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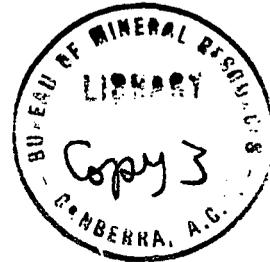
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DEPARTMENT OF NATIONAL DEVELOPMENT.
BUREAU OF MINERAL RESOURCES
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RECORDS:

1964/8



BERYLLIUM REVIEW PAPER

by

D.O. Zimmerman

The information contained in this report has been obtained by the Department of National Development, as part of the policy of the Commonwealth Government, to assist in the exploration and development of mineral resources. It may not be published in any form or used in a company prospectus without the permission in writing of the Director, Bureau of Mineral Resources, Geology and Geophysics.

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BERYLLIUM - REVIEW PAPER

SUMMARY

This paper reviews the production, prospects and geology of beryllium. Recommendations are made should it be decided to conduct a prospecting campaign for beryllium deposits.

The recommendations include literature research, outlining of metallogenetic provinces, geochemical prospecting, detailed geological mapping and investigations using a beryllometer.

Pegmatite dykes provide one of the most important sources of supply of beryllium and consequently should be investigated in Australia e.g. Yinnietharra, Wodgina in Western Australia, Mica and Galah Creeks near Mount Isa and Mount Garnet-Herberton District in Queensland, Broken Hill District in New South Wales and West Arm-Bynoe Harbour in Northern Territory.

Tungsten skarns particularly those which contain fluorite and/or beryl as accessory minerals should be examined e.g. Mount Carbine in Queensland.

Regional geochemical sampling of North Queensland Upper Permian - Lower Triassic acid volcanics should delineate areas of high beryllium background. Post-volcanic faults should be prospected carefully. A broad similarity is seen between this area and Spors Mountain - Topaz Mountain deposits in Utah, U.S.A.

At Aguachile in Mexico beryllium minerals are found in a ring dyke complex. In North Queensland ring dykes have been mapped and may be found in other parts of the Tasman Geosyncline. Schist and gneisses may provide a source of beryllium and should be prospected for.

INTRODUCTION

Since World War II there has been a continual rise in the demand for the mineral beryl, which has been the main source of beryllium. Beryllium is used principally in the manufacture of alloys e.g. high strength copper-beryllium alloys but beryllium and beryllium oxide are becoming increasingly important in the aircraft, spacecraft and nuclear industries*. Sales of beryllium in the United States have increased from a total of about 27 million dollars in 1958 to about 50 million dollars in each of the years between 1960 and 1962. With the increasing interest in beryllium in the technological field it is time that we in Australia assessed our beryllium potential and prepared for prospecting for new beryllium deposits in anticipation of probable future demand.

WORLD PRODUCTION AND PRICES

The total world production of beryllium ore in 1962 was estimated at 8,200 tons, Brazil, Uganda, Madagascar, Argentina, United States and Southern Rhodesia were the main producing countries (see table 1). The United States is the main consumer and in 1962 they imported 8552 tons of beryl concentrates.

* A comprehensive list of the properties and uses of beryllium is given in Appendices I and II.

TABLE 1.

WORLD PRODUCTION OF BERYL BY COUNTRIES. (1)

		(Short tons)					
Country		1953-57 (average)	1958	1959	1960	1961	1962
NORTH AMERICA:							
United States							
(mine shipments):							
Cobbed beryl ..		577	463	328	244	317	218
Other lower grade beryllium ore ..		-	42	97	265	805	760
Total ..		577	505	425	509	1,122	978
SOUTH AMERICA:							
Argentina ..		1,236	1,004	645	739	(2)660	(2) 660
Brazil ..		1,887	1,314	1,127	1,870	1,684	(2) 1,650
Total ..		3,123	2,318	1,772	2,609	2,344	(2) 2,310
EUROPE:							
Norway (U.S.imports)		-	3	4	-	-	-
Portugal ..		311	52	41	32	39	21
Sweden ..		-	28	(3) 41	-	-	(3) 26
U.S.S.R. (2) ..		110	330	390	440	500	550
Total (2)		420	410	480	470	540	600
ASIA:							
Afghanistan ..		23	-	-	11	-	-
India (U.S.imports)		1,210	600	-	1,000	885	150
Korea, Republic of	(3)	3	-	-	-	6	-
Total ..		1,236	600	-	1,011	891	150
AFRICA:							
Congo, Republic of the (formerly Belgian) (4)		935	1,063	280	369	184	(3)485
Kenya ..		1	4	2	1	1	-
Malagasy Republic (Madagascar) ..		390	181	474	701	836	(2)800
Morocco ..		11	-	-	-	-	-
Mozambique ..		1,011	1,161	1,559	1,649	698	441
Rhodesia and Nyasaland, Federation of:							
Northern Rhodesia		10	13	2	2	-	-
Southern Rhodesia		999	333	440	539	396	559
Ruanda-Urundi ..		72	51	187	310	(2) 330	(5)
Somali Republic .	(6)	12	-	-	-	-	-
South Africa.Rep.of		343	464	203	325	192	360
South-West Africa		493	247	170	413	252	159
Swaziland ..		-	-	2	6	7	-
Uganda ..		84	86	235	470	1,136	(3)1,043
Total ..		4,361	3,603	3,554	4,785	4,032	3,847
Oceania: Australia		267	278	355	213	343	(2) 265
WORLD TOTAL (estimate (1))		10,000	7,700	6,600	9,600	9,300	8,200

(1) This table incorporates some revisions. Data do not add exactly to totals shown because of rounding where estimated figures are included in the detail.

(2) Estimates.

(3) United States imports.

(4) Average annual production 1954-57.

(5) Ruanda-Urundi included in Rep. of the Congo in 1962.

(6) Average annual production 1955/57

The price of beryllium concentrates (minimum 10% BeO) in the United States was between \$29 (£(A)12.16.0) and \$32 (£(A)14.5.0) per short ton unit (20 lb) c.i.f. American ports in December 1963. The price of 98% Be powder at the same time was between \$54 (£(A)24.2.0) and \$66 (£(A)29.9.0) per pound. Beryllium of higher purity then sold for up to \$170 per pound Be. Between July 1952 and June 1962 the United States Government offered incentive prices of \$45 per short ton unit for domestically produced beryllium ore. Although there was a steady increase in domestic production over the ten-year period no dramatic results could be attributed to the offer. It was not until after the withdrawal of the offer in 1962 that large strides were made in the development of U.S. resources; in 1963 Brush Beryllium Corporation announced plans for a \$3,000,000 open-pit development of the Spors Mountain deposit in Utah.

AUSTRALIAN PRODUCTION AND PRICES

Australian production of beryl ore in 1962 was 223 tons containing not less than 10% BeO. Production over the last ten years has varied between 213 tons and 355 tons per year. Western Australia and New South Wales have been the principal producing states (see Table 2). The Australian Atomic Energy Commission purchased a large part of Australian production up until June 1962 when it considered its stockpiled reserves sufficient for any future use over a number of years. At the time it ceased purchases, the A.A.E.C. was offering £A15.10.0 per long ton unit (22.4lbs).

FUTURE PROSPECTS

Up until 1962 the United States was importing over 80% of its beryllium ore requirements but with the current development of domestic resources it can be expected to become self-sufficient in beryllium ore within a few years unless the demand for beryllium increases even more than it has done in the last five years. However current research on new uses for beryllium e.g. the development of aluminium-beryllium alloys and the use of the two metals in rocket fuels, if successful, will undoubtedly increase the demand and may also reduce the price of the metal. The increased activity in prospecting for new deposits of beryllium as well as intensive research in beryllium metallurgy and usage, indicates confidence in the future of the industry. Similar interest in the U.S.S.R. is noted by C.F. Davidson (1960 p.646) who says that "the immense amount of research on beryllium mineralogy and geochemistry currently being reported from the U.S.S.R. could not escape notice nor could the many new analyses of beryllium minerals from Vhina recently listed in Soviet literature". In other countries interest in beryllium is being revived or increasing - in Great Britain, beryllium plants have been closed down over the last few years but I.C.I. are confident of the long range future of the metal. In France, the Pechiney group is fabricating very high-grade beryllium metal and in Western Germany, Beryllium Corporation of America have established a branch near Frankfurt to market their alloy products.

If Australia is to compete favorably in world markets as a beryllium supplier it will need to increase production considerably and cut down on the cost of production. This means finding and developing large new deposits. The Conzinc Riotinto Group is already actively prospecting for beryllium deposits. Geological conditions existing at newly discovered beryllium deposits in America are matched in several districts in Eastern Australia so that chances of finding similar large low-grade deposits in

TABLE 2.

