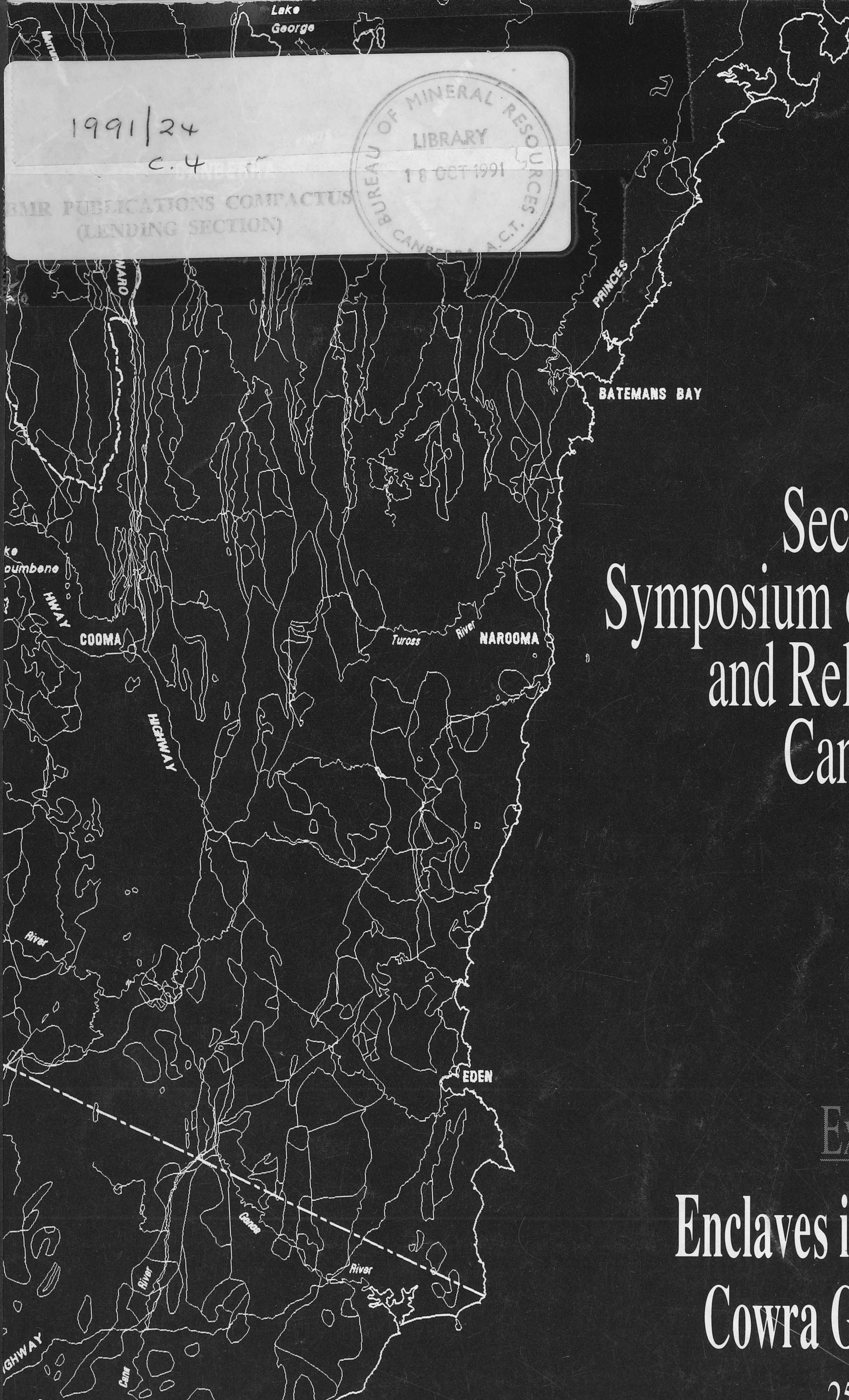

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Excursion Guide

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PART 1 - SILURIAN VOLCANICS OF THE CANBERRA-YASS REGION

The felsic volcanics of the Canberra-Yass region are part of the extensive belt of Palaeozoic felsic granites and volcanics that make up about 50% of the better exposed eastern part of the Lachlan Fold Belt (LFB). The volcanics can be closely compared with different suites of granites, and Wyborn et al., (1981) showed that there were several comagmatic volcano-plutonic associations. Two kinds of associations were defined by Wyborn & Chappell (1986), one where the granites and volcanics were chemically equivalent, and chemical variation was dominated by restite removal, and a second where the volcanics were the felsic complement of mafic plutonic cumulate that separated by convective fractionation. The second kind of association can only develop when restite becomes an insignificant component of the magma.

In the case of the first association, compared to the granites, the felsic volcanics contain a more anhydrous phenocryst mineralogy more indicative of the original composition of the magma, and the mineralogy commonly retains equilibria approximating the original temperature, pressure and volatile fugacities at the source of the magma.

Three suites of felsic volcanics can be distinguished in the Canberra-Yass region, based on the mineralogy of the units. These are

(i) Hawkins Suite

(ii) Laidlaw Suite

(iii) Mountain Creek Suite

Their stratigraphic positions are shown in Table 1. Each suite is derived from a different source-rock of different chemical composition, and derived from a different level in the crust at different temperatures. The Hawkins Suite is the oldest and comes from the shallowest levels in the crust at the lowest temperatures. The Mountain Creek Suite is the youngest and comes from the deepest levels in the crust at the highest temperatures. The Laidlaw Suite is intermediate between the other two. A well-constrained geothermal gradient (Figure 1) can be constructed through the crust using P-T estimates determined for these suites and combining them with evidence from elsewhere in the LFB (Wyborn & Chappell, 1986; Morand, 1990). This temperature profile combines P-T estimates from areas well east and west of Canberra, including the Wagga Metamorphic Belt to the west, and suggests that the maximum geothermal gradient was rather uniform over a large area. It was, however somewhat diachronous according to the age determinations on associated granitic rocks, being older to the west and younger to the east. The distribution of the three suites between Canberra and Cowra is shown in figure 2.

TABLE 1

CANBERRA-YASS REGION STRATIGRAPHIC COLUMN

EARLY DEVONIAN	MURRUMBIDGEE GROUP	limestone, shale, fossiliferous
MOUNTAIN CREEK SUITE	MOUNTAIN CREEK VOLCANICS	rhyolite lava, ignimbrite, airfall tuff, breccia.
UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu	
LATE SILURIAN	YASS BASIN	shale, limestone and siltstone, abundant fossils
LAIDLAW SUITE	LAIDLAW VOLCANICS	composed mainly of a single dacitic ignimbrite
	DEAKIN VOLCANICS	interbedded dacitic lavas, ignimbrite and reworked sediments
EROSIONAL UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu	
LATE SILURIAN	YASS GROUP · YARRALUMLA FORMATION	shale, sandstone, limestone, fossils
HAWKINS SUITE	MOUNT PAINTER VOLCANICS	composed mainly of a single dacitic ignimbrite with the LYONS ASHSTONE at top
	HAWKINS VOLCANICS and correlatives below the Mount Painter Volcanics:	dacitic lava, ignimbrite, rhyolitic ignimbrite, interbedded sediments
EARLY SILURIAN	CANBERRA FORMATION including NARRABUNDAH ASHSTONE near top	siltstone, shale, limestone, sandstone, fossiliferous
UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu	
EARLY SILURIAN	Marine quartz-rich turbidite sequence	
UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu	
ORDOVICIAN	Marine quartz-rich turbidite sequence	

