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Controls of tin-bearing pegmatites and granites in the Precambrian of Broken Hill, Australia

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Abstract: The field setting, mineralogy and geochemistry of the cassiterite-bearing pegmatites and greisens of the Broken Hill area are described for the first time. The tin ore occurs in cassiterite-bearing pegmatites generally emplaced parallel to the bedding of the regional Precambrian, Carpentarian (1700 m.y.) phyllites and schists of the Willyama Complex. The cassiterite is not disseminated through the rocks but is usually found in irregular masses at the intersection of cross-fractures within the pegmatite bodies. Greisens are often associated with these cassiterite pegmatites. The pegmatites are considered to be part of a differentiated felsic sequence derived from a tin-bearing anatectic melt now represented by a foliated biotite granite. A tectonic model is presented that relates the tin deposits to a Proterozoic rifting event controlled by a fundamental regional NE trending dextral shear couple.

INTRODUCTION

Recent investigations on the tectonic and plate tectonic controls of mineralization (Mitchell and Garson, 1976) have also been applied to the Precambrian Broken Hill area (Katz, 1976a, b) ,a region known for its extensive deposits of lead and zinc and other metals. Smaller tin-pegmatite deposits have been recognized for many years (Lishmund, 1974). The Euriowie Tin Field along with the Waukeroo Field were perhaps the largest deposits in the Broken Hill region. The Euriowie Field and its regional setting was studied by Tuckwell (1975). The tin-pegmatites are quartz-albite rocks with muscovite, apatite and tourmaline. Other minerals that may be present include amblygonite, caesium beryl, pyrite, topaz, lepidolite and fluorite. Their nature and tectonic setting show affinity to tin-bearing granites of anorogenic character related to intracontinental rifting, as proposed for the tin-bearing granites of Nigeria and other localities (Sillitoe, 1974; Lowell; 1976; Sawkins, 1976).

REGIONAL SETTING

Broken Hill is situated in Western New South Wales, Australia (fig. 1) and is recognized because of the existence of its huge lead-zinc deposits. Tin in the form of cassiterite was first discovered at Euriowie in 1884 (Kenny, 1928) and extensive mining activity proceeded, gaining impetus from the expanding lead-zinc reserves at Broken Hill. Old mining records are very incomplete but indicate that very little cassiterite was actually found or extracted. Both the lead-zinc and tin mineralization occur in the Precambrian, Carpentarian (1700 m.y.) Willyama Complex. Cassiterite-bearing pegmatites and greisens are found only with the lower grade regional metamorphic rocks (greenschist—lower amphibolite facies). Three regions of tin mineralization can be recognized, in order of importance; the Euriowie (near Bijerkerno), Waukeroo and Kantappa tin fields (fig. 1).

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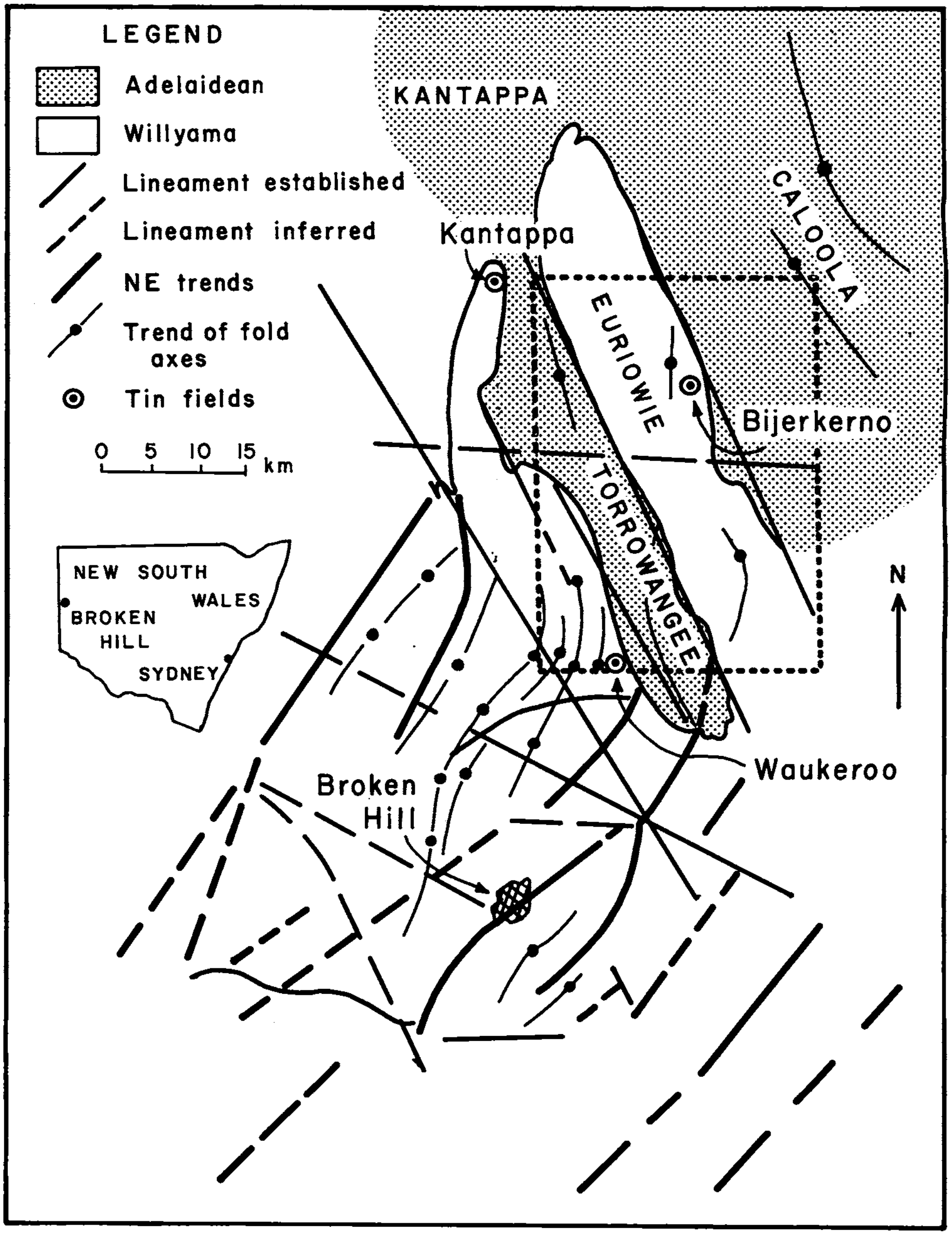