AUSTRALIAN PRODUCTION OF BEPYL 1939--1960

Year	Western Australia		N.S.W.		South Australia		Queensland		Total	
	tons	units	tons	units	tons	units	tons	units	tons	units
1939	7								7	
1940	2								2	
1941	1				2				3	
1942									-	
1943	516.1				1.35		7		524.45	
1944	390.15		14.20		4.15		5.85		414.35	
1945	33.61		8.45		3.85				45.91	
1946	15.49		5.00		2.5				22.99	
1947	44.89	538	8.00						52.89	
1948	34.85	336	7.91				12.00		54.76	
1949	20.45	240	4.00		1.30		9.50		35.25	
1950	16.93	186					6		22.93	
1951	90.77	1,090	11.40	140			10.30	113	112.47	1,343
1952	85.29	1,046	0.98	12	0.85	9			87.12	1,067
1953	124.62	1,497	0.80	8					125.42	1,505
1954	132.15	1,523	9.30	120			7.21	89	148.66	1,732
1955	198.63	2,348	7.15	80					205.78	1,732
1956	310.19	3,728	7.57	85					317.76	3,813
1957	350	4,007	29	350	15	200	1	13	395	4,570
1958	170	2,006	10	120	56	654	11	120	247	2,900
1959	267	3,010	48	560	1	12	1	5	317	3,587
1960	181	2,101	9	120					190	2,221
1961	261	2,975	36	490	9	120			306	3,585
1962	195	2,223	10	130	18	233			223	2,586
Totals:	3458.12		226.76		115.00		70.86		3,860.74	

Australia are encouraging and beryllium prospecting should be stepped up to keep in line with world trends.

GEOLOGY OF BERYLLIUM

PRINCIPAL BERYLLIUM MINERALS

The mineral beryl is the principal source of beryllium; chrysoberyl, helvite and bertrandite contribute only minor amounts. Recently large deposits containing bertrandite and phenacite have been recognised as potential sources of beryllium.

TABLE 3. Principal beryllium source minerals.

<u>Mineral</u>	<u>Composition</u>	<u>%BeO</u>	<u>% Be</u>
Beryl	$3\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$	14	3 - 3.5
Bertrandite	$4\text{BeO} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$	42	15.1
Phenacite	$2\text{BeO} \cdot \text{SiO}_2$	46	16.4
Helvite	Mn, Fe, Be sulphosilicate	14	3.8- 5.4
Chrysoberyl	$\text{BeO} \cdot \text{Al}_2\text{O}_3$	20	7.1

Table 3 shows that both bertrandite and phenacite contain much more beryllium than any of the other minerals. Furthermore, these two minerals occur as primary constituents in replacement deposits and therefore offer possibilities of large tonnages of low-grade ore, and consequently cheaper mining methods. Beryl and chrysoberyl, are most common in pegmatites and because of their high cost of extraction, they are commonly produced as by-products of feldspar, mica, columbite, tantalite, or spodumene mining. The gem varieties of beryl, aquamarine and emerald, have been recognised in numerous, widespread, minor occurrences including gem sands and cassiterite-bearing alluvium. Helvite has a varied mode of occurrence, and is probably most common in skarn deposits.

Bertrandite and phenacite were thought to be rather rare minerals probably because of their macroscopic similarity to quartz and feldspar; an increasing awareness of their potential as a source of beryllium has led to their more widespread recognition in the United States, Mexico and U.S.S.R. Difficulties in extraction of beryllium from bertrandite and phenacite ores have retarded their development but this problem has now been overcome, and large deposits such as that at Spors Mountain, Utah which is stated to contain 3,000,000 tons of 0.75% BeO ore are now being developed (Starratt 1961). Care in evaluation of bertrandite and phenacite deposits is necessary as both can occur as secondary minerals resulting from late stage, hydrothermal alteration of beryl (Timchenko, 1959 Abst.).

A more complete list of beryllium minerals with their more important properties is given in Appendix II. New minerals continue to be discovered.

MINERALS ASSOCIATED WITH BERYLLIUM OCCURRENCES:

The following minerals are commonly associated with beryllium minerals in nature: fluorite, topaz, cassiterite, wolframite, molybdenite, quartz, feldspar, mica, chlorite, tourmaline, columbite, tantalite, spodumene, amblygonite, uranium-minerals, garnet, magnetite, hematite, limonite, manganese oxides, arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, montmorillonite; and in alluvial concentrates topaz, cassiterite, diamond, sapphire, spinel, zircon, rock crystal, amethyst, cairngorm, and gold. Of all these minerals, fluorite (CaF_2), topaz ($9\text{Al}_2\text{F}_2\text{SiO}_4$), and cassiterite (SnO_2), appear to be the most common associates of beryllium minerals, when one excludes the common rock-forming minerals such as quartz. Arsenopyrite appears to be an unusually common associate of beryllium minerals, e.g. danalite, in sulphide ores.

The common association of these four minerals with beryllium occurrences suggests that they can be used effectively as indicator minerals in the early stages of prospecting for beryllium deposits. Of the four, fluorite is probably the most common associate of beryllium minerals. This association fills a very real need, in that most of the beryllium minerals, with the possible exception of beryl, are extremely difficult to recognise in the field; furthermore simple field tests for beryllium, exclusive of those relying on electronic equipment, have yet to be perfected (for discussion of tests see below, and Hosking 1960, p.651-3; Bowie 1961, p.71-72; Dressel and Ritchey, 1960; and McVay, 1960).

Another possible indicator mineral, though of less practical value, is beryllium-bearing idocrase ($\text{Ca}_6(\text{Al}(\text{OH},\text{F})\text{Al}_2(\text{SiO}_4)_5$). Davidson (1960, p.648) says that beryllium-enriched idocrase is as diagnostic of beryllium provinces as tin-bearing biotite is of stanniferous granite. However, idocrase is not readily recognised by field geologists, and an analysis would be required to determine whether or not it was beryllium-enriched.

THE OCCURRENCE OF BERYLLIUM MINERALS:

Beryllium minerals occur as accessories in many rock types, but they principally occur in, or closely associated with, intrusive acid igneous rocks. Rock types in which beryllium is now known to occur, in greater than background quantities, include granites; pegmatites; pneumatolytic veins; greisens; syenites; rhyolites - both intrusive and extrusive - some of which may be ignimbrites or rhyolitic tuffs; metasomatic rocks - particularly skarns; and limestones, schists and gneisses affected by igneous emanations; gossans; coal seams; clays; alluvial deposits - particularly gem and cassiterite-bearing gravels; and tektites (glassy nodules probably of cosmic origin). Economic beryllium deposits have so far been found in about half of these rock types.

At present (January 1964) the principal economic source of beryllium is from beryl in pegmatites but recent discoveries suggest the other sources will become more important in the near future.

In the case of metasomatic deposits, limestone skarns appear to contain the largest deposits; two such deposits are described in the literature, viz., Aguachile, Mexico (McAnulty et al, 1963; Levinson, 1963; and Rowe, 1961) and Mount Wheeler, Nevada (Stager, 1960) where beryllium replacement-type mineralization took place almost exclusively in limestone, although shale occurred nearby.

Warner et al (1959, abs.) have summed up occurrences in sedimentary rocks as follows: "Many sedimentary rocks contain small quantities of beryllium, particularly those formed by residual concentration, as the metal hydrolyses in a manner similar to aluminium." The latter statement may account for the beryllia-rich clays, e.g., at Spors Mountain, Topaz Mountain, Utah (Trover, 1961, p.92) and at the Ishasha Mine, Uganda (Bowie et al., 1961, p.74) associated with some beryl-pegmatites. Warner et al continue: "beryllium tends to be dissipated by processes of weathering and sedimentation. Under simple metamorphic conditions beryllium is not easily mobilized, and therefore it is not concentrated in metamorphic rocks other than pyrometasomatic despoits."

BERYLLIUM-BEARING PEGMATITES

Beryl pegmatites are well known and are the major source of the world's supply of beryllium.

Beryl occurs as an accessory mineral in quartz feldspar mica pegmatites; other accessory minerals are columbite, tantalite, spodumene, cassiterite, tourmaline, amblygonite, etc. Beryl content in pegmatites explored and mined to date ranges up to 3%.

It is recovered from beryl pegmatites as a by-product in the mining of pegmatites for feldspar and mica and more commonly by handsorting and cobbing. At Boa Vista in Brazil handsorting will be followed by flotation. Beryl is also sluiced from eluvial deposits and subsequently handpicked to ore grade.

Pure beryl contains about 14% BeO. A minimum of 10% BeO is specified by buyers. To achieve this grade from pegmatites, handsorting methods have been found to be the most economical and effective. Consequently mining of pegmatites has its best application in countries where labour is cheap and plentiful. In Australia labour and mining costs are high and consequently pegmatites must be amenable to large-scale mining operations, preferably open cut. Development of suitable flotation techniques in Australia should be more profitable than hand sorting.

Until tonnage and grade etc. of beryl pegmatites in Australia are known it is impossible to estimate cut-off grade for mining. The possible by products must also be taken into consideration.

Beryl deposits mined in Australia to date are almost exclusively pegmatitic. Sullivan and Ludbrook (1948) give details of the deposits, most of which are in Western Australia. Principal localities are the Wodgina District and Yinnietharra in Western Australia; the Broken Hill district in New South Wales; and Mica Creek, near Mount Isa, Queensland; West Arm-Bynoe Harbour Northern Territory. The Mica Creek deposit is interesting as it is one of the few known localities for bertrandite in Australia (see Edwards et al., 1959; and Brooks and Shipway, 1960). The bertrandite apparently occurs as an alteration product of beryl.

At Galah Creek 15 miles south of Mica Creek, Brooks (1963) reports that 23 tons of beryl were produced in 1961-62 period from a beryl pegmatite. He estimates possible reserves at 500 to 4000 tons and suggests that the area is favourable for prospects; open cut methods might be applicable.

Beryl is won from pegmatites in Brazil which is the world's

biggest supplier of the ore. Standard Beryllium Corp. is mining and handsorting 2500 tons of beryl per year from two pegmatite dykes near Boa Vista 200 miles north of Rio de Janeiro. Reserves are calculated at 2,000,000 tons of 2.5% BeO at the mine and 14,820,000 tons in the Corporation's concession with an average grade of 3% beryl.