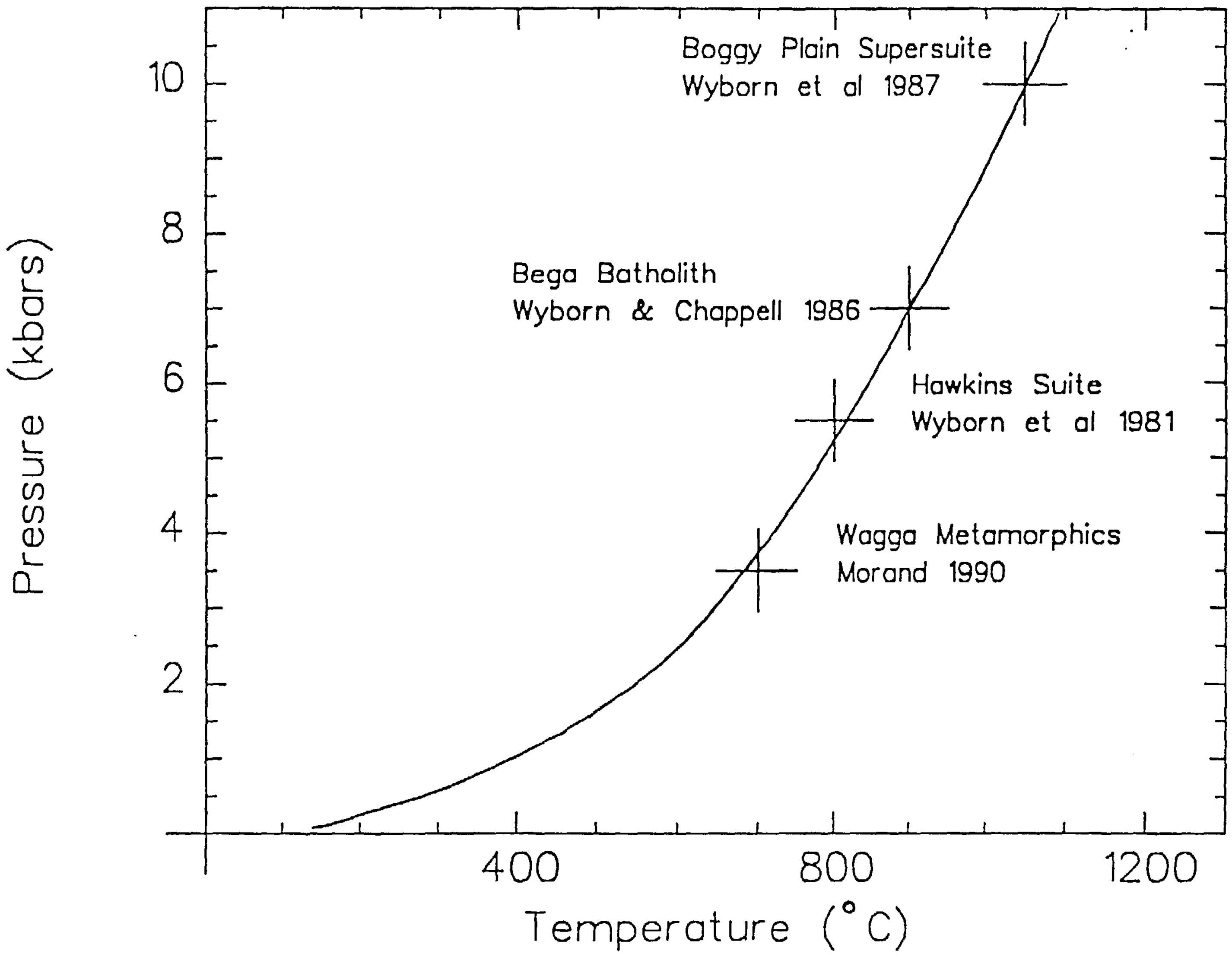
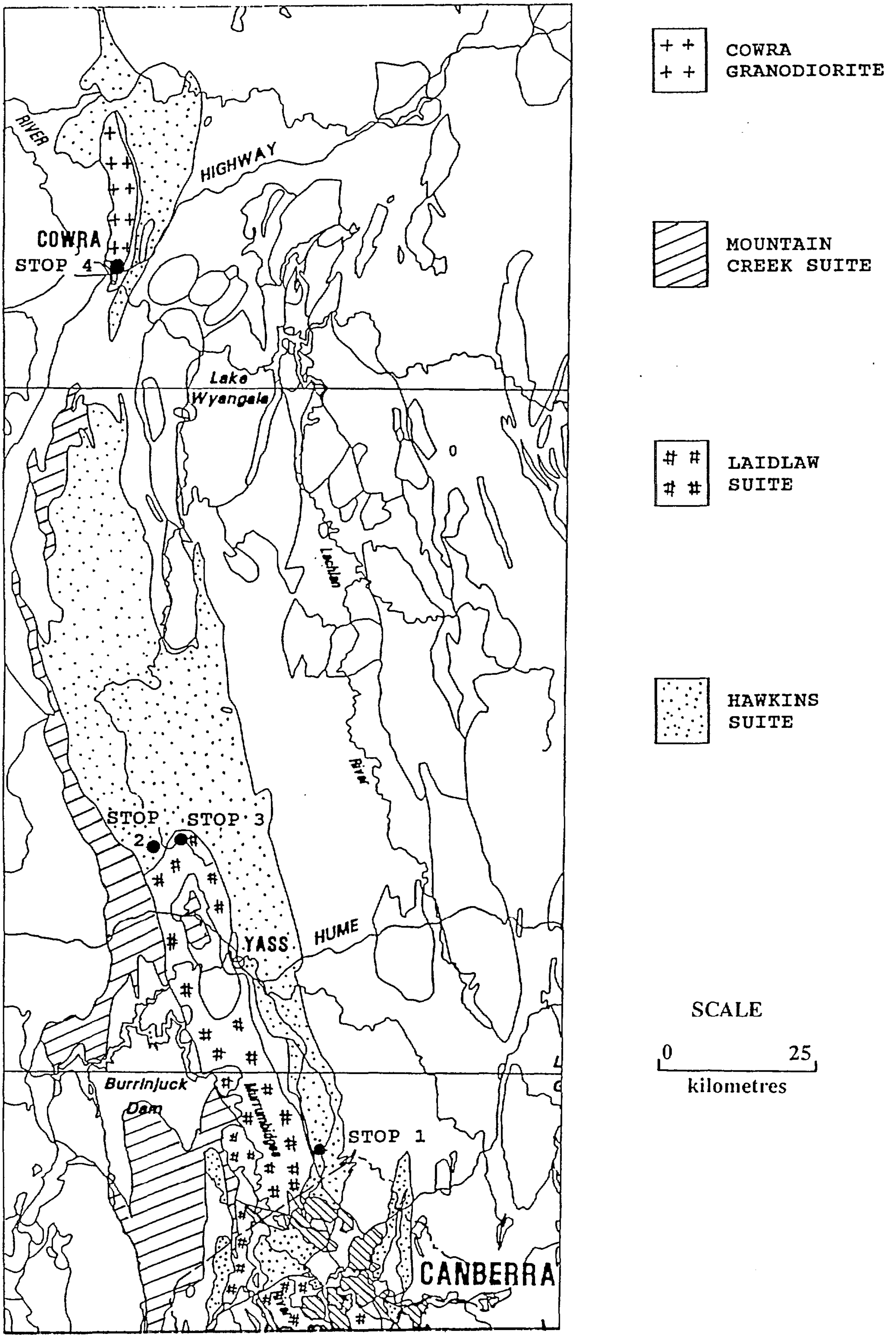


Figure 1. Geothermal gradient at peak metamorphic conditions in the Lachlan Fold Belt in the Late Silurian to Early Devonian. The P-T conditions are interpreted from geothermometry and geobarometry of equilibrium mineral assemblages from widely spaced areas of the eastern Lachlan Fold Belt, and indicate that the gradient was quite similar over a wide area.

FIGURE 2. Generalized geology - Canberra to Cowra



(i) HAWKINS SUITE

The Hawkins Suite of volcanics are part of the most extensive group of magmatic rocks in SE Australia. The intrusive rocks of the suite are known as the Bullenbalong Supersuite. The extrusive and intrusive rocks are comagmatic and chemically equivalent, and belong to the first kind of volcano-plutonic association described above. The volcanics extend over a meridional strike length of over 250 kilometres, from Dubbo in the north to Kiandra in the south. The Bullenbalong Supersuite of granites is even more extensive, extending over 350 kilometres from Cowra in the north, almost to Bass Strait in the south. The most important characteristic of these chemically equivalent S-type suites is that they are strongly peraluminous, and thought to be derived from a mature pelite-rich sedimentary source. This source, however is chemically less mature than the Ordovician greywackes that are widespread in the LFB. The source must have contained more feldspar to give it a higher Na_2O and CaO content than any granitic rocks that could be derived from the Ordovician sediments. S-type granites do occur in the Lachlan Fold Belt that were derived from the Ordovician. The most well known example is the Cooma Granodiorite, which is distinctly lower in Na_2O and CaO than the Bullenbalong Supersuite.

Around Canberra the first evidence of Hawkins Suite volcanism is a shallow marine bed of volcanic ash known as the Narrabundah Ashstone Member which is interbedded in the fossiliferous Early Silurian Canberra Formation. This is soon succeeded by a thick sequence of shallow marine to subaerial volcanics, which have been given a number of names in different areas separated by large faults. These units contain lavas and ignimbrites and some interbedded sediments. Sediments at one locality contain a rich assemblage of trilobites (Chatterton & Campbell, 1980) including 18 species, 8 of which are new. The volcanics are mostly highly porphyritic dacites with about 40-50% phenocrysts, but some of the earliest flows are rather poor in phenocrysts and of rhyolitic composition. The dacite phenocryst mineralogy consists of quartz, plagioclase (mostly albitized by burial metamorphism), biotite, cordierite, orthopyroxene (mg 45-50) and xenocrysts of garnet. Where the plagioclase is unalbitized, it is relatively unzoned around An_{50}. In the granitic equivalents, orthopyroxene is absent, but cordierite and infrequent garnet are present. In the granites the plagioclase grains have broad An_{50-55} cores and narrow strongly zoned rims down to An_{20}. Commonly the garnets and the cores of the cordierites contain schistosely aligned inclusions of sillimanite and aluminous spinel. The high crystal content of the magmas and the presence of obvious high grade metamorphic xenocrystic garnet and inclusion-rich cordierite has lead to the citing of these rocks as supporting the **restite model** of granite genesis (Chappell et al., 1987).

North of Canberra, and in the Yass area these volcanics are known as the Hawkins Volcanics (**STOP 2**). To the south of Yass the Hawkins Volcanics and correlated units around Canberra are topped by a distinctive ignimbrite unit which is extremely crystal-rich (80% crystals of the same variety as in the lower units) and known as the Mount Painter Volcanics (**STOP 1**). The centre of eruption for this ignimbrite was probably quite close to Canberra city, as there it contains the largest and greatest abundance of lithic and flattened pumice fragments. The ignimbrite extends north for over 60 kilometres to an extensive area of poorly mapped Hawkins Suite volcanics north east of Yass. South of Canberra the Mount Painter Volcanics is topped by a bedded ashstone unit, which probably represents part of the complementary fines that settled after the deposition of the ignimbrite unit. Above the ignimbrite, shallow marine sediments were again deposited in places including the Yass Group and the Yarralumla Formation. The Yass Group has been well dated by conodonts (Link & Druce, 1972) as early Ludlovian (the earliest part of the late Silurian). Eruption of the Hawkins Suite fits a pattern consistent with the eruption of a single granite pluton of about $1000km^3$. Earliest eruptions from the top of the magma body were crystal poor and of rhyolitic composition. These were followed by numerous small eruptions of crystal-rich dacitic ignimbrite and lava, and culminated in a climactic ignimbritic eruption of some $500km^3$ to essentially evacuate the magma chamber. Eruption products were deposited in meridional shallow depressions rather than the classical caldera fill and outflow deposits. Continued subsidence after eruption resulted in transgression of a shallow seaway into which the fossiliferous Yass Group and Yarralumla Formations were deposited.

(ii) LAIDLAW SUITE

Volcanism again broke out soon after the deposition of the Yass Group and Yarralumla Formation, but this time the mineralogy of the volcanics was different to the underlying Hawkins Suite. Cordierite and garnet are absent and sanidine and allanite are present. The volcanics, known as the Laidlaw Suite are crystal-rich like the Hawkins Suite, but only part of the phenocryst volume is thought to be restite material. Plagioclase crystals are more strongly zoned (An70-An35) and cores more calcic than those in the Hawkins Suite. Orthopyroxene is more magnesian (mg 50-60). Overall, although calcic plagioclase, orthopyroxene, allanite and some of the quartz and biotite phenocrysts are thought to be of restite origin, quartz, sanidine, sodic plagioclase and biotite have also crystallized from the melt during ascent and cooling. The Laidlaw Suite is thought to be derived from a feldspathic greywacke source beneath the Hawkins Suite source.