Fig. 1. Geological lineament map of the Broken Hill area (after Katz, 1976b). Outlined block refers to location of Fig. 2.

THE EURIOWIE TIN FIELD

Structure, Metamorphism and Igneous Features

The Euriowie tin field is situated on the eastern edge of the Euriowie Horst Block, immediately adjacent to the core region of the Bijerkerno Syncline in greenschist facies carbonaceous meta-siltstones of the Bijerkerno Beds (Tuckwell, 1978) (fig. 2). The host rocks for the cassiterite mineralization are pegmatites, quartz albitites and greisens, which are believed to belong to a differentiated felsic rock series which intrudes both the Bijerkerno and underlying Wookookaroo Beds. The area has suffered two periods of penetrative deformation called D1 and D2. D1, which is roughly contemporaneous with the first medium-high grade metamorphism M1, is the earliest folding event, during which S_1 may be parallel to bedding (S_0) but is usually oblique to S_0 showing constant dextral vergence relationships. Large scale fold closures related to D1 have not been observed, but as facing consistently indicates the rocks are right way up, none are believed to exist in the area. D2 is the second period of deformation which accounts for the major structural configuration and is roughly coeval with the later retrograde metamorphism M2. S_2 schistosity was developed during D2 and is parallel to axial planes of D2 folds, of which the Bijerkerno Syncline is the most conspicuous example (fig. 2). The Bijerkerno Syncline is a northward plunging D2 structure developed on the dextral limb of what is probably a D1 anticline overturned to the east. Prograde regional metamorphic isograds developed during the first metamorphism (M1) (with D1) are nearly parallel to bedding (S_0). Both the isograds and bedding have since been folded about the syncline during D2. Accompanying retrograde metamorphism (M2) has regionally down-graded the host rock assemblages, but has had little effect on the primary mineralogical and chemical characteristics of the tin-bearing pegmatites and greisens.

The felsic intrusive series was emplaced during M1 and differentiated presumably under the influence of the M1 metamorphic (and tectonic) gradient. As a consequence, these intrusives are arranged in nearly discrete zones that are approximately parallel to bedding, and which are also folded. Table 1 details the field and mineralogical relationships displayed by the intrusives. The foliated biotite granite (Type 4) is reasoned to be the parent rock from which the other types developed under the influence of the metamorphic and tectonic gradient. The change from foliated biotite granite at deeper levels through to the cassiterite-bearing pegmatites at shallower levels corresponds to the decrease in metamorphic grade with stratigraphic level. The correlation of metamorphic grade and intrusive type with stratigraphic depth is based on distinctive field relationships.

1) Parallelism of isograds with bedding. A regional heating event would tend to produce isograds parallel to bedding if the rocks were flat lying.

2) Pegmatites which have obviously been intruded parallel to bedding have given rise to a metasomatic alteration zone stratigraphically about the pegmatite. The size of this alteration zone is usually proportional to the size of the pegmatite. Tourmaline and apatite are developed within and adjacent to the upper surface of the pegmatite, and muscovite as a coarse-grained aggregate occurs in a bleached zone further above the tourmaline-apatite zone. There are no effects of alteration at the lower boundaries of the pegmatite. This can only be interpreted to mean that bedding was horizontal, or nearly so, at the time of intrusion of the pegmatite.

