	21	15	118	20
15298	Marble Bar	21	09	118	38
15299	Marble Bar	21	10	118	38
15300	Marble Bar	21	13	118	37
16314	Mt Ramsay	18	55	127	14
16318	Mt Ramsay	18	56	127	14
16362	Marble Bar	21	34	119	25

Sample No.	1: 250 000 Sheet	South Latitude °	'	East Longitude °	'	Sample No.	1: 250 000 Sheet	South Latitude °	'	East Longitude °	'
16365	Marble Bar	21	34	119	26	26254	Port Hedland	20	39	118	54
16366	Marble Bar	21	33	119	36	26265	Marble Bar	21	05	119	50
16367	Marble Bar	21	34	119	25	26266	Marble Bar	21	07	119	56
16373	Marble Bar	21	30	118	47	26267	Marble Bar	21	07	119	56
16380	Marble Bar	21	30	118	47	26268	Marble Bar	21	04	119	58
16391	Marble Bar	21	24	118	54	26269	Marble Bar	21	06	119	56
16446	Marble Bar	21	09	119	53	26270	Marble Bar	21	06	119	56
16447	Marble Bar	21	09	119	53	26271	Marble Bar	21	06	119	56
16496	Marble Bar	21	09	119	53	26273	Marble Bar	21	09	119	57
18417	Nullagine	21	38	120	26	26276	Marble Bar	21	08	119	52
18418	Nullagine	21	38	120	26	26278	Marble Bar	21	09	119	51
21701	Sir Samuel	27	27	120	33	26279	Marble Bar	21	10	119	53
21702	Widgiemooltha	31	32	122	10	26282	Marble Bar	21	06	119	59
21703	Widgiemooltha	31	32	122	10	26285	Marble Bar	21	07	120	00
21704	Widgiemooltha	31	34	122	05	26288	Marble Bar	21	08	119	54
21705	Norseman	32	18	121	43	26295	Marble Bar	21	27	119	32
21706	Norseman	32	06	121	36	26300	Marble Bar	21	31	119	36
21707	Norseman	32	06	121	36	26301	Marble Bar	21	33	119	36
21708	Norseman	32	06	121	36	26303	Marble Bar	21	31	119	25
21710	Kalgoorlie	30	57	120	57	26308	Marble Bar	21	31	119	24
21711	Southern Cross	31	48	118	58	26312	Marble Bar	21	36	119	31
21732	Marble Bar	21	07	119	54	26318	Marble Bar	21	34	119	20
21739	Marble Bar	21	07	119	54	26321	Collie	33	51	116	03
21744	Marble Bar	21	09	119	54	26322	Collie	33	43	116	04
21759	Marble Bar	21	09	119	54	26324	Collie	33	43	116	04
21766	Marble Bar	21	31	119	24	26325	Collie	33	43	116	04
21790	Marble Bar	21	54	119	23	26326	Collie	33	42	116	07
26203	Marble Bar	21	19	118	34	26327	Collie	33	45	116	19
26204	Marble Bar	21	20	118	35	26328	Collie	33	47	116	20
26205	Marble Bar	21	20	118	35	26329	Collie	33	47	116	20
26206	Marble Bar	21	17	118	33	26330	Collie	33	50	116	23
26207	Marble Bar	21	17	118	37	26331	Collie	33	55	116	27
26209	Marble Bar	21	33	119	28	26332	Collie	33	55	116	24
26211	Marble Bar	21	31	119	29	26333	Collie	33	54	116	23
26212	Marble Bar	21	31	119	29	26334	Collie	33	54	116	21
26215	Marble Bar	21	40	119	31	26335	Collie	33	54	116	21
26217	Marble Bar	21	41	119	24	26336	Collie	33	53	116	19
26218	Marble Bar	21	41	119	24	26337	Collie	33	53	116	16
26219	Marble Bar	21	42	119	20	26338	Collie	33	53	116	13
26222	Roebourne	20	51	117	12	26339	Collie	33	54	116	06
26226	Marble Bar	21	17	118	37	26340	Collie	33	50	116	11
26228	Marble Bar	21	16	118	37	26341	Collie	33	50	116	11
26229	Marble Bar	21	17	118	37	26342	Collie	33	49	116	10
26230	Marble Bar	21	17	118	39	26343	Collie	33	48	116	04
26231	Marble Bar	21	18	118	40	26344	Collie	33	48	116	04
26232	Marble Bar	21	16	118	39	26345	Collie	33	47	116	03
26233	Marble Bar	21	16	118	39	26346	Collie	33	46	116	02
26234	Marble Bar	21	09	119	55	26347	Collie	33	46	116	02
26240	Marble Bar	21	08	119	55	26348	Collie	33	47	116	03
26244	Marble Bar	21	08	119	56	26349	Collie	33	54	116	00
26247	Marble Bar	21	07	119	56	26352	Collie	33	54	116	00
26250	Port Hedland	20	47	118	41	26353	Collie	33	54	116	00
26251	Port Hedland	20	39	118	54	26354	Collie	33	55	116	01

Sample No.	1: 250 000 Sheet	South Latitude °	'	East Longitude °	'	Sample No.	1: 250 000 Sheet	South Latitude °	'	East Longitude °	'
26355	Collie	33	56	116	01	26387	Collie	33	50	116	01
26357	Collie	33	55	116	06	26390	Cue	27	43	117	13
26358	Collie	33	55	116	06	26393	Cue	27	09	117	27
26359	Collie	33	58	116	07	26398	Sir Samuel	27	29	120	34
26361	Collie	33	57	116	15	26400	Sir Samuel	27	27	120	33
26362	Collie	33	58	116	15	38024	Marble Bar	21	30	119	20
26363	Collie	33	58	116	08	38025	Marble Bar	21	30	119	20
26367	Collie	33	53	116	05	38026	Marble Bar	21	30	119	20
26368	Collie	33	51	116	07	38027	Marble Bar	21	30	119	20
26369	Collie	33	50	115	56	38031	Marble Bar	21	38	119	57
26370	Collie	33	49	116	00	38098	Collie	33	53	116	07
26371	Collie	33	49	116	00						
26373	Collie	33	52	116	02						
26375	Collie	33	56	116	05		OLD SERIES NUMBERS				
26376	Marble Bar	21	15	118	39	703	Collie	33	51	116	03
26377	Marble Bar	21	15	118	39	1990	Collie	33	51	116	03
26378	Marble Bar	21	15	118	39	5392	Marble Bar	21	07	119	45
26384	Collie	33	47	115	59	5397	Marble Bar	21	08	119	53
26385	Collie	33	47	116	00	2/4839	Marble Bar	21	31	119	35

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