Prospecting for beryl-bearing pegmatites apparently is still going on overseas. The September 1961 issue of "Mining Engineering" reports (p.1023) the discovery of at least 600,000 tons of beryl at Bernic Lake, Manitoba, with an average grade of 0.15% beryl, i.e. 0.021% BeO.

Pegmatite dykes provide one of the most important sources of supply of beryllium. They are numerous in various parts of Australia and should be prospected: Wodgina, Yinnietharra Ravensthorpe in Western Australia, Mica and Galah Creek areas in Queensland and the Broken Hill District in New South Wales, West Arm and Bynoe Harbour Northern Territory are worthy of early attention. Investigation of other pegmatite deposits should be also carried out. At Rum Jungle beryllium values were detected in cuttings of weathered rock from auger holes made in the vicinity of pegmatites. 14 anomalous Be values in the range 15 to 150 p.p.m. were detected.

NON-PEGMATITIC BERYLLIUM DEPOSITS:

A comprehensive list of non-pegmatite beryllium occurrences is given on page 4. So far only a few of these have proved to be of economic importance. The most up-to-date description of the various non-pegmatitic deposits, known to date, is given by Rowe (1961); a short article in the Mining Magazine (anon, 1960) is also helpful, though rather brief. Examples of the new types of deposits are discussed below, and possible equivalents in Australia are recorded.

Greisens.

The best documented beryllium-bearing greisen is in the Lake George district, Colorado; and particularly at the Boomer Mine where bertrandite is the newly recognised ore mineral. Sharp and Hawley (1960) describe the mineralized rocks as mica-quartz greisen zones and associated high temperature quartz veins in Precambrian granite, and along its contacts with metamorphic rocks. Fault zones in the area are commonly greisenized (see Hawley et al., 1960). Fluorite is almost universally present in the greisens, and topaz is abundant locally; other minerals comprise bertrandite, pyrite, sphalerite, molybdenite, wolframite, galena, chalcopyrite, arsenopyrite, and sooty pitchblende.

Prior to the discovery of bertrandite in 1959, beryl had been known to occur in quartz veins in the area; the discovery was made during a geochemical prospecting survey using a beryllometer. Sharp and Hawley (1960) note that the bertrandite-rich greisen at the Boomer Mine appears to contain more fine-grained yellow muscovite than the normal grey greisen, but otherwise the bertrandite ore is very difficult to recognise macroscopically. Bertrandite is considered to be a primary constituent of greisens, and, because of its similarity in composition, phenacite could also be expected.

There is evidence in the literature that the Russians are also paying particular attention to greisens. Kalenov (1959, abst.) describes helvite occurring in a quartz-muscovite greisen in Central Asia, accompanied by beryl, bromellite (100% BeO), bismuthinite, and scheelite. Rub (1957, abst.) in describing some greisens from the south-western

Primorie region, mentions "a regional phase of greisenisation characterised by muscovitisation of the biotite; replacement of feldspar by quartz and mica; and formation of tourmaline, fluorite, topaz, and cassiterite", i.e., four of the principal beryllium indicator minerals. No mention of beryllium is made in this abstract but it certainly would be expected in such an association.

Possible Beryllium-bearing Greisens in Australia: (see also section on Tungsten Greisens)

The chances of finding beryllium-bearing greisens in Australia are good. Firstly, most of the cassiterite occurrences in Eastern Australia are related to greisenised granite containing, in addition, fluorite, topaz, wolfram, and molybdenite, and occasional crystals of beryl. From north to south, these include the mineral fields of Cooktown, Herberton, Kangaroo Hills, Stanthorpe, New England (Tamworth-Tenterfield), Mount Tallebung-Albury including the Ardlethan field; and the Branhholm-Blue Tier, Moina, Ben Lomond, and Royal Gorge districts of northern Tasmania. The intrusives associated with these deposits are of Palaeozoic age. Tin is reported in Precambrian greisen and pegmatites at Euriowie and Yanco Glen near Broken Hill, and most of the tin deposits in Western Australia are associated with Precambrian pegmatites.

The Maranboy tinfield in the Northern Territory is another possibility. Here quartz mica greisens contain cassiterite, topaz, tourmaline, apatite and fluorite as accessory minerals. The deposits have been described by Walpole (1958).

Dallwitz (1954) made a petrographic examination of a specimen of "radioactive granite" from Bollinger's Lode (Blatherarm), Torington, New England District, New South Wales, and found that the three principal minerals were beryl, phenacite, and milarite, i.e., all beryllium minerals. Other less common minerals are fluorite, biotite, albite, monazite, possibly topaz, and an unidentified yellow uranium mineral. Only a single hand specimen was submitted and the field occurrence was not examined. However Mulholland (1953, p.944) describes the Torington greisens as being "rich in topaz and fluorite", i.e., the beryllium indicator minerals. These two observations and the analogy with Lake George, Colorado, deposits, suggest that the Torington area would be a good place to start prospecting for deposits of beryllium in greisens, and a short survey was carried out over this area in April 1962 to test geochemical techniques for beryllium.

Cassiterite-fluorite-topaz greisens are common in the North Queensland tinfields; e.g. at Mount Gibson, and Glen Linedale near Mount Garnet, and near Fischerton; reconnaissance prospecting for beryllium-greisens will be integrated with current B.M.R. field work on tin prospecting in these areas.

Prospecting for beryllium deposits in greisens should ultimately be carried out over all tinfields in Eastern Australia. From present knowledge, Torington would be the most promising place to start such a survey.

Tungsten skarns:

The best example of this type of deposit is the Mount Wheeler Mine, White Pine County, Nevada. Stager (1960) notes that originally it was a tungsten deposit in which a few occurrences of beryl were known. In 1959, analyses of concentrates gave a much higher BeO content than could be explained by the

observed amount of beryl; investigations subsequently revealed abundant phenacite and lesser bertrandite, which had previously been mistaken for quartz.

The Mount Wheeler deposits are selective vein type replacements in limestone lenses within a sequence of quartzites, shales, and limestones. Granite is believed to underlie the area at shallow depth. The replacement zones are partly controlled by steeply dipping fault fissures. The deposits consist of quartz, scheelite, phenacite, bertrandite, pyrite, fluorite, sericite, manganian siderite, and traces of sphalerite and galena.

No ore reserves are quoted, but a grade of about 1% BeO, i.e., 0.36% Be is mentioned. One ore shoot is from 15 to 20 feet thick, a few feet - to more than 10 feet wide, and about 1500 feet long (Anon, 1960); a rough estimate of this volume would be 17' x 15' x 1500' = 127,500 cubic feet. At an average density of about 2.65, i.e., about 13 cubic feet per ton, this would be about 9,800 tons of 1% BeO ore. Other deposits of similar dimensions are said to occur in the area.

Possible Tungsten Skarns and "Greisen" Type Tungsten Deposits in Australia:

There are numerous tungsten deposits in Australia but, in choosing some which might be similar to the Mount Wheeler deposit, it is perhaps best to take those which have fluorite and/or beryl as accessory minerals. Referring again to Sullivan and Ludbrook's summary report on beryllium in Australia (1948, p.p.8 & 9) one notes that beryl is associated with wolfram and molybdenite at Mount Carbine, North Queensland; at Heffernan's wolfram mine at Torington, in molybdenite pipes at Tenterfield, and in wolfram deposits near Emmaville, New South Wales. However, all of the deposits are located in granites. In fact there are few records of tungsten deposits located in limestones, other than the classic King Island scheelite deposit (Knight & Nye 1953); no mention of fluorite, beryl, topaz, or cassiterite at King Island was found, though the tungsten-skarn association justifies testing of a few samples of King Island scheelite ore for beryllium content. Minor occurrences of scheelite are reported in the Albury - Mount Tallebung and Boorowa districts; limestones are known in these areas and a detailed literature search might suggest tungsten-skarns worth prospecting for beryllium. Other possible areas are around the margins of the New England batholith, including the Stanthorpe batholith and one example is the Faddys River scheelite deposit; the Kangaroo Hills field, where limestone roof pendants occur in granite; and the Herberton area where a few small limestone lenses occur in the Mount Garnet Formation. The Chillagoe limestones are intruded by granite, but no tungsten deposits are known there.

While examining the literature on tungsten deposits it becomes increasingly apparent that tungsten (wolfram)-fluorite-topaz - cassiterite lodes similar to the greisen lodes discussed in the previous section are relatively common. Examples are the Mount Carbine, Glen Linedale, Torington, Tenterfield, and Emmaville lodes mentioned above. Further, Connah (1952; 1953) has described three wolfram mines in the Kangaroo Hills field which fit into this category of altered granite - or contact - wolfram lodes. In describing the "Back In" wolfram mine at Kangaroo Hills, Connah (1953, p.142) notes that the lode material is white and predominantly siliceous, but contains small patches of a pale yellow sericitic mineral and occasional nests of fluorspar. One cannot help wondering if this "pale yellow sericitic mineral" is similar in any way to

the "unusually fine-grained yellow muscovite" which indicates bertrandite mineralization in the greisen lodes at the Boomer Mine, Colorado (Sharp & Hawley, 1960). The "Back In" deposit should be checked for bertrandite or phenacite early in any beryllium prospecting programme.