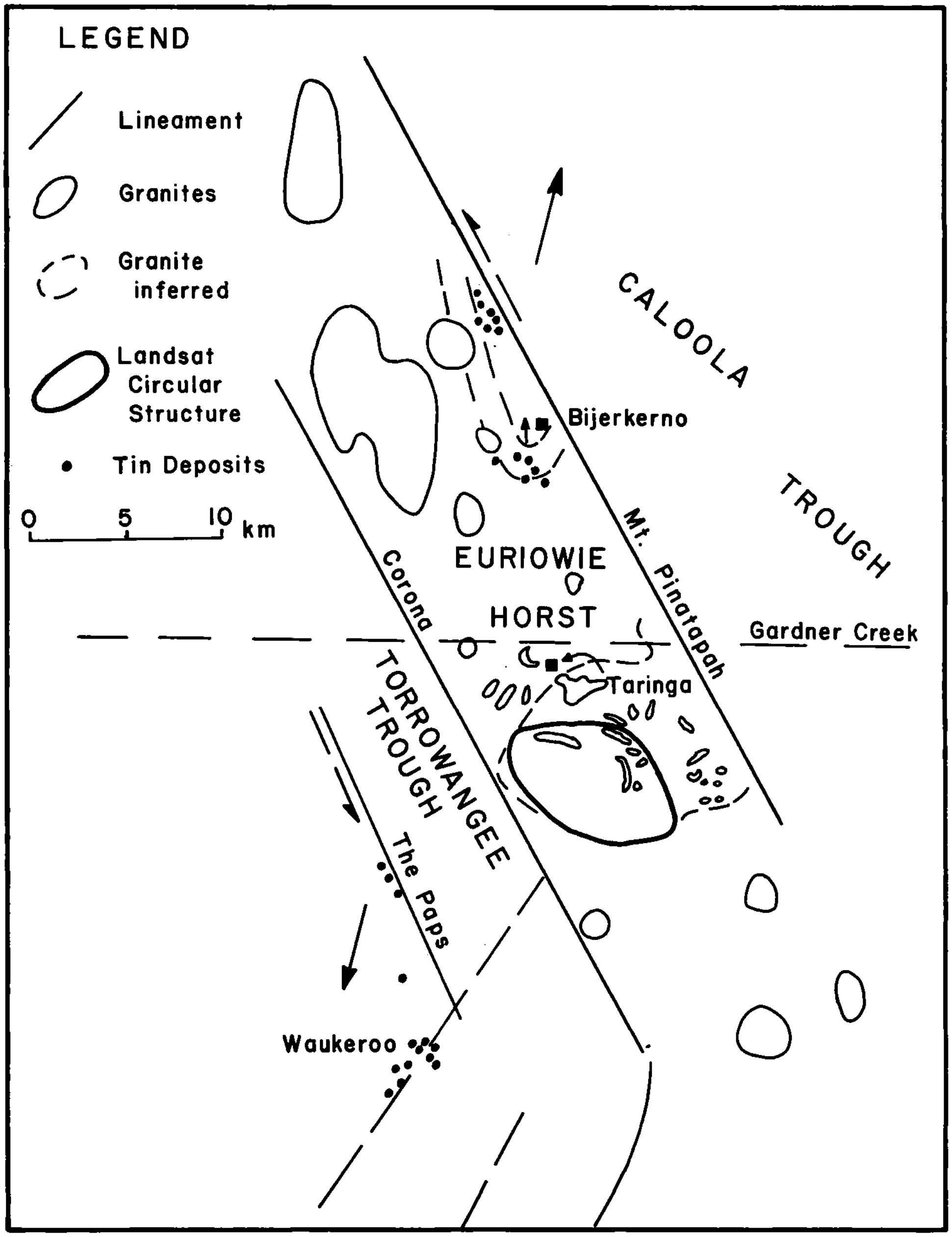

Fig. 2. Tectonic framework of tin mineralization at Euriowie (Bijerkerno) and Waukeroo (after Geological Survey of New South Wales, 1970, Cooper et. al. 1975, Bureau of Mineral Resources, 1976, Katz, 1976b). NW Conjugate Riedel sinistral shear couple under a primary regional NE dextral shear leads to extensional forces which developed a graben-trough, horst arrangement of blocks. Granite-diapiric intrusives are well developed in the Euriowie horst.

TABLE 1

MAIN FEATURES OF THE FELSIC INTRUSIVES FOR THE EURIOWIE BLOCK

1 Depth		2 Stratigraphy	3 Metamorphic Grade	Intrusive Type	Mineralogy of Intrusive	Field Setting of Intrusive
	BIJERKERNO BEDS	Late Precambrian Carbonaceous Chlorite/Biotite phyllites and quartzites	CHLORITE	TYPE 1	*TYPE* 1 Quartz albite+muscovite (lemon yellow-green in colour)+apatite+tourmaline+cassiterite. Includes rock types, pegmatite quartz, albitites and greisens. Pegmatite is generally the host rock to the other two.	Thin tabular sheets 0.25m to 2m thick, parallel to bedding but locally discordant. Folded. Feeder veins are discordant and strongly folded.
500m—		Calcsilicate Unit Slightly carbonaceous quartzite and biotite, andalusite schists	ANDALUSITE BIOTITE	TYPE 2A TYPE 2B TYPE 3	*TYPE* 2 Quartz albite+microcline+muscovite+garnet pegmatites and granitoids. A. Concordant pegmatites. Quartz+albite+garnet, pegmatites and garnet albitites. B. Discordant pegmatites. Quartz+albite+microcline+garnet intrusives with large perthite crystals up to 1m long. Garnet confined mainly to coarse-grained groundmass. C. Equigranular garnet-muscovite granitoids. Coarse-grained equigranular quartz+microcline+muscovite+albite+garnet. Granoblastic texture. Sillimanite may be present as an accessory.	A. Thin tabular sheets – often boudinaged and lenticular 1—3m thick, often displaying internal mineralogical zoning. B. Highly irregular in shape discordant and sometimes dyke-like. About 1km² in area. C. Larger foliated masses usually discordant but locally parallel to bedding and/or foliation. Up to 5km² in area.
1000m—		Minor Calcareous quartzites with andalusite+sillimanite schists	SILLIMANITE	TYPE 2C		
1500m—	WOOKOOKAROO BEDS	Sillimanite schists with quartzites		TYPE 4	*TYPE* 3 Highly variable very coarse-grained pegmatites texturally similar to *TYPE 2B*. Do Not contain garnet or sillimanite, but are characterised by coarse albitised K-feldspar and may contain coarse biotite and/or interstitial microcline.	Very irregular coarse-grained usually discordant pegmatites more or less directly associated with *TYPE 2C* and *2B* intrusives.
2000m—			K.SPAR.	?	*TYPE* 4 Very distinctive but texturally similar to *TYPE 2C*. Granoblastic aggregates of quartz+microcline+albite with segregation of biotite and minor muscovite. Well toliated and consistently contains accessory sillimanite.	Foliated granitoids structurally elongate parallel to bedding and/or foliation. Locally concordant with bedding and up to 20km² in area.