Volcanology of the Laidlaw Suite is somewhat similar to the underlying Hawkins Suite in that early numerous small eruptions of both lava and ignimbrite with a variety of stratigraphic names, were followed by a large climactic ignimbritic eruption to form the unit known as the Laidlaw Volcanics. This unit is up to 500m thick, can be mapped for southern Canberra to north of Yass (**STOP 3**) and has a total strike length of about 100km. It appears to represent a single ignimbrite eruption of nearly $1000km^3$, that once covered an area of at least $2000km^2$.

At Yass, the Laidlaw Volcanics are overlain by a richly fossiliferous sequence that has been studied in great detail. The sediments range in age from Early Ludlovian to very early Devonian. The lowest beds contain the same conodont zone fossil assemblage (the <u>Neoprioniodus</u> <u>excavatus</u>

Zone) as the Yass Group, which underlies the Laidlaw Volcanics. Thus the Laidlaw Volcanics are restricted to a short interval in the Early Ludlovian, and have been used as a control point for the geological time scale (Wyborn et al., 1982; Compston et al., 1982).

(iii) MOUNTAIN CREEK SUITE

The sediments overlying the Laidlaw Volcanics at Yass were gently folded prior to the eruption of yet another suite of volcanics, this time of Early Devonian age, known as the Mountain Creek Suite. The deformational break is known as the Bowning fold episode. The Mountain Creek Volcanics occupy the mountainous area west of Canberra, and are distinctly different from the Silurian volcanics. They are crystal-poor rhyolitic lavas and ignimbrites with a phenocryst mineralogy of plagioclase, clinopyroxene and orthopyroxene. Quartz phenocrysts are absent in most units. These volcanics are I-type derived from lower crustal sources at high temperatures. Magnetite-ilmenite geothermometry gives temperatures over 1000°C. They represent the second kind of volcano-plutonic association defined by Wyborn & Chappell (1986), whereby the volcanics represent the complementary fraction of intrusive cumulates that separated by convective fractionation. The volcanics belong to a suite of intrusives and extrusives that extend in a meridional belt from NE Victoria for over 500km to Dubbo in central New South Wales (Wyborn et al., 1987). They will not be examined on this excursion.

CHEMISTRY

The three volcanic suites, although similar in silica content (Table 2) are mineralogically distinct, and this is mainly reflected in the relative abundance of alumina and alkalis, which is in turn related to the composition of the source-rocks. The Hawkins Suite has an excess of alumina (peraluminous) reflecting its pelitic sedimentary source, the Laidlaw Suite has alumina and alkalis balanced, and the Mountain Creek Suite is metaluminous, reflecting its mafic igneous lower crustal source. This can best be represented in a plot of SiO2 versus ASI, where ASI stands for aluminiun saturation index (molecular (Al2O3/Na2O+CaO+K2O)) (Figure 3).

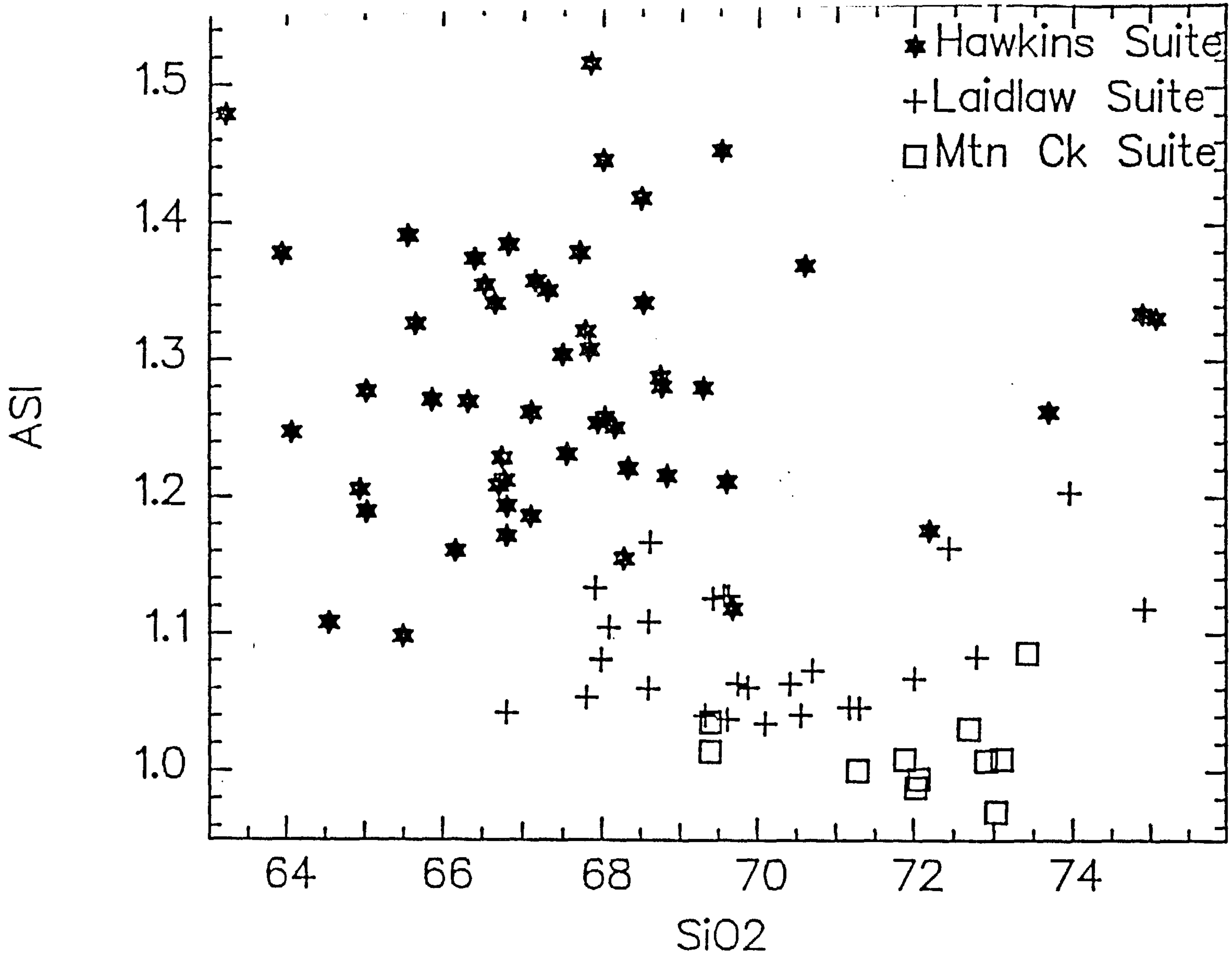


FIGURE 3 - Plot of aluminium saturation index (ASI) versus SiO2 for Canberra volcanic suites. The large range of ASI in the Hawkins Suite is mainly caused by burial metamorphism.

TABLE 2: AVERAGE CHEMICAL COMPOSITIONS OF SOME VOLCANIC UNITS

Volcanic Unit	Hawkins	Mt.Painter	Laidlaw	Mtn Ck
no. of analyses	13	9	26	11
SiO2	67.82	66.30	70.00	71.89
TiO2	.56	.59	.43	.53
Al2O3	13.99	13.93	14.17	13.93
Fe2O3	1.85	.68	1.01	0.83
FeO	2.65	4.33	2.10	1.39
MnO	.06	.09	.05	.12
MgO	1.92	2.63	1.31	.60
CaO	1.17	2.28	2.86	1.86
Na2O	2.28	1.86	2.74	3.62
K2O	4.49	3.58	3.31	4.29
P2O5	.12	.11	.09	.07
H2O+	2.18	2.47	1.23	.53
H2O-	.19	.10	.11	.05
CO2	.37	.57	.14	-
Rest	.22	.20	.20	.20
Total	99.88	99.73	99.74	99.31

Trace elements in parts per million

Ba	783	562	655	940
Rb	204	156	137	170
Sr	84	111	180	315
Pb	111	20	47	22
Th	16	15	15	18
U	4.5	3.8	3.8	3.5
Zr	190	189	177	243
Nb	4	5	4	4
Y	30	25	28	30
La	46	53	58	39
Ce	75	86	100	86
V	117	135	87	41
Ni	18	29	12	8
Cu	15	34	17	12
Zn	73	89	60	68

PART 2 - COWRA GRANODIORITE

The Cowra Granodiorite is an elongate intrusion of mafic garnet cordierite granodiorite outcropping over an area of 95 km^2. Despite its mafic character, contact metamorphic affects are only discernible within about 1m of its contact. The pluton outcrops in the northern part of the Kosciusko Basement Terrane of Chappell et al. (1988). S-type granites are here as extensive as those in the Kosciusko region in the southern part of the this Terrane, but around Cowra many granites are associated in space and time with S-type volcanics of equivalent composition (Wyborn et al. 1981). The Cowra Granodiorite is a medium to coarse grained rock with crystals of quartz, plagioclase, K-feldspar and cordierite up to 3mm across and smaller sometimes perfectly shaped red-brown biotites commonly 0.5-1mm across. Large garnets surrounded by cordierite are so sparse that they are seldom seen in thin sections. Their compositions are virtually identical to the garnets in the Hawkins Volcanics, that is they have mg values of 20-25, and contain 1-2% MnO and CaO. Plagioclase which may also appear as perfectly shaped crystals is complexly twinned and zoned with the composition mostly being in the range An_{30-50} although there are some strongly sericitized cores. K-feldspar is weakly perthitic and there may be some granophyric texture when it is in contact with quartz. Cordierite appears as pinite and/or mica pseudomorphs some of which have perfect rectangular outlines: within some cordierite pseudomorphs there are small rosettes of secondary muscovite. Zircon and chunky prisms of apatite are accessory minerals.

Chemical analyses of eleven samples of the Cowra Granodiorite are shown in Table 3. They are all remarkably similar in composition. The pluton is one of the most mafic S-types from the Lachlan Fold Belt, averaging 67.8% SiO2, 2.0% MgO and 4.5% total FeO (Table 5). Compared to Bullenbalong Supersuite rock from the southern part of the Kosciusko Basement Terrane the granodiorite has distinctly higher Th and lower Mg, Sc, V, and Cr, while Ti and Ba tend to be higher and Ca and Sr generally lower at comparable Fe content.