Acid Tuff Deposits

The classic example of this type of deposit is at Topaz Mountain, Spors Mountain District, near Juab, Utah. The area has long been a source of fluorspar, and the geology is well documented (see Staatz and Osterwald, 1959). The mineralization is in Tertiary rhyolite tuff; Staatz & Griffiths, 1961, note that fluorite deposits occur in the centre of the district and beryllium-rich fluorite-poor deposits lie around the periphery. Fluorite is found in pipe-like bodies, veins, and disseminated bodies. The bodies containing disseminated fluorite are the only ones known to contain beryllium; they form irregular layers in the tuff close to faults and there may be more than one beryllium-rich layer at any one locality. Minerals found in the beryllium fluorite bodies are: fluorite, montmorillonite, quartz, opal, chalcedony, calcite, dolomite, carnotite, sanidine, biotite, bertrandite, gypsum, and bixbyite. Beryl has been found in the area. Nodules of fluorite, silica minerals, and calcite are commonly embedded in the tuff, and these generally have a much higher Be content than the enclosing tuff. Clay fractions from several deposits which contain no nodules have been found to contain economically recoverable beryllium (Trover, 1961 p.92). It is likely that there are some as yet unidentified beryllium minerals in the deposit. The mineralization is thought to have accompanied the last stages of the rhyolite extrusion, and to have been trapped below a mantle of solidified rhyolite and tuff. The ore occurs adjacent to post-volcanic faults and this suggests that the trapped volatiles moved upwards along these zones and replaced favourable layers near them.

The grade of beryllium ore at the Spors Mountain deposits (Trover 1961, p.92) ranges from 0.10% to over 3.0% BeO, with an average probably slightly less than 1.0%. Rowe (1961) notes that individual nodules may contain as much as 10.7% BeO. Starratt (1961) mentions a deposit of approximately 3,000,000 tons containing 0.75% BeO in the Spors Mountain area. Trover notes that "the host rock is generally highly altered, containing a variety of clays, silicate minerals (both crystalline and amorphous), up to 15% fluorine, and lesser amounts of iron, manganese, magnesium and lime." The altered rocks should be rather soft and therefore easy to mine in bulk; moreover, the large tonnages favour bulk handling and consequently cheaper mining and milling costs (cf. pegmatite deposits).

Possible Beryllium-bearing tuff deposits in Australia.

Rowe (1961) in discussing the Spors Mountain - Topaz Mountain deposits, notes that the extrusive and intrusive igneous activity, and the mineralization, are all related genetically. The intimate relationship of the intrusive and extrusive acid igneous rocks finds a very close analogy in North Queensland; there Branch (1961) has found substantial evidence that the acid extrusives (rhyolites and ignimbrites) are genetically related to the Permian Elizabeth Creek Granite. Furthermore, this granite is known to be the parent of the tin-fluorite-tungsten-molybdenum mineralization and minor beryl occurrences of the Herberton mineral field, and probably the Kangaroo Hills mineral field. Mineralization in any form is, as far as is known, uncommon in the acid extrusives of the area; another difference from the Spors Mountain deposits is that the extrusive rocks are homogeneous ignimbrites (welded tuffs) and rhyolites rather than

fragmental tuffs with intercalated sediments, including limestone, which might have been more susceptible to replacement. A random specimen of ignimbrite from North Queensland was analysed for beryllium in the B.M.R. Laboratory, Canberra, and gave a result of 100 p.p.m. Be, i.e., 0.01% Be or about 0.028% BeO. This is nearly one third of the cut-off grade quoted above for Spors Mountain, i.e., 0.10% BeO, and must be considered encouraging. Regional sampling of the North Queensland Upper Permian - Lower Triassic acid volcanics should delineate areas of high beryllium background which might repay detailed prospecting. From the close association of ore with post volcanic faults at Spors Mountain it is obvious that comparable structures in North Queensland should be prospected carefully. Other areas of comparable granite-acid volcanic relations may exist in the Tasman geosyncline (the Brisbane Tuff?), and these should also be prospected.

Beryllium Deposits associated with Ring Dykes.

McAnulty et al (1963) describe the geology of the Aguachile beryllium-bearing fluor spar deposits, Mexico. Another paper by Levinson (1962) deals with the mineralization.

Mining of fluor spar in the Aguachile area began in 1952. In 1957 an analysis of drill cores revealed the presence of beryllium, and this led to the recognition of bertrandite in the deposit.

Briefly, the Aguachile area consists of a ring dyke of rhyolite porphyry enclosing an area of cauldron subsidence, now floored by quartz microsyenite. These rocks are probably Miocene or Pliocene in age, and they intrude Cretaceous sediments consisting of limestones and lesser amounts of shale, mudstone, and clay. The intrusion and collapse resulted in intense faulting and brecciation, especially along the contact of the ring dyke and sediments. A high degree of brecciation in limestone appears to have been a prime requisite for localisation of the fluor spar deposits.

Beryllium is associated with most of the fluor spar deposits of the Aguachile district, but is only significant in a few. The deposits contain the following minerals: fluorite (50-99%), calcite, quartz, hematite, and limonite, and minor aragonite, powellite, adularia, kaolinite, gypsum, sericite, and bertrandite. The beryllium content ranges from nil to several percent, and the principal Aguachile beryllium orebody has an average beryllium content of 0.1% (i.e., approximately 0.3% BeO). Most of the beryllium is contained in bertrandite, but a small amount probably is ionically combined in fluorite. The largest deposits occur in limestone along its contact with dykes of rhyolite porphyry, which occupy fault zones in local, intensely brecciated areas in contact zones along the downthrow side.

McAnulty et al recognised three, progressively weaker, episodes of fluoritisation, all of which were probably related to the parent magma of the rhyolite and quartz microsyenite and represented different stages in the magmatic sequence. Fluoritisation was probably a late hydrothermal phase following intermittent intrusive phases. Beryllium appears to be associated with the second period of fluoritisation.

Ore reserves are not known but McAnulty et al. state "data available indicate that the Aguachile beryllium-bearing fluor spar deposit contains more than 1,000,000 pounds of potentially recoverable beryllium oxide". Taking a figure of

450 long tons of BeO, i.e., 1,008,000 lbs of BeO, and the knowledge that the average grade is about 0.3% BeO, i.e., about 333 tons of ore contain one ton of BeO, we can calculate the minimum tonnage allowing no loss of BeO during concentration, viz., $333 \times 450 = 149,650$ tons of ore. It should also be remembered that this figure represents an absolute minimum estimate of available tonnage of ore grade 0.3% BeO at only one of the deposits in the area. However, this deposit is said to be the largest found there so far.

Australian Ring Dykes and their beryllium potential

North Queensland appears to be the most promising area for prospecting. Numerous ring dykes and ring complexes associated with the Elizabeth Creek Granite (parent of Sn, F, W. Mo, & Be mineralization) are known but they mostly occur through Herberton Beds east of Almaden. These Beds consist of quartzite, greywacke, slate and siltstone and contain several tin mines, e.g. around Koorboora and Sunnymount. The Gilmore Ring Complex occurs immediately to the south of the Templeton Ring Dyke, and a small lens of Chillagoe-type limestone is located in an intense fault zone along its southern boundary, near Mount Cardwell homestead. A small copper mine is located in this limestone lens, and malachite, calcite, and green garnet are the principal constituents with lesser hematite and iron and manganese staining. Both of these ring structures fringe stanniferous areas, containing accessory fluorite and topaz, and therefore should be prospected for beryllium.

Ring structures intruding limestone may occur in other parts of the Tasman Geosyncline, and a careful survey of the literature should be made in order that no other possibilities are overlooked.

Beryl-bearing Schists.

Rowe (1961) quotes Jahns (1960) as reporting beryl-bearing schists occurring near beryl pegmatites in Brazil. Beryl, chrysoberyl, phenacite, and fluorite occur as metacrysts and cavity linings in schists and gneisses. No information was obtained on grades or whether or not the deposits are economic.

Prospecting for such occurrences could be carried out around the numerous beryl pegmatites in West Australia, and near Broken Hill and Mount Isa.

Beryllium Gneisses adjacent to a Syenite Intrusion

Rowe (1961) reports barylite ($\text{BaBe}_2\text{Si}_2\text{O}_7$) in fenitized (i.e. soda-metasomatized) gneisses at Seal Lake, Labrador. Barylite accounts for only a part of the beryllium present, and there must be other beryllium minerals in the deposit. Rowe reports that two deposits have been discovered; one contains more than 9000 tons of 0.44% BeO ore per vertical foot, and the other contains about 800 tons of 0.76% BeO ore per vertical foot. Pyrochlore also occurs in the gneisses.

No possible equivalents of this mineralization in Australia are known. However, a careful search of literature dealing with Precambrian rocks in Australia might suggest some areas for examination.

METALLOGENETIC PROVINCES

It should be possible to delimit broad areas of possible beryllium occurrence. This is because beryllium occurs in and around acid igneous masses, and is commonly associated with the

volatile and more common element, fluorine (in fluorite and topaz). Such areas constitute metallogenetic provinces for beryllium. Examples of such provinces in Australia are the beryl pegmatite areas of Western Australian, Broken Hill, and Mica Creek near Mount Isa; the New England batholith in New South Wales; and the stanniferous areas of Stanthorpe, Kangaroo Hills, Herberton - Mount Garnet and Cooktown in Queensland; and Maranboy-Yeuralba in the Northern Territory. These and others will be discussed in more detail in the section on prospecting in Australia. Separate maps showing the distribution in Australia of the diagnostic associates of beryllium, viz., fluorite, topaz, cassiterite, wolframite, molybdenite, and pegmatites would assist greatly in delimiting the metallogenetic provinces prior to prospecting. Such a technique would not assist greatly in locating the larger, more obvious areas, such as New England or North Queensland, but they could draw attention to isolated minor occurrences of indicator minerals which might otherwise be overlooked. Examples of such distribution maps are included in Plates 1 to 6, but they are by no means comprehensive.