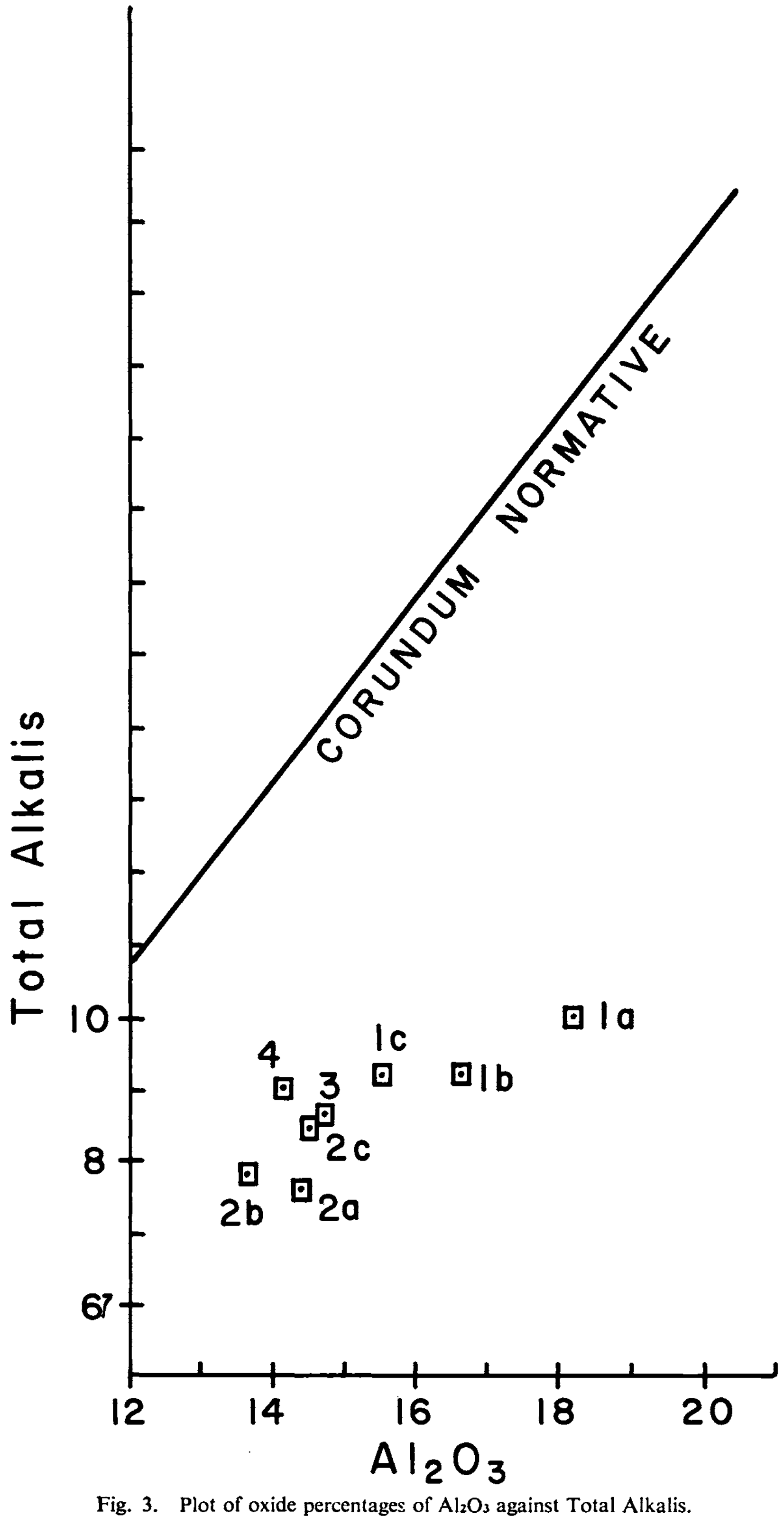

Fig. 3. Plot of oxide percentages of Al_2O_3 against Total Alkalis.

These lines of evidence suggest that the rocks were horizontal and younging upwards at the time of metamorphism M1 and intrusive emplacement. Under these conditions, metamorphism can be correlated with stratigraphic depth.