Canowindra volcanics

The Canowindra volcanics ("porphyry") are intrude by the Cowra Granodiorite at the plutons northern end (Figure 2). These volcanics are almost certainly part of the Hawkins Suite as they contain the same mineralogy, but they were extruded into a shallow marine environment and are rather more altered than the subaerial volcanics to the south. However Stevens (1952) found "sparsely-distributed red garnet". Pseudomorphs of cordierite and orthopyroxene are also recognizable. Thus the Cowra Granodiorite is a sub-volcanic intrusion.

TABLE 3 - ANALYSES OF COWRA GRANODIORITE

Sample	LFB491	LFB492	LFB493	LFB494	LFB495
G.R.	570607	570607	569605	572584	565555
SiO2	67.27	67.87	67.46	68.21	67.52
TiO2	.68	.68	.65	.65	.64
Al2O3	14.45	14.59	14.40	14.48	14.38
Fe2O3	1.11	.81	.98	.46	1.30
FeO	3.86	4.02	3.77	4.18	3.34
MnO	.12	.11	.09	.08	.08
MgO	2.08	2.13	1.96	2.10	2.04
CaO	2.44	2.37	2.34	2.24	2.37
Na2O	1.77	1.80	1.98	1.92	1.93
K2O	3.46	3.60	3.53	3.60	3.47
P2O5	.15	.15	.14	.14	.14
H2O+	2.15	1.98	2.16	1.61	2.23
H2O-	.13	.26	.13	.20	.24
CO2	.16	.13	.25	.15	.24
Rest	.20	.20	.19	.19	.19
Total	100.03	100.70	100.03	100.21	100.11
C.I.P.W. norms					
Q	33.43	32.92	32.54	32.76	33.40
C	3.66	3.70	3.35	3.63	3.42
Or	20.58	21.26	21.01	21.37	20.64
Ab	15.03	15.17	16.82	16.27	16.38
An	11.36	10.92	10.93	10.39	11.06
Hy	10.47	11.04	10.12	11.60	9.25
En	5.20	5.28	4.90	5.24	5.10
Fs	5.27	5.76	5.22	6.37	4.15
Mt	1.63	1.19	1.44	.68	1.91
Il	1.30	1.29	1.24	1.24	1.22
Ap	.36	.36	.34	.34	.34
Colour I	13.41	13.53	12.81	13.53	12.39
Pl	26.38	26.09	27.75	26.66	27.44
Norm Pl	43.04	41.85	39.38	38.98	40.31
mg no.	48.99	48.56	48.09	47.24	52.12
Trace elements in parts per million					
Ba	540	500	535	505	510
Rb	164	175	180	177	177
Sr	135	136	128	128	131
Pb	27	25	27	27	27
Th	21	21.5	20.5	19.8	20.5
U	3.6	3.6	3.0	4.0	3.6
Zr	186	196	193	189	194
Nb	12	12	11.5	13	12
Y	31	31	29	31	29
La	30	33	29	32	30
Ce	69	72	71	72	70
Nd	27	27	26	26	26
Sm	-	-	-	7.2	-
Eu	-	-	-	1.23	-
Tb	-	-	-	1.2	-
Ho	-	-	-	1.1	-
Yb	-	-	-	3.0	-
Lu	-	-	-	0.44	-
Sc	15	16	13	15	14
V	80	80	73	79	79
Cr	52	50	48	48	52
Mn	930	860	735	620	590
Co	16	13	16	16	15
Ni	19	21	19	20	19
Cu	21	17	24	17	18
Zn	182	155	104	104	81
Sn	7	6	7	8	6
Ga	17.4	17.0	17.2	17.4	17.8

TABLE 3 (cont.) ANALYSES OF THE COWRA GRANODIORITE

Sample	LFB496	LFB497	LFB498	LFB499	LFB500	LFB501
G.R.	573571	567552	572768	567639	557551	565672
SiO2	67.67	67.71	67.77	67.69	68.28	68.01
TiO2	.65	.66	.65	.61	.65	.62
Al2O3	14.39	14.40	14.46	14.44	14.50	14.39
Fe2O3	.57	.66	.78	1.08	.66	.75
FeO	3.92	3.81	3.69	3.35	3.76	3.58
MnO	.07	.06	.07	.06	.06	.05
MgO	2.02	2.05	2.03	1.85	2.06	1.92
CaO	2.29	2.45	2.47	2.23	2.41	2.30
Na2O	2.05	2.06	2.13	2.02	1.98	2.26
K2O	3.52	3.47	3.52	3.79	3.62	3.62
P2O5	.15	.15	.15	.14	.15	.15
H2O+	1.78	1.96	1.76	2.18	2.29	2.23
H2O-	.17	.17	.16	.15	.33	.18
CO2	.08	.05	.08	.16	.20	.09
Rest	.19	.19	.19	.18	.18	.18
Total	99.52	99.85	99.91	99.93	101.13	100.33
			C.I.P.W. norm			
Q	32.28	32.09	31.66	32.33	32.29	31.23
C	3.36	3.11	2.96	3.25	3.21	2.87
Or	21.03	20.65	20.94	22.56	21.30	21.45
Ab	17.48	17.50	18.09	17.16	16.63	19.11
An	10.65	11.41	11.50	10.37	11.08	10.60
Hy	10.88	10.61	10.27	9.00	10.44	9.79
En	5.07	5.13	5.07	4.63	5.09	4.78
Fs	5.82	5.48	5.20	4.37	5.34	5.01
Mt	.85	.98	1.15	1.59	.97	1.10
Il	1.24	1.26	1.24	1.16	1.23	1.18
Ap	.36	.36	.36	.34	.36	.36
Colour I	12.99	12.85	12.67	11.76	12.64	12.08
Pl	28.12	28.91	29.59	27.53	27.71	29.71
Norm Pl	37.85	39.47	38.87	37.66	39.99	35.68
mg no.	47.87	48.95	49.50	49.60	49.40	48.87
			Trace elements in parts per million			
Ba	520	530	525	500	520	495
Rb	176	171	173	195	178	184
Sr	131	133	128	121	130	121
Pb	38	22	26	27	20	16
Th	21.5	20.5	20.5	20.0	21.0	21.0
U	3.4	3.8	3.2	3.6	4.2	2.4
Zr	194	191	187	192	195	189
Nb	12.5	12.5	12.5	12.0	13.0	13.0
Y	30	31	33	29	32	32
La	32	32	31	30	30	33
Ce	67	70	69	69	70	73
Nd	25	26	25	25	25	28
Sc	16	16	16	13	15	14
V	79	82	78	68	82	72
Cr	50	50	47	47	51	45
Mn	570	470	540	485	465	380
Co	15	16	14	14	15	16
Ni	21	21	22	17	22	20
Cu	18	16	21	18	3	32
Zn	96	59	69	58	53	38
Sn	7	6	7	8	6	7
Ga	18.0	17.4	17.6	16.8	17.8	17.4

Cowra Granodiorite Enclaves

Stevens (1952) in a comprehensive study for its time, listed five types of enclaves in the Cowra Granodiorite which he called 1) pelitic, 2) psammitic, 3) calcareous, 4) igneous and 5) granitized. Most of the "psammites" of Stevens (1952) are rich in quartz and have the assemblage quartz + plagioclase + biotite ± K-feldspar. The plagioclase is much more sodic than that in the other enclave types. The "psammites" are considered to be hornfels locally derived from the adjacent Silurian sediments and they are not discussed further. We have not found any examples corresponding to Stevens's orthopyroxene-bearing "psammites".
The pelites, considered to be the most abundant, are of the kind here referred to as mica-rich schistose and include surmicaceous types. The following is a list of assemblages modified from Stevens (1952) :-

Cordierite + spinel + plagioclase ± sillimanite ± K-feldspar ± quartz.
Cordierite + spinel + corundum + plagioclase
Sillimanite + spinel.
Cordierite + sillimanite + plagioclase ± biotite ± K-feldspar ± quartz.
Cordierite + K-feldspar + biotite + quartz.
Cordierite + plagioclase + biotite + quartz.
Cordierite + garnet + biotite ± plagioclase.
Cordierite + garnet + sillimanite + quartz + biotite.
Garnet + orthopyroxene + biotite ± cordierite ± quartz.
Orthopyroxene + plagioclase + K-feldspar + biotite + quartz.

Cordierite appears as large crystals commonly enclosing plagioclase and almost invariably altered at least in part to yellow pinite and/or to a mass of fine grained phyllosilicates. Altered cordierite makes many of these enclaves appear more surmicaceous than they really are although red-brown biotite dominates the mineral assemblage in many and variation of biotite outlines the banding seen in some. In some enclaves, large garnets up to three cms across, surrounded by a sericitic zone and then a felsic zone rich in quartz, appear in a mass of phyllosilicates and quartz which we (and Stevens) interpret as originally rich in cordierite. We have not found garnets with enclosed orthopyroxene or rimmed by orthopyroxene as recorded by Stevens (1952), but garnet rimmed by orthopyroxene is present in the Hawkins Suite volcanics. Quartz lumps similar to those found in all other Lachlan Fold Belt S-type granites are common although not mentioned by Stevens(1952). One oval-shaped quartz lump 45 cms in longest dimension found in the Japanese Gardens, has a rim on one side of biotite schist or gneiss containing large garnet crystals.

Calc-silicate rocks are clearly distinguished in the field by their pale greenish colour, very fine grainsize and common outer reaction zone. The granodiorite may be epidotized around the enclave but there is no sign of amphibole expected if there was contamination to any great extent. The typical mineral assemblage is epidote (or clinozoisite) + plagioclase + quartz. Actinolitic amphibole, calcite and rarely minor K-feldspar may also occur. Rounded zircons, titanite and chunky crystals of apatite are minor.

The "xenoliths of igneous origin" discussed by Stevens (1952) are microgranular enclaves and because of the controversy surrounding this type we have studied them in more detail. Analyses of 9 microgranular enclaves are given in Table 4. They are generally fine grained and massive but include what was considered in the field to be a meta-pelite with bedding (CI-4). This appears in thin section and in chemical composition (Table 4) to be a microgranular type. These were thought to be igneous by Stevens on the basis of the "blastophytic fabric" and one analysis that indicated an andesitic composition although he states, "Very few of the xenoliths are of definite igneous origin". Vernon (1983) also uses the microfabric to argue for an igneous origin. We have found and analysed only one enclave having a composition similar to that of an andesite (Table 4, sample CI-5). This is similar in chemical composition to an analysis of a rock presented by Stevens (1952), but is the only enclave considered to be a microgranular type in the field that does not have any trace of the pseudo-dolerite fabric. The sample has the least calcic normative plagioclase composition and highest normative corundum (most peraluminous) content of all analysed samples (Table 4).