PROSPECTING METHODS

The initial stages of a prospecting campaign and the selection of metallogenetic provinces for regional prospecting have been broadly outlined in this discussion. Non-pegmatite type deposits in other parts of the world have been described and possibly analogous areas in Australia suggested.

Once a metallogenetic province has been selected the prospector has to decide between using geochemical or geophysical techniques. Beryllium deposits generally are not associated with metallic minerals, so that the normal electrical and magnetic methods of geophysical prospecting would have little application. However, an electronic instrument, called a beryllometer, has been developed, and, in that it gives direct readings of Be content, it may be regarded as an automatic geochemical analyser. Cost of the instrument is 2800 dollars (U.S.).

Useful description of the beryllometer in laboratory and field use are given by Gowie et al (1960) and Johnson (1961). The Press Information Office of the Nuclear Corporation of America explains the instrument as follows:

In use the beryllometer captures neutron emitted by beryllium ore as a result of its gamma irradiation. Neutrons are counted either by direct reading or headphones. The measurements are compared with those for known standards thus giving quantitative results.

Johnson (1961) outlines the advantages and disadvantages of the beryllometer as follows:

Advantages:

1. Portable enough for spot checks, e.g., on outcrops, alluvium, or mine dumps.
2. It is specific for beryllium regardless of its chemical combination. There are not interfering elements.
3. It is roughly quantitative for small volumes close to the detector, i.e., one square foot immediately below the instrument to a depth of three inches.
4. Accurate quantitative analyses for Be or BeO can be made on properly prepared samples by comparison with known standards in the laboratory.

5. Beryllometer analyses are faster, cheaper, and give better reproducibility than conventional wet chemical or spectrographic methods.

Disadvantages

1. There is a radiation hazard and the instrument must be licenced.
2. The weight is normally more than 36 lbs and this, combined with the radiation hazard, makes it necessary to have two men to operate it.
3. The limited detection range and slow counter rate (at least half a minute in one spot) prevent measurements while on the move.
4. The activated Sb^{124} source decays and must be replaced every four months or so at a cost of 140 dollars. There is also the difficulty and expense of transporting a new radioactive source from the nuclear laboratory, e.g., Lucas Heights, to the instrument in the field.

According to an A.E.C. circular* the cost of reactivating at Lucas Heights would be about £15, (33 dollars) and this is much lower than Johnson's figure. Bowie et al. (1960 and 1961) explain that a laboratory beryllometer can carry out 10,000 or more analyses in a year. Allowing 250 - 8 hour days in a working year, this means 40 analyses per day. Wet analyses can also produce about 40 results a day with comparable detection limits but lower reproducibility. Bowie et al (1961, p.72) also claim that the field model beryllium monitor is ideal for sampling stream sediments. It apparently gives higher results because it measures the total beryllium present in the sediment; this appears to be an advantage over normal stream sediment sampling, where the beryllium content determined by spectrographic or wet chemical analyses will only be the content of the particular size fraction chosen. Debnam (1961, p.637-641) has shown that the beryllium content is unevenly distributed throughout the various sediment size fractions, and that this size distribution differs from place to place. This represents a distinct disadvantage because beryllium anomalies tend to be of a very low order. A normal background value for beryllium in sediments and rocks would be less than 5 p.p.m. whereas a value of more than 10 p.p.m. may represent a fringe anomaly.

Conventional geochemical methods of prospecting are discussed by Griffiths and Oda (1960), Debnam and Webb (1960) and Hunt et al. (1960). For the reasons given above, a field model beryllometer seems preferable.

In prospecting for beryllium whatever the analytical technique used the approach should be the same. It should start first with regional geochemical prospecting of drainage sediments and rock types followed by detailed work on any anomalies. Several areas in Australia were suggested for detailed prospecting and, if these are examined and the results are promising, regional surveys will be justified. Regional geochemical drainage sampling carried out in North Queensland during the 1961 field season provided a set of samples which will give an idea of the regional distribution of beryllium in the area. However, it should be remembered that the sampling programme was directed at the Herbert River Granite rather than the Elizabeth Creek Granite, the possible

*

See B.M.R. file 167/1 Part 5 Entry 228.

source of beryllium in the area, and many of the favourable areas were not sampled at all, even on the regional scale.

The portable beryllometer is eminently suitable for prospect evaluation, once anomalies have been localised. It would also be a necessity in grade control during mining.

RECOMMENDATIONS

Exploration for beryllium deposits in Australia appears justified to ensure that adequate supplies of the element are available to meet current and future demands. A bonus in the investigation of beryllium deposits is the vast amount of data on other economic minerals which would be collected.

Any proposals to prospect for beryllium would fall into three stages which could be carried out separately or simultaneously.

(1) Literature study and examination of museum specimens coupled with the preparation of a metallogenetic map.

(2) Stream sediment and hard rock sampling for geochemical studies to isolate anomalous areas; testing of known beryllium-bearing deposits with beryllometer; geological mapping.

(3) Detailed geological mapping; testing of selected anomalous areas with beryllometer; shallow waggon drilling and analysis of cuttings by beryllometer or other means to select higher grade sectionsⁱⁿ lodes; at this stage exploratory diamond drilling to determine size and shape of the lodes might be needed.

Should a programme of this type be envisaged two beryllometers, one for field and one for office use will be needed.

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APPENDIX 1.

SOME PHYSICAL PROPERTIES OF BERYLLIUM METAL AND BERYLLIUM
OXIDE

(adapted from Knoerr, 1960)

	Be	BeO
Atomic number	4	-
Atomic weight	9.04	25.04
Specific gravity	1.84 - 1.85	3.025
Melting point	1,284 - 1,300°C	2,570°C
Boiling point	2.970°C	-
Hardness	55-90 knoop	2,000 knoop

Beryllium has the electrical, thermal, and lustrous properties of a true metal, but it is not readily ductile or malleable, although it has high ductility at about 600°C. It is also rather brittle, especially when cooled rapidly from high temperatures, and this is one of the main disadvantages to its more general use. Beryllium metal has a very low capacity for the absorption of X-rays and thermal neutrons. Its most valuable properties are its light weight, high tensile strength, and very great rigidity.

Beryllium is similar in some respects to aluminium. Both form protective oxide coatings on exposure to air or an oxidising environment.

Beryllium metal dissolves readily in hydrochloric or sulphuric acids, and less readily in nitric acid. In general the reactivity increases with temperature, and molten beryllium is very reactive. Impurities also have a marked effect on the degree of reactivity.

Beryllium compounds may be toxic in the form of dust or fumes (see below).

Beryllium is an important alloying material, particularly with copper. It gives the copper strength and elasticity without causing any reduction of its high thermal and electric conductivity. Other properties of the alloy are high resistance to corrosion and fatigue, stability under load, and excellent castability and machineability.

Properties of Major Light Metals and Steel

	Density (lb/in.)	Melting Point °C	Modulus of Elasticity, (psi) x 10 ⁶	Tensile Strength, psi x 10 ³
Beryllium	0.066	1290	40	40-80
Aluminium	0.100	660	9.6	25-85
Magnesium	0.065	650	6.5	24-52
Steel	0.280	1510	30	185-250
Titanium	0.165	1815	15.5	130-170

Comparison of beryllium with other metals as a heat-sink material

	Specific Heat	Melting Point °C	Density g/cc.	Pounds of metal required for equal heat absorption
Beryllium	0.46	1,290	1.85	350
Aluminium	0.22	660	2.70	700
Steel	0.12	1,510	8.0	1,350
Copper	0.09	1,082	8.9	1,750

More comprehensive lists of the properties of beryllium and beryllium oxide are given by Knoerr (1960, p.101).

Toxicity of beryllium

Dust and fumes from beryllium compounds, when absorbed by man, may cause the development of skin and respiratory diseases. The skin disease takes the form of dermatitis and ulcers; open wounds are particularly susceptible to infection. The respiratory disease may take the form of acute irritation of the respiratory tract (chemical pneumonia), or the chronic lung disease, berylliosis.

Provided working places and working clothes are kept clean, and workers wash their hands frequently, the danger is minimised. No worker must be exposed at any time to an atmospheric concentration of more than 25 micrograms of beryllium per cubic metre, and average concentration over an eight-hour shift should not exceed 2 micrograms of beryllium per cubic metre (McQuillan and Farthing, 1961).

APPENDIX 2.

USES OF BERYLLIUM AND ITS COMPOUNDS

Alloys:

The use of beryllium in beryllium-copper alloys accounts for about 80 percent of the production at present. Beryllium is also alloyed with nickel, iron, aluminium and magnesium, and the products have nuclear and high temperature applications.

Nuclear Applications: (McQuillan and Farthing 1961)

Beryllium and its oxide have been used extensively in nuclear reactors. Beryllium has a lower absorption of thermal neutrons than any other structural metal. Neutrons are the means by which nuclear reactions are propagated in reactors, so that reactor efficiency depends on keeping neutron absorption and losses to a minimum. Beryllium also has a very low atomic weight (9.04), which fits it for use as a moderator - i.e., the material surrounding the reactor fuel - whose purpose is to slow down the neutrons produced in the fission process so that they can more efficiently interact with additional uranium nuclei.