Intrusive Rock Chemistry

Selected samples of each intrusive type recognized on the basis of mineralogical similarities and field setting were analysed by X-ray flourescence (XRF). The mean results for each type were normalised by the CIPW norm calculation as revised by Hutchison (1974) (Table 2).

1) All intrusives are corundum-normative indicating that they were probably derived from an anatectic melt (fig. 3).

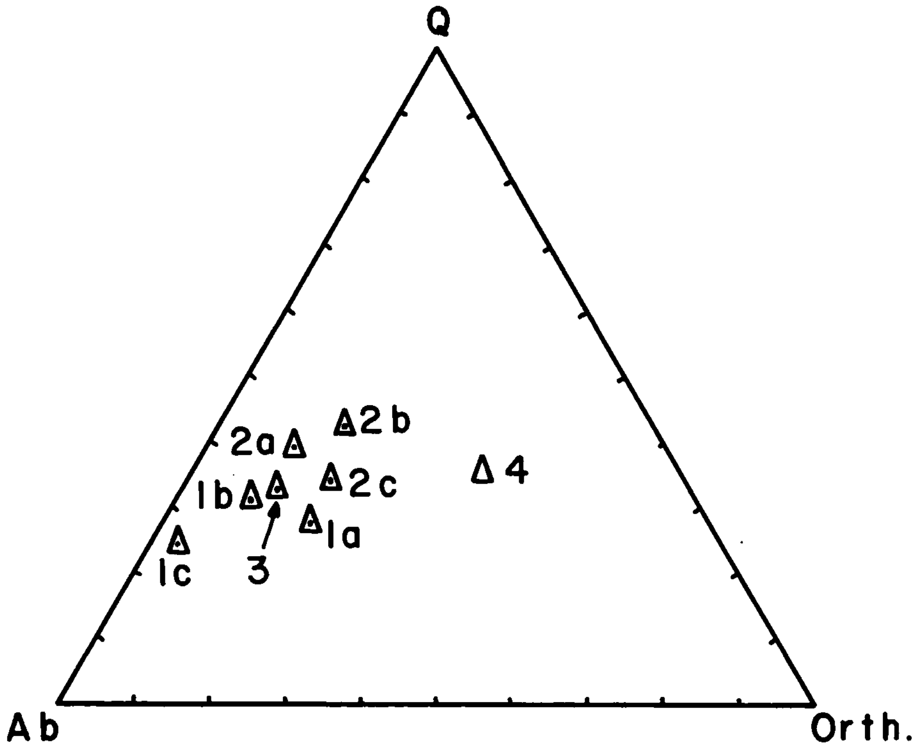

Fig. 4. Ternary plot in terms of normative Albite-Orthoclase-Quartz. Type 4 intrusives plot close to the ternary minimum of Luth, Jahns & Tuttle (1964).

2) The foliated biotite granite (Type 4) approximates very closely to the ternary minimum for water vapour pressures of 3.6 kb (Luth, Jahns and Tuttle, 1964) (fig. 4).

3) The Na enrichment trend through Types 2–1 is explained by the loss of potassium relative to sodium to the country rocks to form muscovite (fig. 5).