Many of the microgranular enclaves have a clearly defined reaction rim about 1/5 of the dimension of the enclave. The mineral assemblages of the cores are 1) plagioclase + quartz + orthopyroxene ± biotite or 2)plagioclase + quartz + orthopyroxene + cordierite ± biotite with accessory opaques (ilmenite and sulfides) and apatite that is present as elongate needles. All are characterized by pseudo-doleritic fabric in which lath-shaped plagioclases project into, and are enclosed by quartz. The plagioclase core compositions range from up to An_{94} in one sample to about An_{55}, though most have cores of An_{70-80} . Probe analyses giving the highest anorthite contents come from relatively large grains that are crowded with quartz and lesser orthopyroxene inclusions. Orthopyroxene may occur as elongate prisms and project into quartz in a similar manner to the plagioclase, or it may appear as more or less equigranular grains. Cordierite when present appears as partly altered grains interstitial to or intergrown with the quartz grains. A typical rim assemblage consists mainly of quartz into which project plagioclase laths with normal zoning (An_{45-50}) surrounding an irregularly replaced more calcic core, and red-brown biotite. There are some irregular patches of K-feldspar and accessory elongate zircons even though these are not present in the core. Apatite rods are also accessory. The boundary between the core and the hydrated rim is gradational on the scale of a thin section the most important change being the replacement of orthopyroxene by biotite and the introduction of K-feldspar. The "granitized xenoliths" of Stevens (1952) could be enclaves which consist entirely of the rim assemblage. Chen et al.(1989) described two peraluminous microgranular enclaves from the Jillamatong Granodiorite with calcic plagioclase, that almost certainly were derived in a similar way to the Cowra enclaves. The Jillamatong enclaves do not however contain fresh orthopyroxene.

TABLE 4
COWRA GRANODIORITE MICROGRANITIC ENCLAVES

Sample	CI-1	CI-4	CI-5	CI-7	CI-9	CI-10	CI-14	CI-16	CI-17
SiO2	60.14	59.67	58.23	63.07	61.90	65.45	61.13	61.83	61.58
TiO2	.74	.61	1.07	.85	.50	.47	.65	.93	.99
Al2O3	16.38	16.12	18.26	15.75	14.99	13.87	16.00	15.24	15.65
Fe2O3	1.55	1.53	1.51	1.28	1.03	.98	1.08	1.06	1.07
FeO	5.14	5.79	4.60	5.28	5.20	5.34	5.36	6.50	5.41
MnO	.11	.12	.08	.11	.11	.11	.11	.12	.10
MgO	3.74	4.23	2.20	2.82	4.69	3.69	3.95	2.91	3.76
CaO	7.12	7.60	4.79	5.86	6.42	5.00	6.93	6.31	5.71
Na2O	.91	.70	3.31	2.04	.96	1.57	1.16	1.51	1.96
K2O	1.52	.92	2.46	1.26	1.25	1.17	1.21	1.05	1.50
P2O5	.09	.07	.22	.14	.09	.10	.11	.14	.13
H2O+	1.79	1.82	2.35	1.01	1.84	1.28	1.65	1.17	1.43
H2O-	.30	.30	.38	.26	.38	.31	.33	.35	.30
CO2	.26	.21	.23	.19	.30	.23	.16	.31	.22
Rest	.14	.12	.22	.16	.16	.17	.15	.15	.18
Total	99.93	99.81	99.91	100.08	99.82	99.74	99.98	99.58	99.99
			C.I.P.W. norms						
Q	25.25	25.86	14.06	26.64	27.47	32.21	25.67	27.31	23.52
C	.46	.29	1.91	.67	.56	1.13	.41	.44	.68
Or	9.08	5.51	14.68	7.50	7.47	6.98	7.21	6.28	8.95
Ab	7.74	5.95	28.16	17.31	8.17	13.37	9.85	12.89	16.65
An	35.03	37.52	22.65	28.37	31.59	24.47	33.89	30.79	27.73
Hy	16.50	19.19	11.10	14.48	19.84	17.70	17.95	17.12	17.01
En	9.36	10.59	5.51	7.04	11.75	9.25	9.87	7.31	9.40
Fs	7.15	8.60	5.59	7.43	8.09	8.45	8.09	9.81	7.61
Mt	2.30	2.27	2.24	1.90	1.54	1.46	1.61	1.59	1.59
Il	1.41	1.16	2.04	1.62	.96	.90	1.24	1.78	1.89
Ap	.21	.17	.53	.33	.22	.24	.26	.34	.31
Colour In	20.22	22.63	15.38	18.00	22.37	20.08	20.81	20.50	20.51
Pl	42.77	43.47	50.81	45.68	39.76	37.84	43.73	43.68	44.39
Norm Plag	81.91	86.30	44.58	62.11	79.44	64.67	77.48	70.49	62.49
mg number	56.46	56.56	46.01	48.76	61.64	55.18	56.77	44.38	55.33
			Trace elements in parts per million						
Ba	245	62	415	230	270	340	185	255	345
Rb	153	110	168	79	91	66	92	57	120
Sr	178	167	258	211	163	191	179	180	145
Pb	11	11	153	19	12	13	13	16	17
Th	5.6	5.0	13.0	10.0	9.6	6.0	10.0	11.0	13.2
U	1.8	1.8	4.0	3.4	2.4	2.1	2.6	2.6	2.2
Zr	69	103	205	148	118	134	143	161	191
Nb	7.0	4.5	17.5	10.0	6.5	6.5	6.5	8.5	10.0
Y	18	21	32	25	22	19	26	33	31
La	12	13	36	26	19	19	23	25	28
Ce	29	28	71	53	41	39	48	55	61
Nd	12	12	31	24	16	17	22	23	25
Sm	-	-	6.10	5.10	-	3.50	4.90	-	-
Eu	-	-	2.40	1.63	-	1.52	1.18	-	-
Tb	-	-	1.20	.90	-	.70	1.00	-	-
Ho	-	-	1.40	1.00	-	.70	1.00	-	-
Yb	-	-	3.80	2.80	-	2.20	2.90	-	-
Lu	-	-	.55	.42	-	.33	.41	-	-
Sc	-	-	20	23	-	23	27	-	-
V	197	182	162	184	166	126	158	196	143
Cr	25	19	<1	23	155	127	43	15	89
Mn	865	1020	715	860	905	880	910	980	840
Ni	10	7	8	13	28	20	20	6	31
Cu	19	21	44	32	31	24	22	24	25
Zn	82	81	91	96	76	94	81	96	83
Ga	17.2	16.4	21.6	18.0	16.2	17.0	17.0	18.8	18.6
Cs	-	-	9	10	-	9	18	-	-

Discussion of enclaves in S-type granites - what we can learn from those at Cowra

Mica-rich schistose and surmicaceous enclaves and lumps of milky quartz are common to all S-type granites although their abundance is inversely proportional to how felsic is the host. When present, microgranular enclaves in S-type granites from different environments within the Lachlan Fold Belt have many similarities but their differences are considered to shed some light on the problem of their origin (White et al. 1990). Those at Cowra are considered to be the most primitive and most informative with respect to their origin.

Mica-rich schistose and surmicaceous enclaves

The Cooma Granodiorite occurs within regionally metamorphosed rocks with migmatites near the contacts (regional aureole granite): clearly it has been derived from these metamorphic rocks. The mica-rich schistose and surmicaceous enclaves of the Cooma Granodiorite appear to be directly derived from the adjacent country rocks.

The Bullenbalong Supersuite granites of the Kosciusko Batholith e.g. Jillamatong and Cootralantra Granodiorites (White et al., 1977; White and Chappell, 1988; Chen et al., 1989) have narrow contact aureoles consisting of hornfels. These are contact aureole granites. White et al. (1977) record no sillimanite in the contact aureoles of these granites and this together with the large size of some sillimanites and cordierites in the mica-rich schistose and surmicaceous enclaves, suggests that these are derived from depth below the level of intrusion. The mica-rich schistose and surmicaceous enclaves are therefore either plucked off the walls and incorporated into the magma from some high grade region between the source of the granite magma and the presently exposed surface (e.g. Stevens, 1952), or represent unmelted rock fragments from the source regions of the host magma ie. they are restite (e.g. Didier, 1964, White et al. 1977, Phillips et al. 1981, Fang 1984). For the Jillamatong Granodiorite, Chen et al. (1989) pointed out that a restite origin is more probable because I-type intrusions in contact with this granodiorite do not contain any mica-rich schistose enclaves. Also the enclaves have mineralogical and chemical features that reflect that of their host. For example hair-like rutile inclusions in the quartz grains of the Jillamatong Granodiorite are also seen in the quartz of its enclaves. The reflection of the mineralogy of the mica-rich schistose enclaves in other granites may also be explained if they are restite rather than wall rocks.

The Cowra Granodiorite has a very limited contact aureole but is associated with volcanics of the same composition: it is a subvolcanic granite. The mica-rich schistose and surmicaceous enclaves in the near surface intrusion of Cowra Granodiorite are clearly derived from depth. As pointed out by Stevens (1952), "the Silurian wall-rocks are not greatly affected by the intrusion" whereas the enclaves are of "high grade" and must have been "carried upward by the magma".

The data on mica-rich schistose enclaves of S-types of the Lachlan Fold Belt including those of Cowra are best interpreted as restite or unmelted fragments from the source. However, Chen et al. (1989) argue that those in the Jillamatong Granodiorite are not residue from which melt has been extracted because the plagioclases are less calcic and cordierite is less magnesian than in the host. They suggest that they are pelitic fragments that have not melted to any appreciable extent during the partial melting event because they were deficient in one or more of the essential components (plagioclase and, in some examples, quartz) necessary to produce enough melt to enable it to be extracted. Patches showing granophyric intergrowths between quartz and feldspars may be indicative of small amounts of preexisting melt phase.