Beryllium oxide is also used to retard fission neutrons, to reflect neutrons back into the core, and in thermal radiation shields.

Beryllium is an excellent casing material for uranium fuel in graphite moderated and gas-cooled reactors. However, magnesium is preferred because it can be used at lower temperatures and is more readily available. Advanced gas-cooled reactors will work at high temperatures (about 600°C), although stainless steel will be used in preference to beryllium because of the latter's brittleness.

Aircraft and Space Applications:

The light weight and high melting point of beryllium make it attractive for use in the aircraft, missile, and rocket industries. Because of its properties of low ductibility, confined in two directions, and brittleness its usage is restricted to non-structural applications in these industries. It is used in missile nose cones, and space capsules (e.g. Mercury) as a heat shield, tail fins, meteor bombardment shield, and instrument parts. The high heat resistance of beryllium oxide makes it suitable for use as lining material in rocket nozzles.

Rocket Fuel: Beryllium may be used as a solid fuel for rockets. Theoretically it seems suitable; a detailed discussion of the subject is given by Brenner and Kopelman (1961).

Refractories:

Beryllium oxide is an excellent high temperature refractory material. Consequently it is used in electrical heating apparatus, thermal radiation shields, crucibles, furnace linings, electronic and aerospace components. Its use in nuclear industries is discussed above.

General:

Beryllium metal and compounds are used in windows of X-ray tubes, aircraft brake drums, gyroscope parts, electrical contacts, springs, bellows, engine parts for aircraft, marine propellers, gears, bearings, precision castings, and rollers.

Beryllium Research:

The main aims of current research are to give beryllium more uniform room temperature ductibility, and to improve its workability at higher temperatures by eliminating minima in the ductibility/temperature curve. The tendency for fracture cleavage to occur on the basal plane must also be overcome.

Future of Beryllium:

The future of beryllium depends largely on the success of current research projects. Other factors are availability and cost. New discoveries suggest that it need not be in short supply. If research is successful in overcoming the disadvantages of the metal the resulting increased usage should lower the cost of production because of the greater turnover.

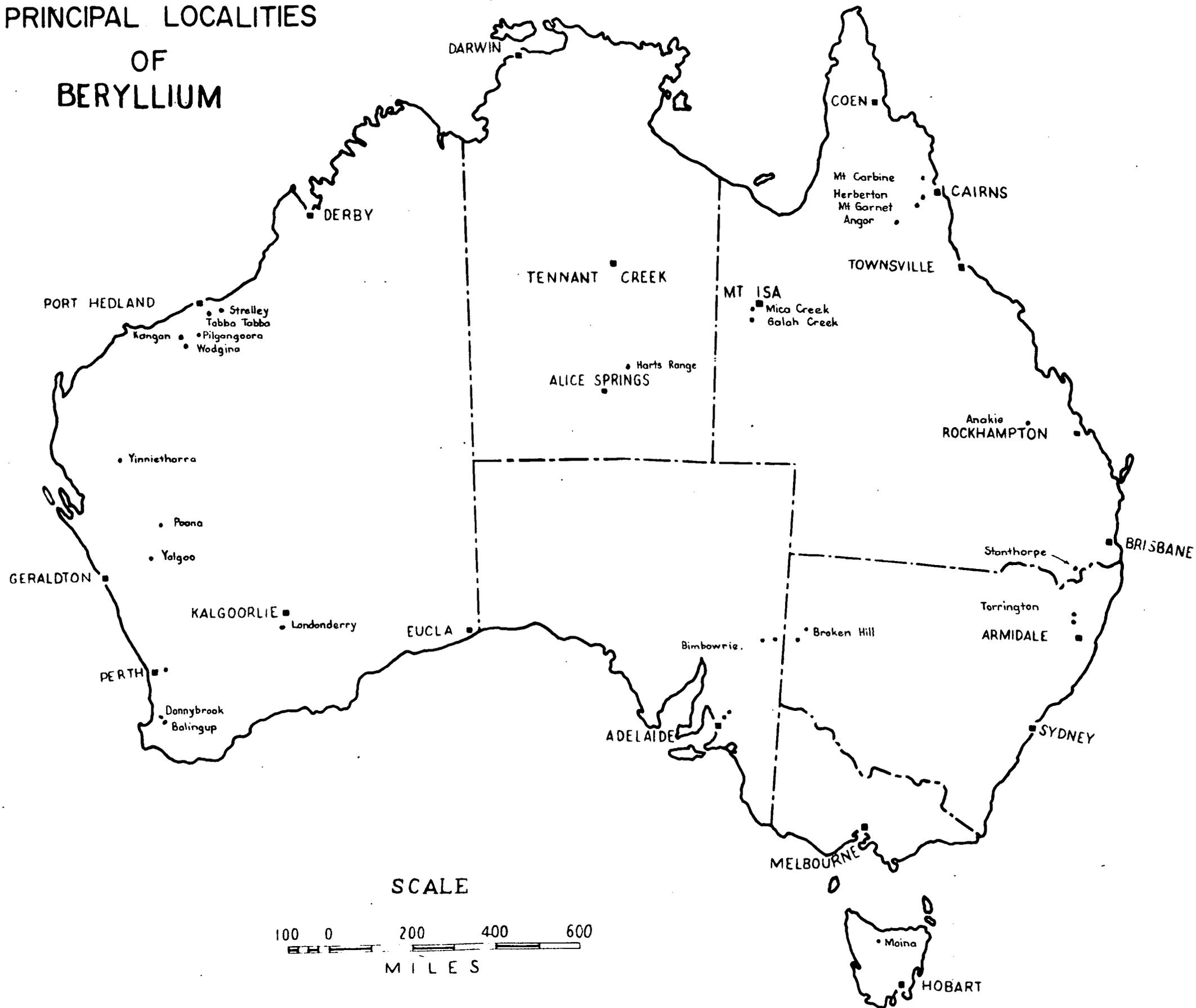
APPENDIX 3.

PRINCIPAL BERYLLIUM MINERALS - THEORETICAL PERCENTAGE.

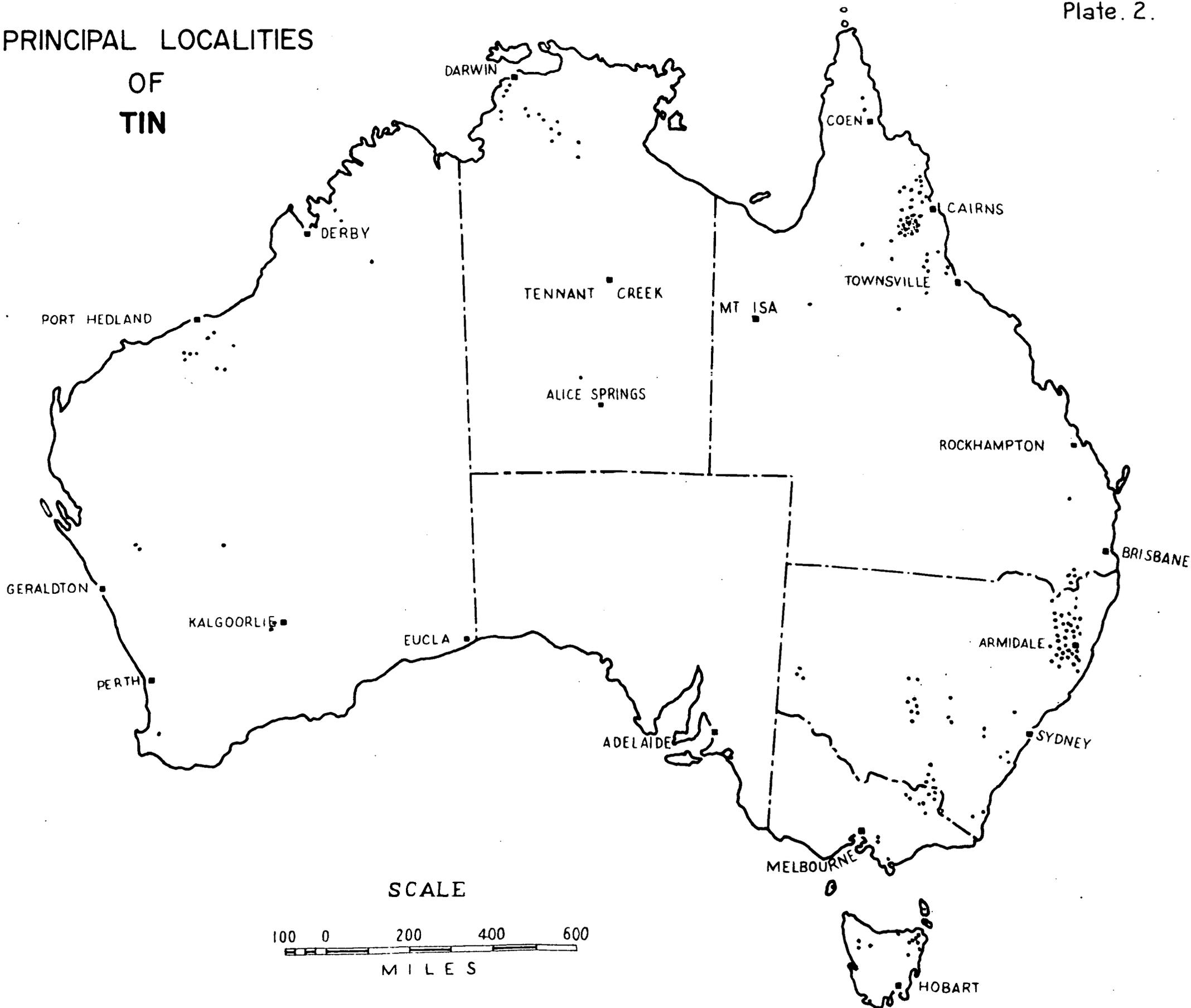
Mineral	Composition	S.G.	BeO Content	Be Content	Occurrences.
Barylite	$\text{Be}_2\text{BaSi}_2\text{O}_7$	4.0	15	5.6	Contact met., greisen.
Bertrandite (1)	$4\text{BeO} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$	2.6	42	15.1	Granite, pegmatite, greisen, skarn tuff.
Beryl (1)	$3\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	2.6-2.8	14	3-3.5	Granite, pegmatite.
Beryllonite	$\text{Na}_2\text{O} \cdot 2\text{BeO} \cdot \text{P}_2\text{O}_5$	2.8	20	7.1	" "
Bromellite	BeO	3.0	100	36.0	Contact met.
Chrysoberyl (1)	$\text{BeO} \cdot \text{Al}_2\text{O}_3$	3.5-3.8	20	7.1	Granite pegmatite.
Euclase	$2\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot \text{H}_2\text{O}$	3.1	17	6.1	" "
Eudidymite	$\text{Na}_2\text{O} \cdot 2\text{BeO} \cdot 6\text{SiO}_2 \cdot \text{H}_2\text{O}$	2.6	10	3.7	Neph. Syonite.
Gadolinite	Variable	4.0-4.5	10	3.2-4.7	Granite pegmatite.
Hambergite	$4\text{BeO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$	2.3	53	19.2	Granite & syonite.
Holvite (1)	Mn, Fe, Be sulfosilicate	3.2-3.4	14	3.8-5.4	Various
Harderite	$\text{CaO} \cdot \text{CaFOH} \cdot 2\text{BeO} \cdot 2\text{P}_2\text{O}_5$	3.0	15	5.6-5.9	Granite pegmatite
Leucophanite	Ca, Na, Be, fluosilicate	3.0	10	4.0	Syonite pegmatite
Moliphanite	Ca, Na, Be "	3.0	13	3.4-5.0	" "
Phonacite (1)	$2\text{BeO} \cdot \text{SiO}_2$	3.0	46	16.4	Granite pegmatite, greisen, skarn.
Milarite	$\text{K}_2\text{O} \cdot 4\text{CaO} \cdot 4\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 24\text{SiO}_2 \cdot \text{H}_2\text{O}$	2.55	?	?	?
Trimerite	$(\text{Mn}, \text{Ca})_2\text{SiO}_4 \cdot \text{Be}_2\text{SiO}_4$	3.5	?	?	?
Danalite	$3(\text{Fe}, \text{Mn}, \text{Zn})\text{BeSiO}_4 \cdot \text{ZnS}$	3.4	?	?	Granite
Kolbeckite	Be phosphate	2.40	?	?	?