TABLE 2

INTRUSIVE ROCK CHEMISTRY

Sample Type	1a		1b		1c		2a		2b		2c		3		4	
No. of Analyses	5		3		13		10		2		9		6		5	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
SiO_2	68.20	3.09	71.95	5.18	73.33	4.83	74.90	1.56	76.44	2.12	74.90	1.14	74.61	0.40	72.77	0.74
TiO_2	0.01	0.02	0.02	0.01	trace		0.02	0.03	0.03	0.01	0.01	0.01	0.03	0.03	0.11	0.05
Al_2O_3	18.21	1.69	16.62	3.85	15.53	2.99	14.37	1.56	13.63	1.01	14.50	0.48	14.67	0.34	14.12	0.34
Fe_2O_3	0.74	0.40	0.44	0.10	0.61	0.75	1.46	0.58	1.42	0.95	1.30	1.17	0.71	0.21	0.40	0.26
FeO	ND		ND		ND		ND		ND		ND		ND		1.25	0.20
MnO	0.04	0.03	0.03	0.01	0.03	0.02	0.46	0.52	0.05	0.01	0.25	0.33	0.02	0.01	0.05	0.02
MgO	0.14	0.10	0.42	0.05	0.07	0.14	0.41	0.33	0.50	0.19	0.16	0.17	0.37	0.36	0.51	0.31
CaO	1.53	0.82	0.74	0.23	0.53	0.25	0.42	0.14	0.78	0.02	0.45	0.18	0.51	0.12	0.38	0.10
Na_2O	5.60	2.30	7.24	1.85	8.10	2.24	5.41	1.86	4.45	0.37	5.10	1.13	6.11	1.01	2.78	0.53
K_2O	2.89	1.44	1.24	0.96	0.56	0.42	1.79	1.08	2.62	0.18	2.98	1.62	1.99	1.14	5.84	0.51
P_2OS	1.11	0.58	0.62	0.22	0.49	0.21	0.18	0.03	0.12	0.06	0.15	0.03	0.29	0.13	0.19	0.06
Loss	1.26	0.42	0.74	0.43	0.78	0.25	0.99	0.52	1.00	0.05	0.74	0.28	0.88	0.16	1.67	0.53
TOTAL	99.74		100.48		100.02		100.39		101.10		100.55		100.17		99.75	
Qtz.	24.61	5.69	29.23	10.95	23.71	17.09	35.90	6.84	38.58	3.63	32.60	2.47	30.98	3.19	32.30	4.18
Cor.	5.89	3.40	4.05	2.43	1.55	1.57	3.33	2.89	2.37	0.70	2.31	0.72	2.38	0.69	2.99	0.98
Orth.	17.10	8.49	8.70	3.31	3.33	2.49	10.57	6.41	15.48	1.09	17.60	9.58	11.67	6.73	34.54	3.03
Ab.	46.50	18.16	54.07	7.27	68.73	19.15	45.13	15.77	37.49	2.88	43.82	9.46	51.51	8.60	23.45	4.53
An.	0.39	0.29	0.00	–	0.01	0.02	0.91	0.74	3.09	0.13	1.24	1.03	0.64	0.62	0.67	0.34
Ap.	2.61	1.41	0.91	0.33	0.95	0.44	0.43	0.06	0.27	0.08	0.36	0.08	0.68	0.30	0.44	0.15
Ilm.	0.02	0.04	0.04	0.05	0.00	–	0.02	0.02	0.05	0.01	0.02	0.03	0.05	0.05	0.32	0.09
Mag.	0.11	0.12	0.05	0.05	0.08	0.06	0.95	0.99	0.09	0.07	0.72	1.11	0.15	0.30	0.59	0.38
Haem.	0.59	0.49	0.54	0.15	0.49	0.76	0.74	0.37	1.36	0.90	0.81	0.44	0.55	0.27	0.00	–
Hyp.	0.46	0.19	1.33	0.41	0.18	0.34	1.08	0.87	1.24	0.47	0.40	0.43	0.93	0.89	3.05	1.05
Sphen.	0.05	0.04	0.05	0.05	0.02	0.02	0.11	0.10	0.05	0.06	0.05	0.05	0.04	0.03	0.0	0.021
Acm.	0.23	0.51	0.00	–	0.18	0.43	0.00	–	0.00	–	0.00	–	0.00	–	0.00	
TOTAL	98.55		98.96		99.22		99.15		100.04		99.93		99.54		98.36	

Rock types 1a, 1b, 1c respectively are cassitente-bearing greisens, quartz albitites and pegmatites

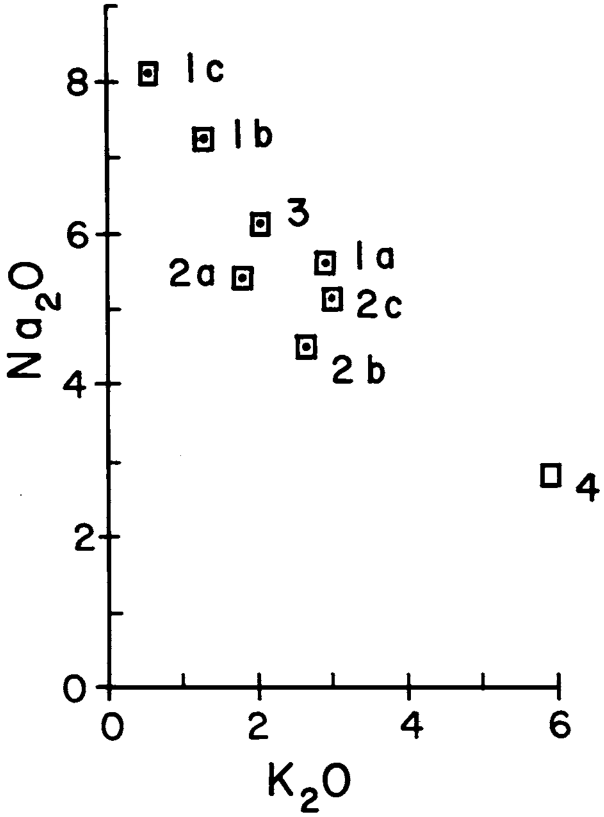

Fig. 5. Plot of oxide percentages of K_2O against Na_2O.

4) Strong negative correlations are evident between SiO_2 and Al_2O_3 (fig. 6) and between Na_2O and K_2O (fig. 5). Both these trends reflect the breakdown of K–feldspar to form albite and muscovite and loss of K_2O and SiO_2 from the pegmatites to the country rock. These changes correlate with events at shallower levels in the crust.

5) Within the cassiterite-bearing rocks, CaO and P_2O_5 possess a linear positive relationship (fig. 7). The slope of this line is nearly exactly that for apatite. CaO is enriched in these rocks with respect to all other components and it is bound up in the apatite. During the calculation of the norms of these rocks it was noticed that there was often a very slight excess of P_2O_5 over CaO (fig. 7, 1b, 1c). This may be explained by the presence of the mineral amblygonite (LiAl(F, OH) PO_4), which has been recorded from many of the pegmatites.

This large analytical standard deviations present especially in rock types 1 and 2 (Table 2) are probably due to the degree of alteration that these samples have undergone due to loss or concentration of volatile components during emplacement (see points 3) and 4) above). This concentration of volatile components in the late stage intrusives is believed to be one of the factors controlling transport and deposition of tin within the rocks.