Quartz lumps

The origin of the quartz lumps that are relatively rare but ubiquitous in all S-type granites of the Lachlan Fold Belt is somewhat controversial. In her description of the Cooma Granodiorite, Joplin (1942, p 186) suggested that the "quartz nodules represent undigested quartz veins which invade the Ordovician sediments" but Vernon and Flood (1982) say that milky and smoky quartz occur near xenoliths of pegmatite in the Cooma Granodiorite and they suggest that "pegmatitic quartz may be a more suitable explanation of quartz fragments in peraluminous granites". Occurrences of composite enclaves consisting of both quartz and mica-schist or gneiss, like that recorded here in the Cowra Granodiorite leave us in no doubt that the quartz lumps are part of the mica-rich schistose enclaves and represent vein quartz in the original metamorphic sequence from which the granite magmas have been derived.

Microgranular enclaves

According to Didier (1964, 1973) microgranular enclaves in general are fine-grained, massive, rounded and have mineralogical and chemical characteristics reflecting that of the host granite. Many have fabrics suggestive of igneous rocks (pseudo-doleritic fabric). Didier (1964) described the common occurrence of needle-shaped apatite and suggested that these could result from magma quenching: he quoted the experimental work of Wylie et al. (1962) to support this suggestion.

In the regional aureole Cooma granite, there are no microgranular enclaves having pseudo-doleritic fabric. Likewise Didier (1973) pointed out that microgranular enclaves are absent in deep-seated, autochthonous migmatitic granites such as the Velay granite of France.

Several hypotheses have been proposed for the origin of the microgranular enclaves found in the contact aureole and subvolcanic granites. Because of the igneous-looking fabric and presence of needle apatite, Didier (1964) suggested that some of them could be chilled more mafic igneous rocks contemporaneous with the formation of the granite magma: this was the seeds of the magma mingling hypothesis presently in vogue. Based on the mineralogical and chemical coherence with the host he also suggested that early crystallization of granite on the walls and subsequent reincorporation into the magma is a possible explanation.

For the Bullenbalong Supersuite contact aureole granites, nothing resembling the microgranular enclaves are represented in the wall rocks themselves or in the granite margins, and hence these enclaves cannot be locally derived. The absence of peraluminous microgranular enclaves in the I-types adjacent to the Jillamatong Granodiorite again suggests that they are source rocks or at least part of the Jillamatong magma. Also the fact they are peraluminous "rules out the possibility that they could represent crystallized blobs of an extraneous mingling magma such as basalt or andesite" (Chen et al., 1989), except if metasomatic alteration (the granitization of some workers) has altered their composition beyond recognition, but not their fabric. White et al. (1977) suggested that the microgranular enclaves of the contact aureole Cootralantra Granodiorite are "crystallized pieces of Cootralantra Granodiorite that have been reincorporated in the magma". However, for the Jillamatong Granodiorite, Chen et al. (1989) argued that because certain elements lie off the geochemical trends shown by the host granite then they cannot be early crystallization products. They suggested that they are restite and represent massive even grained lithologies in the source that were too mafic and too low in Na to produce the rheologically critical melt percentage (RCMP) necessary for melt extraction. They argued further that this small amount of melt could give rise to the igneous textures.

The microgranular enclaves from the subvolcanic Cowra Granodiorite include types that have major element chemical compositions resembling andesites (Table 4, analysis CI-5, and Stevens, 1952). However, the majority have cores that have been arrested in the process of modification by the granite and rims that have been modified by the granite so that they resemble those in the more deep-seated Bullenbalong Supersuite granites. Chemical data (Table 4) on the most primitive rocks from the cores clearly indicate that these are not igneous compositions (basalts or andesites) in spite of the well developed pseudo-doleritic texture. For instance, all are peraluminous and low in Na and K for the measured SiO_2 values. Variation diagrams show that for all elements they are not on the trends shown for the host granodiorite. The enclaves exhibit a range of compositions that correlates with the anorthite content of the contained plagioclase. The samples with the most anorthitic plagioclase have the lowest abundance of needle apatite as indicated by their P2O5 content. They are also lowest in Zr and Nb and least peraluminous (Figure 4). Rare earth element analyses of selected samples are similar to the host granodiorite (LFB494), except that the rather large negative europium anomaly of the granodiorite is not present in the enclaves (Figure 5). The europium anomalies of the enclaves are slightly positive for samples CI-5 and CI-10, nonexistent for CI-7 and negative for CI-14. From this limited data it appears that the rocks with the lowest anorthite contents have the highest europium (CI-5), and those with the highest anorthite content have the lowest europium (CI-14).

The chemical composition and mineralogy is best explained as that of rocks from which a hydrous granitic melt phase has been extracted; the anorthitic plagioclase is that expected to be in equilibrium with a felsic granite in the five phase system Qz+Or+Ab+An+H_2O (e.g.Johannes, 1984) where the plagioclase melt loop is strongly flattened. Thus residual plagioclase of high anorthite content is in equilibrium with sodic melt (granite), and the sodic melt has been extracted. Orthopyroxene is expected as a residual phase from the breakdown of biotite which provides Or component as well as volatiles to give melt. The abundance of residual quartz and the occasional presence of cordierite suggests that the original rocks were quartz-rich and peraluminous and hence sedimentary. The inverse correlation of anorthite content with ASI, P_2O_5, Zr, Nb and Eu can be explained by the degree of melt fertility of a range of feldspathic sedimentary source rocks, with those having the highest anorthite content being the least fertile and having the least melt extracted from them. Thus the anorthite contents in these residues will range from over An_{90} in rocks with only a few percentage melt extracted, down to An_{55} with just less than the rhealogical critical melt percentage (RCMP) extracted from them. The granite magma itself formed from the bulk of the source which melted to the RCMP and produced residual (restite) plagioclase of An_{50}-An_{55}. Source sediments that produced enclaves such as CI-5 and CI-10 were relatively fertile and had a moderately high pelitic component. The large amount of melt extracted left a residue with a positive europium anomaly. Enclaves like CI-14 (and probably the even less fertile CI-1, CI-4 and CI-9) had a low pelitic component and a small amount of melt extracted. The negative europium anomaly of CI-14 is thus not too different from the original feldspathic sedimentary source rock, and not too different from the granite itself.

We suggest that the chemical and mineralogical arguments for these primitive microgranular enclaves being restite rather than some type of igneous rock are far more compelling than the presence of a pseudo-dolerite fabric (c.f. Vernon, 1983). It is possible that this fabric results from melt extraction at the biotite breakdown curve to produce granulite facies migmatitic residues just prior to the mobilization of most of the source rocks into the magma at the RCMP. These refractory residues would have been entrained in the mobilized magma as enclaves. The mineral assemblage orthopyroxene + anothitic plagioclase + quartz ± cordierite is probably stable up to about 7Kb, a pressure consistent with that at which partial melting could have occurred.

The progressive alteration of primitive microgranular enclaves of restite origin such as the introduction of K_2O and hydration to form biotite from orthopyroxene and to produce K-feldspar, takes place during the cooling and crystallization of the host granite. The low K/Rb ratios (70-140) of the enclaves compared to the host granite (160-170) suggest diffusional introduction of Rb at a greater rate than K. In the subvolcanic environment of the Cowra Granodiorite this process is arrested early enough for some primitive rocks to remain. In the more deep-seated contact aureole environment of the Bullenbalong Supersuite granites, the process is so advanced that only possible pseudomorphs of orthopyroxene remain but the pseudo-doleritic fabric is still recognizable. In the even more deep-seated environment of the Cooma Granodiorite all traces of the original fabric has disappeared, or perhaps these residues never formed because the biotite breakdown curve was never reached.

It is concluded that all enclaves in S-type granites of the Lachlan Fold Belt, except those clearly recognizable as local country rock hornfels, are restites of various types. Pressure quenching in near surface environments such as that at Cowra, results in the preservation of microgranular enclave compositions as well as fabrics.

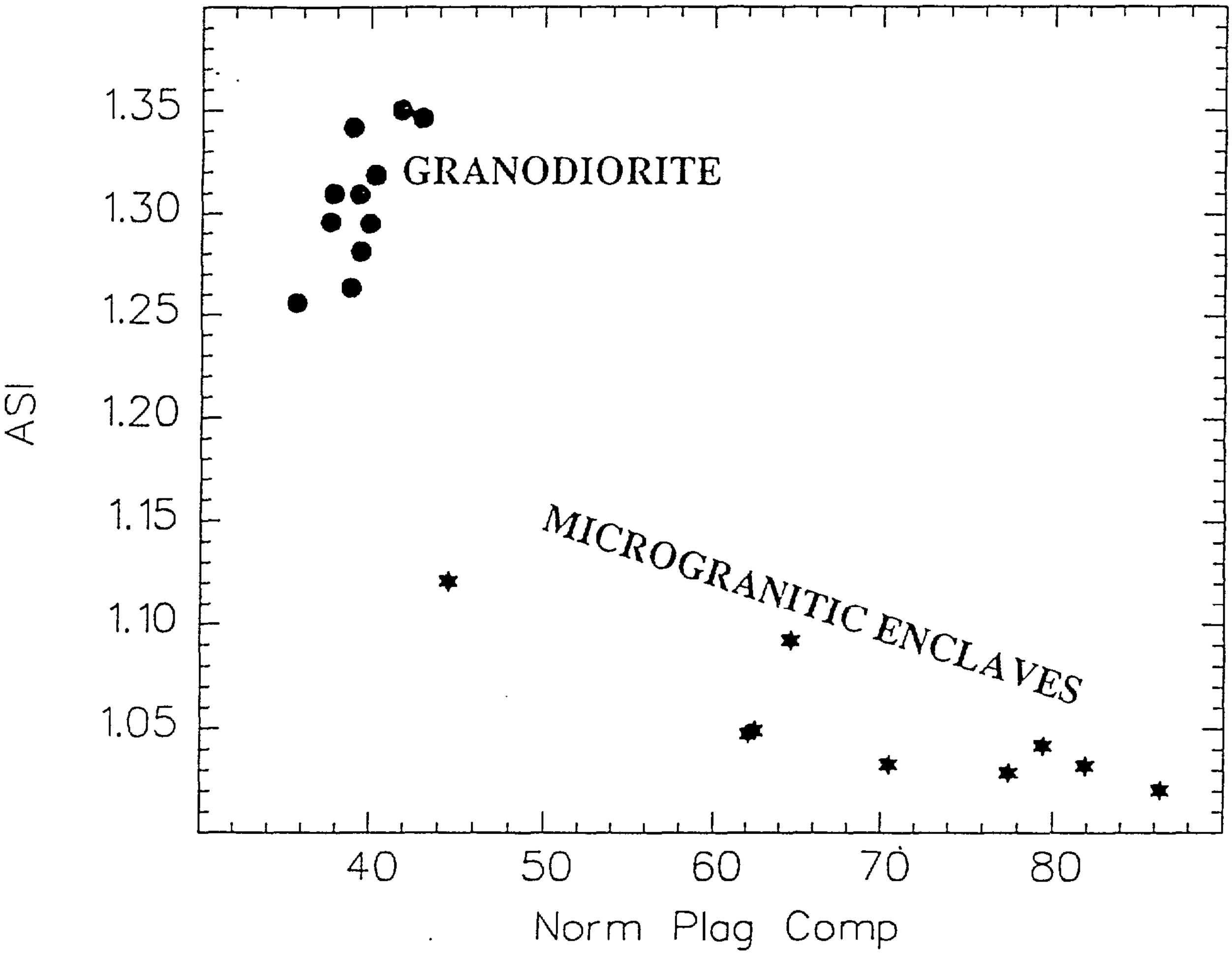


Figure 4 - Plot of normative plagioclase versus aluminium saturation index (ASI)