(1) Most important potential beryllium source minerals.

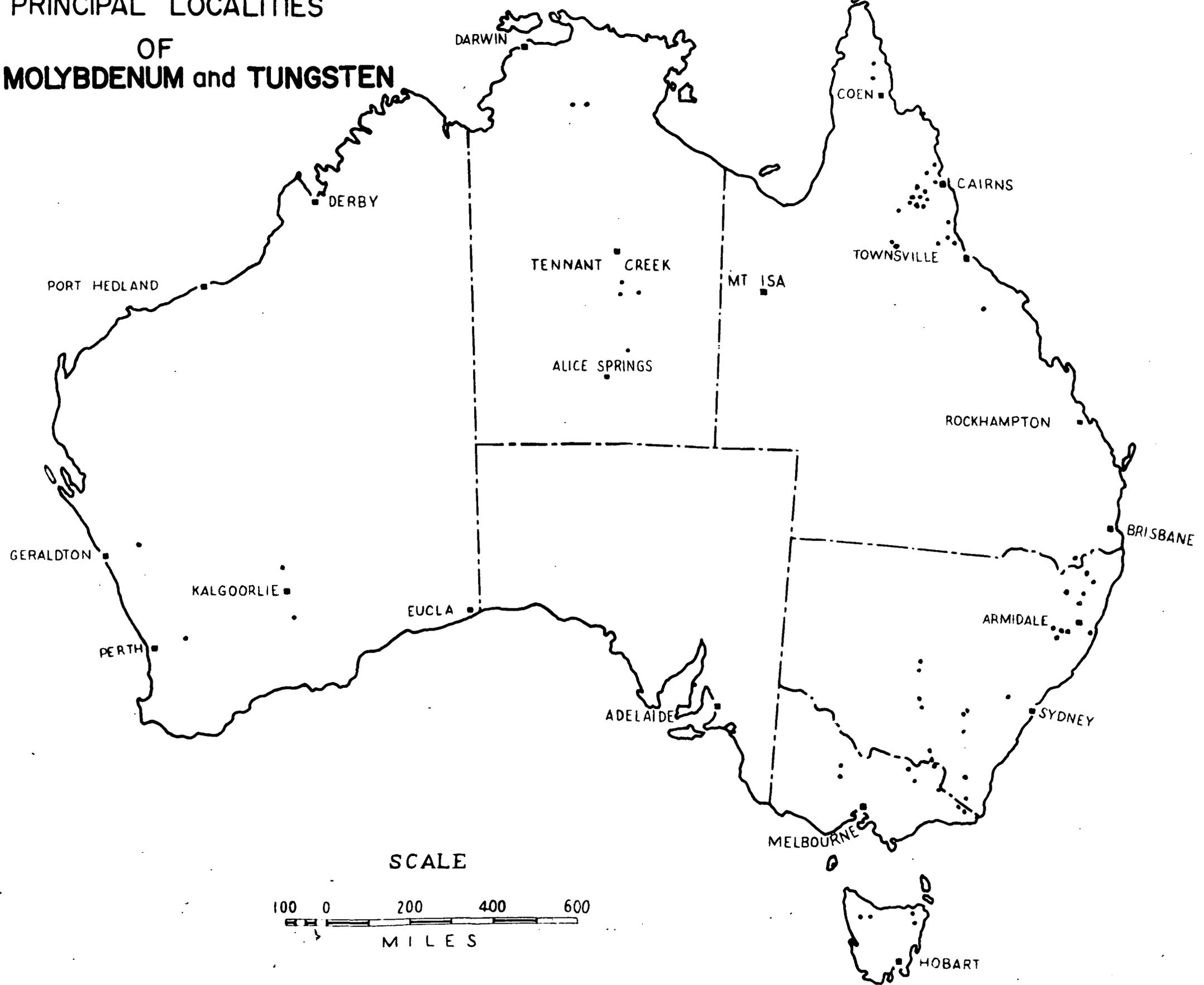
PRINCIPAL LOCALITIES OF BERYLLIUM



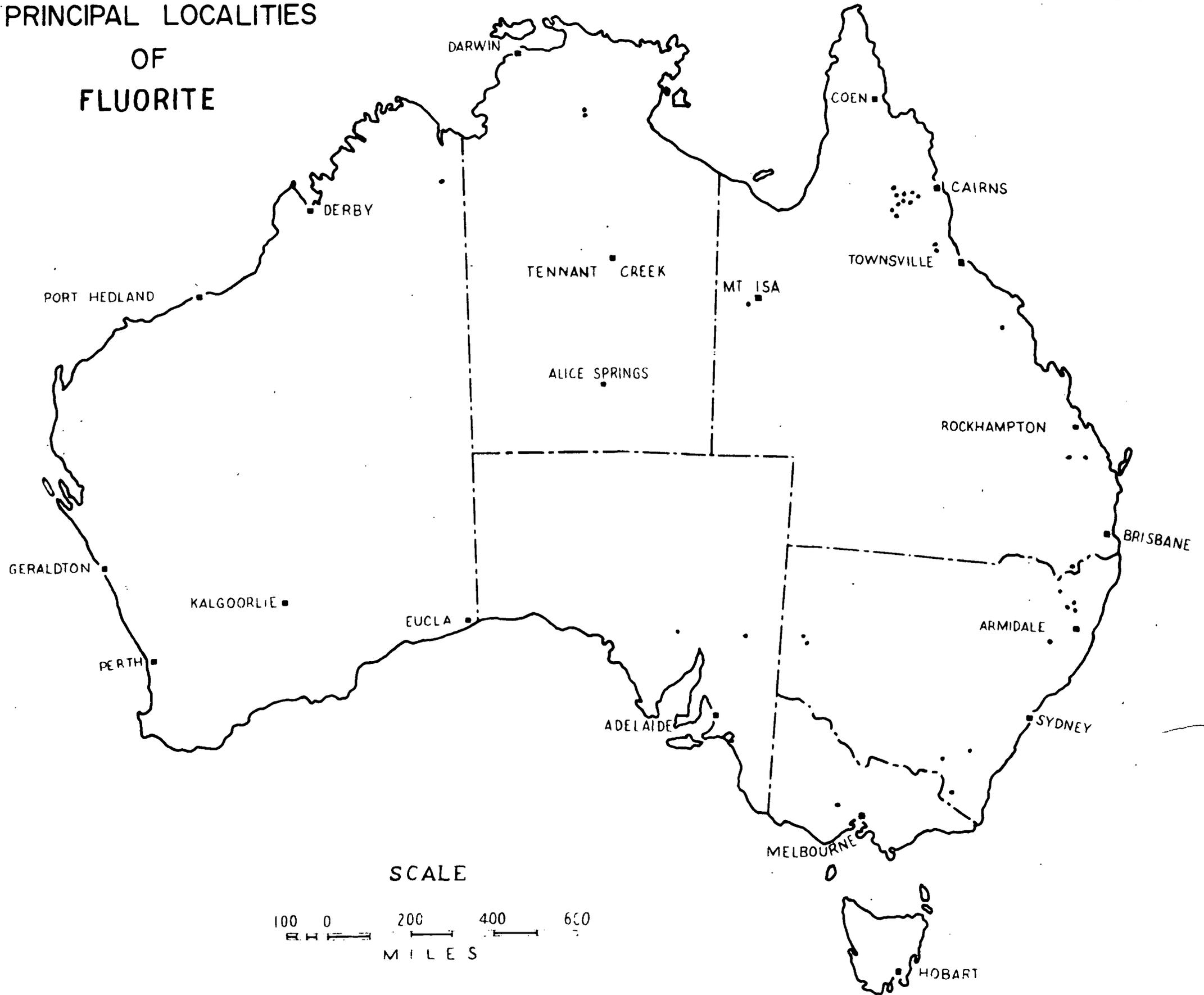
PRINCIPAL LOCALITIES OF TIN



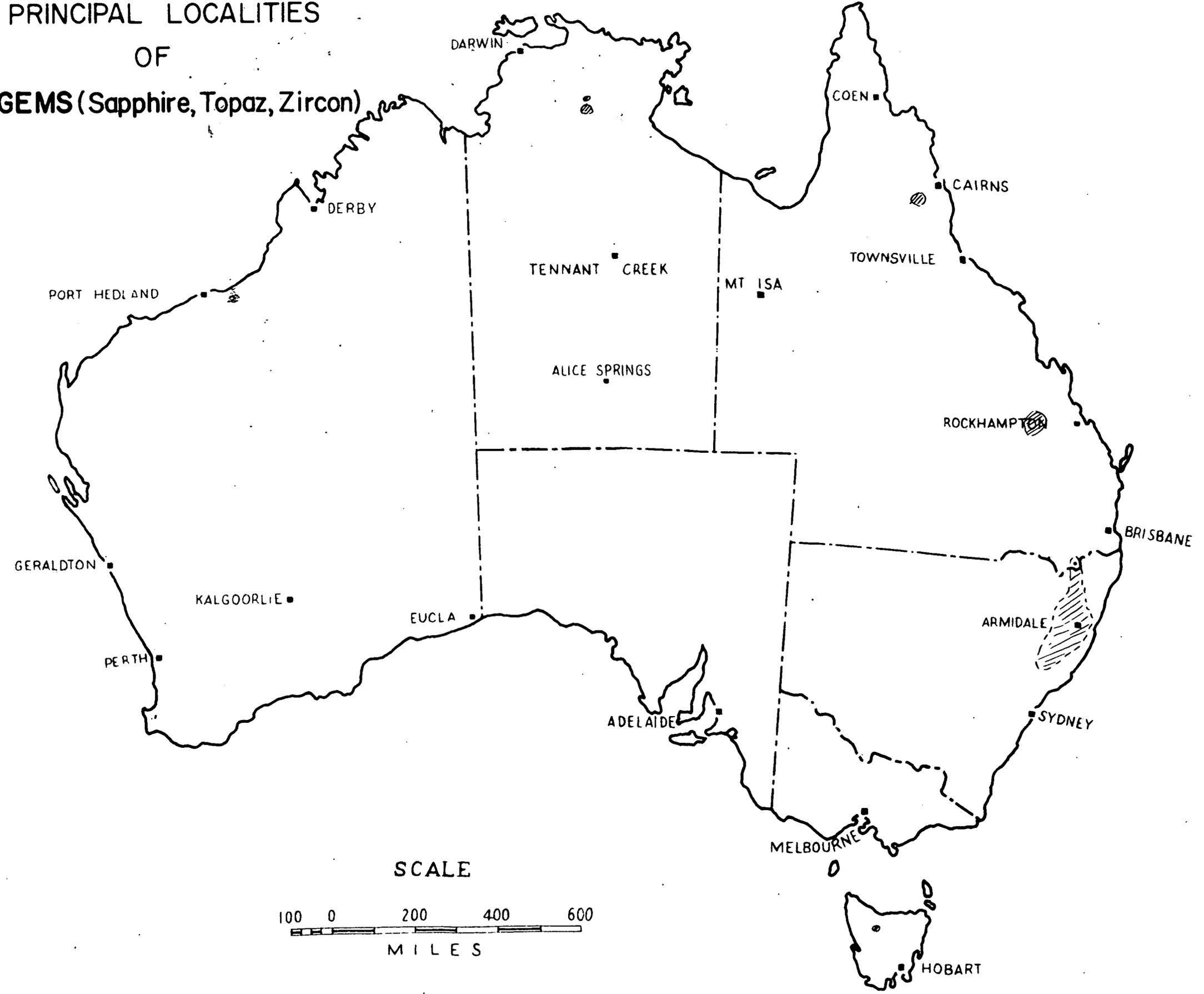