Genesis of Tin

The formation of the anatectic melt which eventually yielded the foliated biotite granite leached the small amount of tin from the country rock (assumed to be in the order of 1–3 p.p.m.) and this was transported in the vapour phase and deposited at higher levels in the crust as very late stage Type 1 pegmatites and greisens. Tischendorf et al., (1971), Hesp (1971) and Barsukov (1957) suggest that tin in granitic rocks is carried during the orthomagmatic stage in biotite and that subsequent breakdown

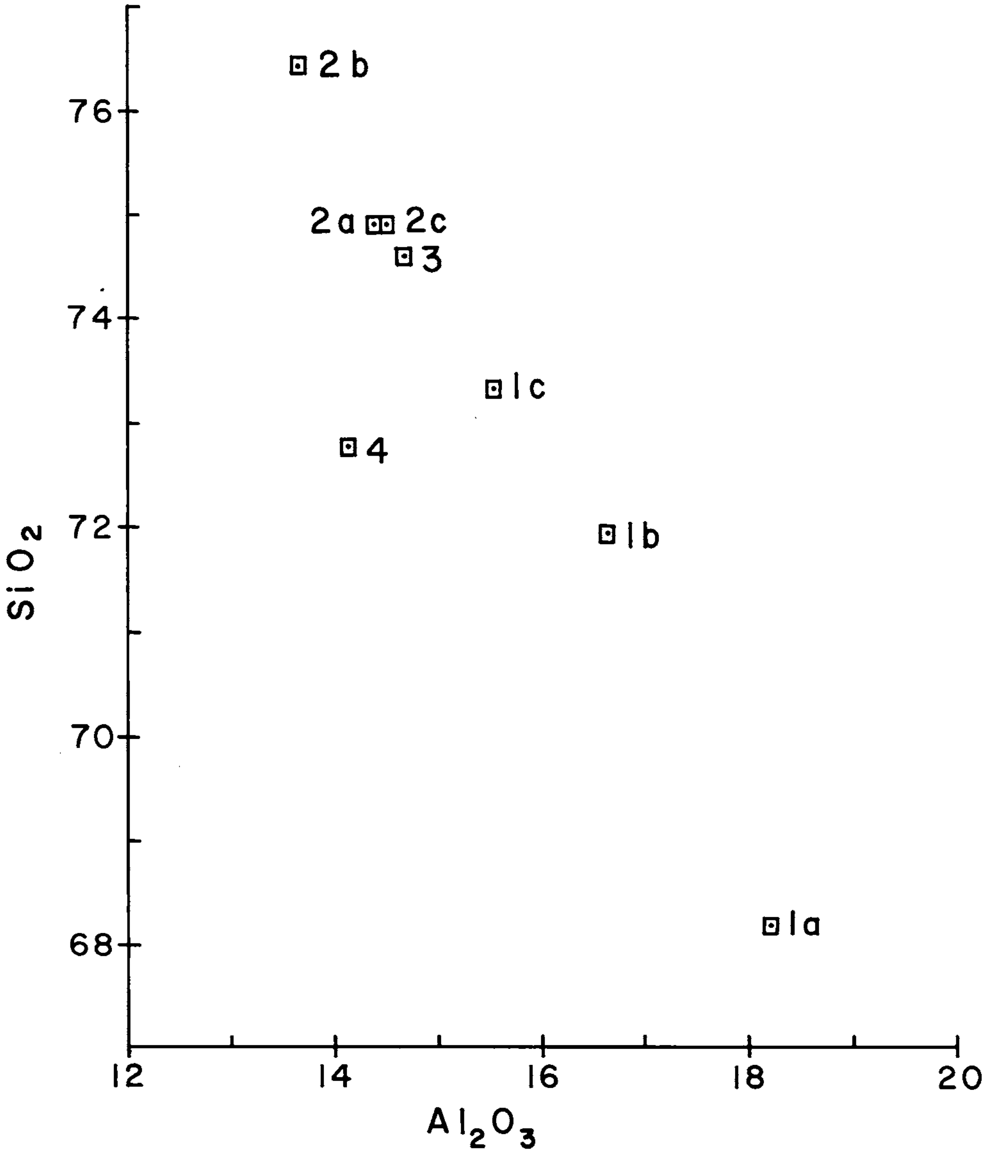

Fig. 6. Plot of oxide percentages for Al_2O_3 against SiO_2.

of that mineral releases tin for formation of cassiterite. It is envisaged that the tin was carried in the biotite of the Type 4 foliated granite and as these differentiated, the tin was liberated into the volatile phase present during crystallization of most of the higher level pegmatites and greisens. The deposition of cassiterite from the fluid phase in cross fractures in the Type 1 pegmatites and greisens was probably brought about by a rapid drop in P H_2O within these joints.