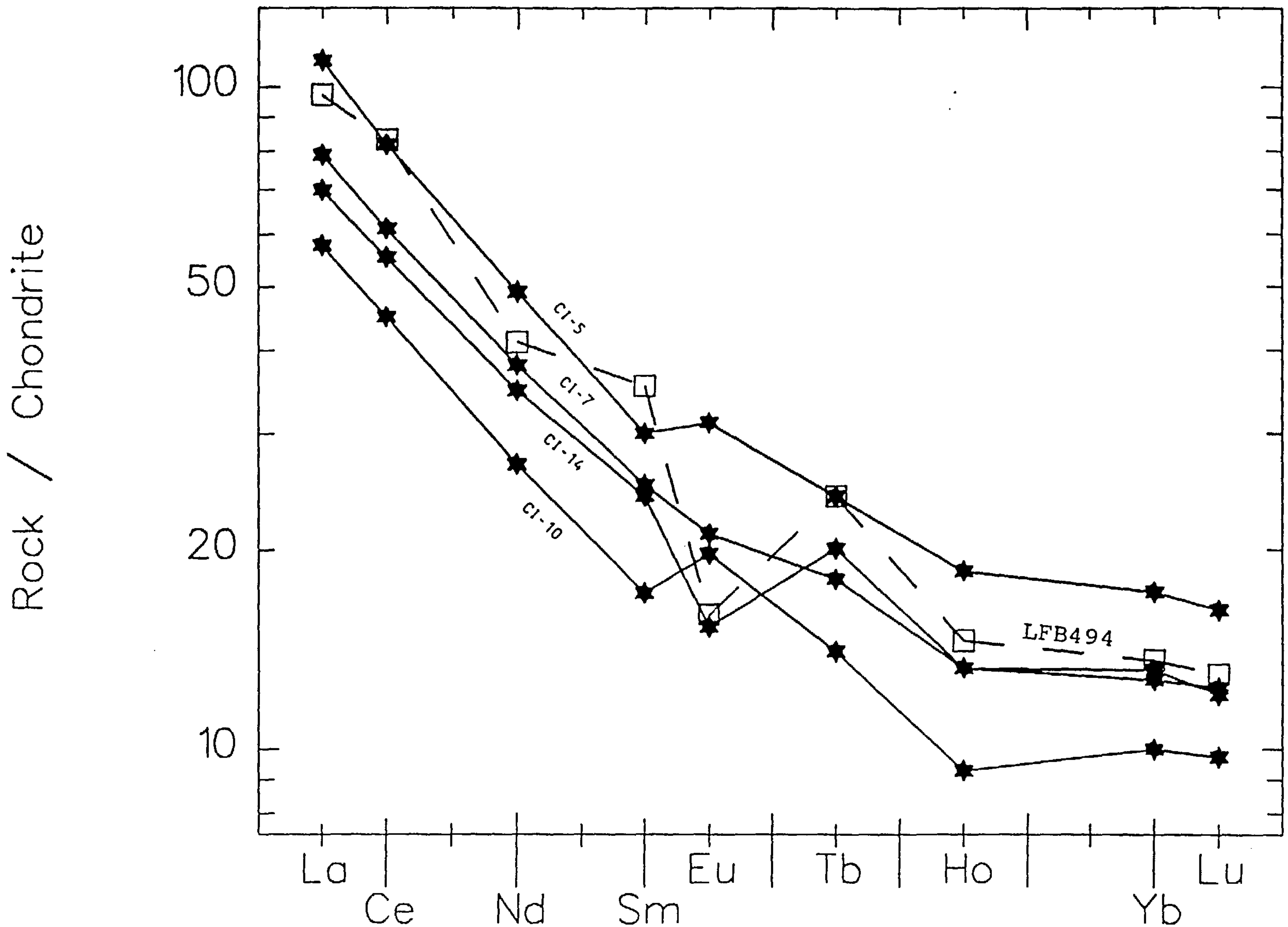


Figure 5 - Rare earth element plots for selected enclaves and the granodiorite LFB494. Enclaves with positive europium anomalies such as CI-5 and CI-10 were the most fertile and have had the most granitic melt removed. They have the lowest normative plagioclase composition. Enclaves such as CI-14 were the least fertile, they have only had a small amount of melt extracted, have negative europium anomalies approaching that of the original rock, and have the highest normative plagioclase content.

TABLE 5: ANALYSES FROM EXCURSION STOPS

UNIT	Hawkins	Laidlaw	Cowra Gdr.
LOCALITY	STOP 2	STOP 3	STOPS 4 & 5 (average of 11)
SiO2	68.05	70.05	67.77
TiO2	.61	.50	.65
Al2O3	14.41	14.03	14.44
Fe2O3	1.15	1.00	.83
FeO	3.31	2.32	3.75
MnO	.06	.03	.08
MgO	2.05	1.31	2.02
CaO	2.68	2.48	2.36
Na2O	2.03	2.26	1.99
K2O	3.58	4.09	3.56
P2O5	.15	.13	.15
H2O+	1.12	1.37	2.03
H2O-	.15	.17	.19
CO2	.24	.08	.14
Rest	.19	.18	.19
Total	99.91	100.00	100.16
	Trace elements in parts per million		
Ba	510	605	516
Rb	166	177	177
Sr	136	134	129
Pb	26.5	36.5	25
Th	19	21.6	20
U	3.8	3.6	3
Zr	180	180	191
Nb	12	11.5	12
Y	32	34	30
La	32	26	31
Ce	74	64	70
V	84	67	77
Cr	55	41	49
Ni	21	15	20
Cu	15	14	18
Zn	70	59	90
	Modes		
phenocrysts	56.3	63.0	
quartz	17.4	26.8	
plagioclase	19.3 (An51)	21.0 (An70-35)	
biotite	9.6 (mg55)	8.7 (mg52)	
orthopyroxene	4.2 (mg48)	4.3 (mg55)	
cordierite	5.4 (mg65)	-	
K-feldspar	-	3.2 (Or70-75)	
opaques	0.4	tr	
garnet	tr (mg25)	-	

PART 3 - EXCURSION STOPS

STOP 1 Grid ref. 868118 Canberra 1:100 000 sheet (Figure 2)

Mount Painter Volcanics north of Nanima Road

At this locality the Mount Painter Volcanics consists of an extremely crystal-rich ignimbrite with over 80% phenocrysts in the matrix, but also contains conspicuous flattened pumice fragments, testifying to its ignimbritic origin. The pumice fragments are aligned indicating a shallow dip to the west. They are also crystal-rich, but only contain about 50% phenocrysts, and their glassy matrix has been replaced by chlorite. The phenocrysts include the peraluminous minerals cordierite (totally altered at this locality), biotite and rare xenocrystic almandine garnet, but are dominated by quartz and plagioclase, and also include altered orthopyroxene.

STOP 2 Grid ref. 622622 Yass 1:100 000 sheet. (Figure 2)

Hawkins Volcanics on Bendenine Road

This locality contains boulders of the freshest and least metamorphosed lavas of the Hawkins Volcanics. Primary mafic minerals and unalbitized plagioclase phenocrysts are preserved. Chemical and modal analyses are shown in Table 5. Compared to the average Hawkins Suite (Table 2), the analysis from this locality is less oxidized and higher in CaO reflecting its more pristine composition.

The garnets from the Hawkins Volcanics are almandines with a mg range of 22-31 (46 analyses), their MnO and CaO contents are typically 1-2%. Commonly they contain schistose inclusions of sillimanite and are surrounded by reaction products of vermicular intergrowths of cordierite and orthopyroxene, the latter giving a P-T of equilibration of 550 megapascals and 800°C (Wyborn et al., 1981), which is believed to be the conditions in the source during melting (Figure 1).

STOP 3 Grid ref. 665626 Yass 1:100 000 sheet (Figure 2)