PRINCIPAL LOCALITIES OF MOLYBDENUM and TUNGSTEN



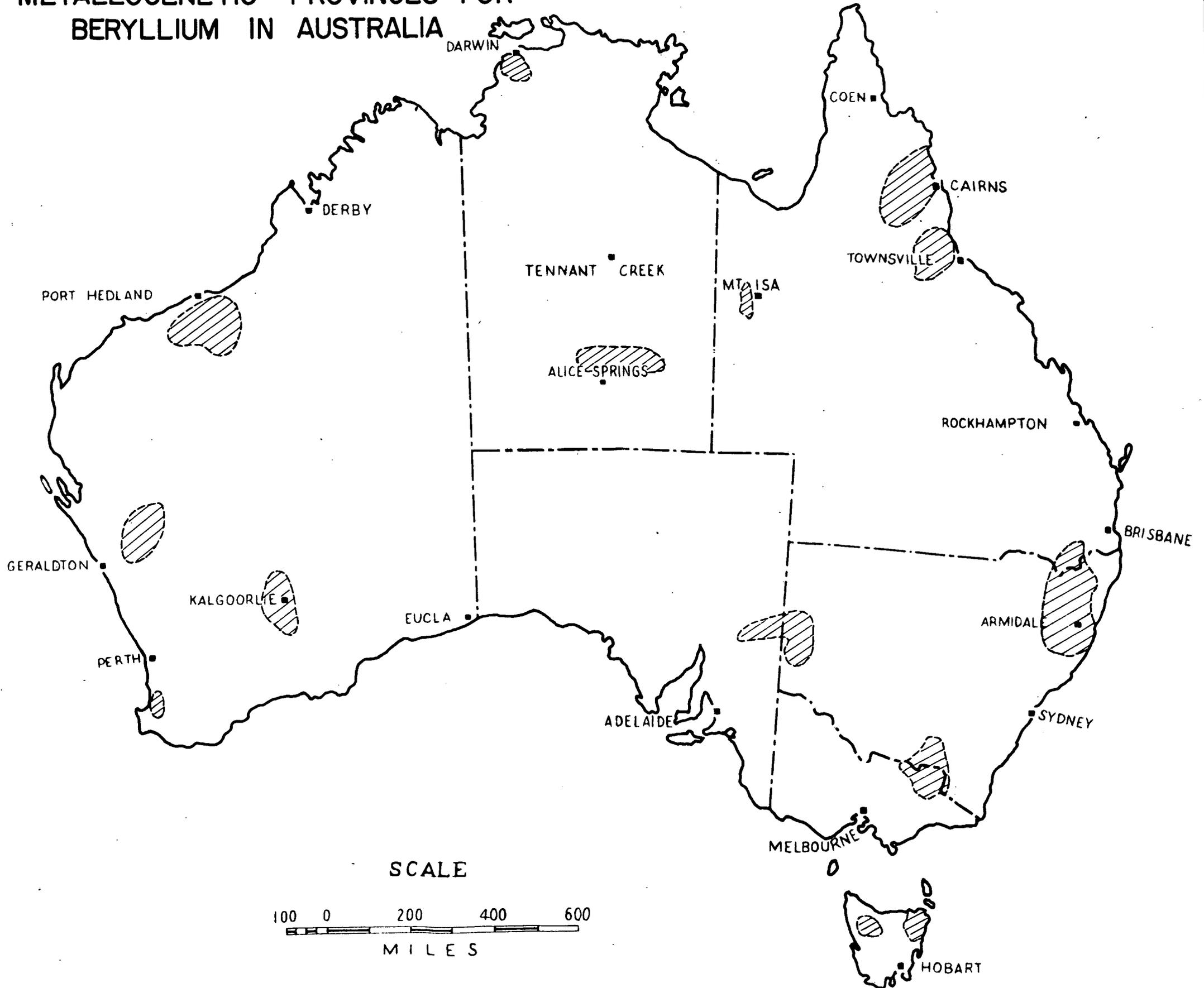
PRINCIPAL LOCALITIES OF FLUORITE



PRINCIPAL LOCALITIES OF GEMS (Sapphire, Topaz, Zircon)



METALLOGENETIC PROVINCES FOR BERYLLIUM IN AUSTRALIA



SCALE