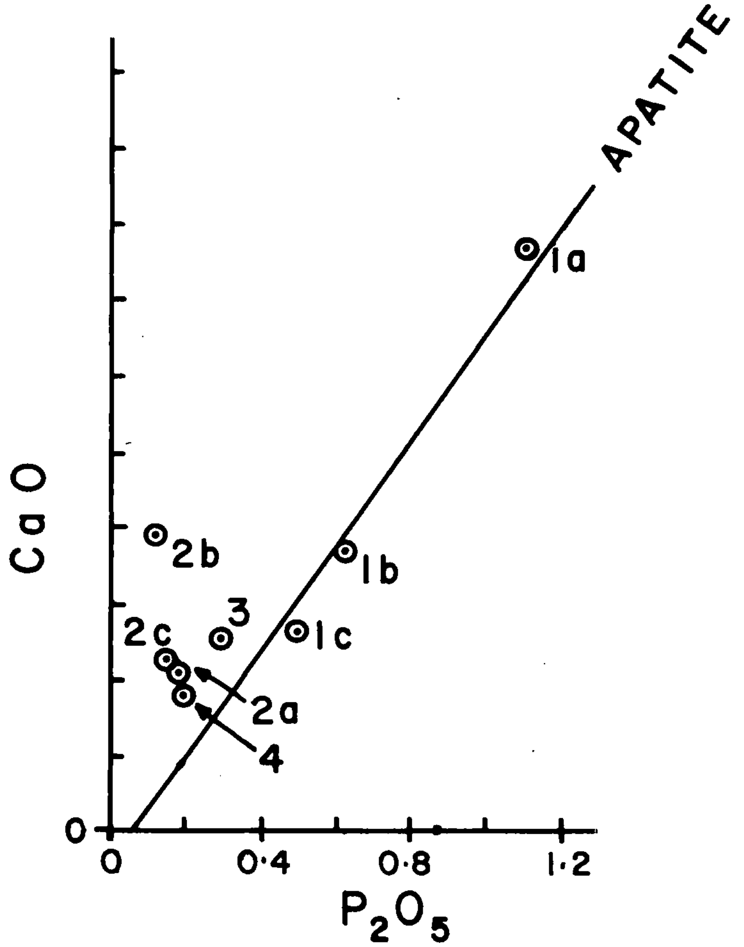

Fig. 7. Plot of oxide percentages for P_2O_5 against CaO.

Tectonic Control of Mineralization

The lineament—tectonic framework of the Willyama Block of the Broken Hill area has been presented by Katz (1976b) and Katz and LeCouteur (1978). A tectonic model is derived that postulates control of the major lineaments of the Willyama Block to a regional NE dextral shear couple acting on the bounding NE lineaments (fig. 1). Riedel type lineaments are formed; a synthetic dextral Riedel shear trending east-west and an antithetic sinistral Conjugate Riedel shear trending northwest. Riedel lineaments are secondary lineaments and faults formed as a result of primary shearing along major faults or fault couples. The resulting clockwise rotation of the Willyama Block buckles the Riedel shear and rotates and extends the Conjugate Riedel shear. The extension of the NW Conjugate Riedel shear lineaments leads to the development of rifts, grabens or troughs, and horsts in the northeast part of the Willyama Block. The Adelaidean (~1000 m.y.), Torrowangee and Caloola Troughs, and the Willyama Euriowie Block (horst) are bounded by these NW lineaments (figs. 1 and 2). The Paps and the Mt. Pinatapah NW lineaments seem to play a role in controlling the tin mineralization at Waukeroo and Euriowie (Bijerkerno) respectively. (fig. 2). Lineament control of tin mineralization has been reported elsewhere (e.g. Wright, 1970).

The tin deposits near Bijerkerno, known as the Euriowie Field, are concentrated about a northward plunging syncline in the Euriowie Horst (fig. 2). Sinistral movement on NW lineaments developed tensional forces oriented northeast-southwest, and these forces operating on the Euriowie Horst created a favourable environment for the emplacement of igneous bodies as diapirs. This tensional regime facilitated anatexis at deeper levels, and pegmatites were emplaced at higher stratigraphic levels. The emplacement of the pegmatites were structurally controlled by the flat lying bedding planes (S_0) and other structures related to D1. As shear couple deformation became more important sinistral movement on the Mt. Pinatapah NW lineament related to D2 dragged the beds into what is now the Bijerkerno syncline, thus preserving the younger, higher level pegmatites and greisens, the host rock for the tin mineralization. As mentioned earlier, the source rocks for the tin mineralization are considered to be the Type 4 foliated granites. Several plutons are recognized on the basis of available geological and geophysical maps (Geological Survey of New South Wales 1970, Cooper, et al., 1975. Bureau of Mineral Resources 1976). A circular (ring?) structure visible on LANDSAT imagery has been termed the Taringa Granite (Katz, 1976b). This feature dominates the central portion of the Euriowie Horst (fig. 2). The size, shape and distribution of these granites show similarities to the granites of the Nigerian tin fields (MacLeod, Turner & Wright, 1971).

CONCLUSIONS

It is suggested that the Euriowie Horst underwent prograde M1 metamorphism during D1, which is regionally referred to as the Willyama event (1700 m.y.) .According to Katz (1976b) the Willyama event was initiated by lineament activity, and in the Euriowie area a tensional regime was developed that facilitated anatexis and diapirism. The igneous emplacement may be related to a somewhat later event known as the Mundi Mundi episode (1540 m.y.), characterised by igneous emplacements elsewhere in the Willyama Block, controlled by NW and WNW extensional type lineaments. The D2 event which developed the Bijerkerno syncline may be related to further lineament activity and retrograde metamorphism (M2) (600 m.y.) (Katz, 1976b). The diapiric, anatectic granites formed in this tensional regime are considered the source rock for the stanniferous pegmatites and greisens emplaced at higher stratigraphic levels and now preserved in the core of the Bijerkerno syncline.

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