Laidlaw Volcanics at Boorowa River Crossing

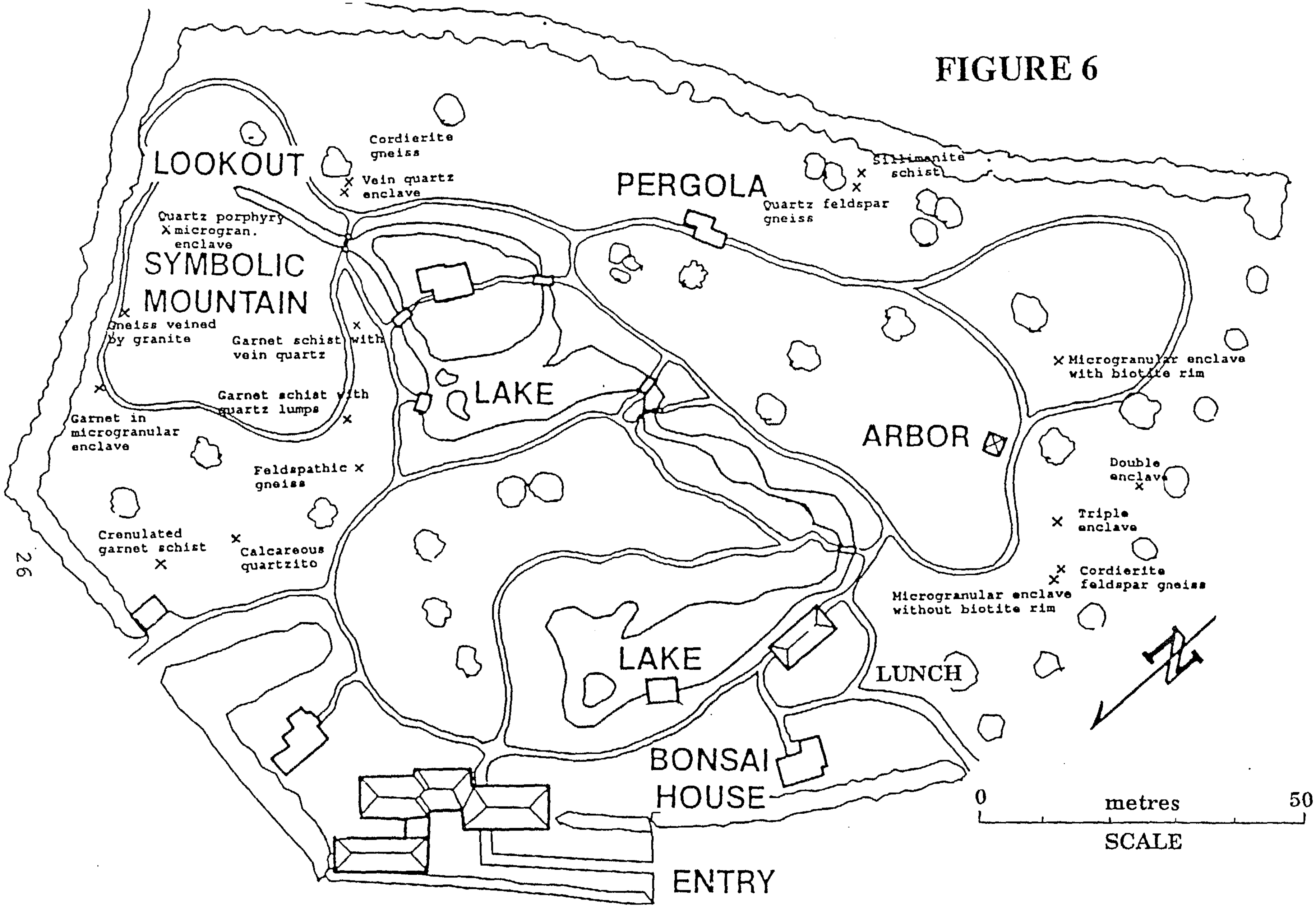
A cutting north of the bridge on the western side of the road provides the most easily accessible locality of the Laidlaw Volcanics en route to Cowra. The unit is crystal-rich (Table 5) and structureless at outcrop scale, but well-developed eutaxitic structure can be seen in thin section. Mafic minerals are mostly altered at this locality, but elsewhere the mafic minerals are perfectly preserved. Biotite has been used to date the unit by K/Ar and Rb/Sr methods at 420.7 ± 2.2ma and has been used as an important constraint on the age of the geological time scale.

STOP 4 Grid ref. 569555 Cowra 1:100 000 sheet (Figures 2 and 6)

Cowra Granodiorite at Japanese Gardens

This beautiful locality contains magnificent exposures of the Cowra Granodiorite in an idyllic garden setting. The gardens have been maintained by the Cowra Tourist and Development

FIGURE 6



STOP 4 - Cowra Granodiorite in Japanese Gardens

Corporation since 1978 to commemorate the fateful day in August 1944 when 231 Japanese prisoners and 4 Australians died during a mass break-out from the nearby prison camp. The granite tors in the gardens have been exposed to over a decade of irrigation with chlorinated town water, and the lichen and mosses that normally cover the exposures in this region have been largely killed off. Thus the gardens provide a superb location for examining the many enclaves that are present in the Cowra Granodiorite. A map of the gardens is shown in Figure 6 indicating the localities of some of the more significant enclave types. Note that when we arrive, lunch will be provided on the lawns to the south of the Bonsai House. The purpose of this stop while wandering leisurely around the gardens is to establish spirited discussions on the origins of the various enclave types. Once satisfied that all has been resolved (sic) we will walk over to the lookout south of the gardens where further excellent exposures are present.

STOP 5 Grid ref. 568552 Cowra 1:100 000 sheet

Cowra Granodiorite at Cowra Lookout

Samples of the granodiorite will be obtainable from this locality if required. The view from the lookout shows the old Tertiary erosion surface about 200 metres above the present Lachlan River plain. The hills to the south are part of a Late Devonian terrestrial sequence that is widespread over the Lachlan Fold Belt (Old Red Sandstone equivalents), and which indicates that the earlier Silurian to Early Devonian magmatism was not associated with major uplift and erosion. The red beds were deposited directly on volcanics and unroofed high-level granites. This in turn indicates that there was virtually no continental crustal addition during magmatism, as occurs at active continental margins today. Rather the magmatism was continental reworking and overturning without new continental growth.

The flat topped hills to the south west are of Early Devonian I-type granite, part of the suite of granites with which the Mountain Creek Volcanics discussed in Part 1 are associated.

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APPENDIX

STUDIED SPECIMENS OF INCLUSIONS

CI - 1 (Analysed)

Close to the edge of zoned enclave showing hydration rim. A general observation in the Cowra area is that many of the enclaves are zoned whereas in other regions such as Kosciusko zoned enclaves appear to be rare. The enclave sampled here is about 15cms in diam.
Wall below parking space at lookout (STOP 5).
Petrographic notes

Quartz appears as large crystals but these are enclosed and pierced by laths of very anothitic plagioclase and orthopyroxene both of which are quite altered in this rock. Red brown biotites commonly surround and clearly replace the orthopyroxene. Apatite prisms pierce the anorthitic plagioclase. Opaque minerals are accessory and include sulfides. Plagioclase is sericitized, biotite is chloritized or partly chloritized and epidote is secondary.

CI-2

Calcsilicate enclave

Within gardens about 50 m southeast of lookout at the back of a boulder in which there is a very large enclave.

Petrographic notes

Quartz is sometimes elongate to impart a weak foliation. Calcsilicate minerals include epidote, actinolite and calcite with accessory titanite. Apatite occurring as chunky prisms and rounded zircons are also accessory. The boundary with the surrounding granodiorite is sharp: the granodiorite is epidotized and partly chloritized but there is no sign of amphibole or enrichment of biotite which would be expected if there was magmatic contamination.

CI-3

Quartzite enclave.

Within gardens about 50 m southeast of lookout.

Petrographic notes

This is fine grained relative to the granodiorite and other enclaves. Quartz amounts to about 80% of the rock. Other minerals are plagioclase, red-brown biotite some of which appears as perfect crystals. Apatite occurs as equant crystals and zircon is also in accessory amounts.

CI-4 (Analysed)

Field identification was "Quartzite showing bedding". In thin section this is clearly a typical microgranular enclave.

Within the Kangaroo enclosure. Top of ridge, Chappell chip shot north of lookout.

Petrographic notes

The mineral assemblage is quartz, plagioclase, orthopyroxene, biotite (red-brown and replacing orthopyroxene) and accessory apatite (needles) and opaques. There is much secondary alteration with sericitization of plagioclase and the formation of montmorillonite or bastite around the orthopyroxene.

CI-5 (Analysed)

"Microgranite" was what we called this sample in the field and this is what it is in thin section. It is pretty well altered with sericitized plagioclase, chlorite replacing much of the biotite and epidote granules. It does not have a pseudo-doleritic fabric.

Top of ridge, good Chappell 7 iron shot north of lookout.

Petrographic notes

The irregular grey and white colored patches seen in the hand sample are found in thin section to result from sericitization, chloritization and epidotization causing a bleaching of the white portions. In places the rock is completely replaced by these secondary minerals.

Quartz grains are up to 2.5mm and contain inclusions of well shaped plagioclase laths. Some of the bigger laths project into the edges of the quartz crystals. Plagioclase is zoned (An_{35-50}) with some cores at least An $_{60-65}$), is lath shaped and the laths have random orientation. Biotite (α= straw colored, β=τ=red brown). K-feldspar is up to 2.5mm and interstitial. Apatite appears as elongate prisms but is **not** needle shaped. Opaques include some ilmenite rods in biotite and sulfides. Zircon is also accessory.

CI-7 (Analysed)

Microgranular enclave that appears in hand sample to be coarser than CI-5

It has pseudodoleritic fabric and orthopyroxene.

Same locality as CI-5, i.e.top of ridge and a good Chappell 7 iron shot north of lookout.

Petrographic notes

Quartz into which project calcic plagioclase. Some of the calcic plagioclase has cores that are crowded with tiny inclusions of other minerals. Orthopyroxene mostly occurs as granules but also some prisms and is in places replaced by red brown biotite which also occurs as fairly well shaped crystals. Cordierite (2mm) partly pinitized is rare. There are a few patches of interstitial K-feldspar in the more biotite rich parts. Tiny apatite needles are accessory as are tiny rods of ilmenite.

CI-9 (Analysed)

Microgranular enclave 50 cms across.

Specimen taken from the center of the large enclave. First boulders at the southern end of the playing fields.

Petrographic notes

Quartz, calcic plagioclase, orthopyroxene,red brown biotite . Tiny apatite needles are accessory as are scattered opaques. This rock is badly altered, so it is impossible to say whether there are any altered cordierites.

CI-10 (Analysed)

Microgranular enclave 25 cms across having no rim visible in the field. Boulders at the southern end of the playing fields.

Petrographic notes

Quartz, calcic plagioclase, orthopyroxene and red brown biotite. Fairly fat apatite needles are accessory as are rare opaques that appear to be magnetite. There are a few zircons. No cordierite was found

CI-11 (Analysed)

Garnet meta-pelite 50cms long and 30 cms across. Homogeneous except for lumps of garnet in veins which have salic rims.

Boulders at the southern end of the playing fields.

Petrographic notes

The dark colored rims around the garnet seen in handsample are aggregates of fine grained sericite. The paler zones around the garnet outside the sericite rims, consist of relatively coarse grained quartz + rosettes of muscovite + large chlorite pseudomorphs after biotite. There are also a few crystals of very cloudy feldspar, opaques and late (at same generation as chlorite ??) titanites. Further from the garnets the rock relatively fine grained : it consists of sericite aggregates presumably after feldspar, equidimensional quartz and some scattered red brown biotites that are partly chloritized.. The few grains of a high relief fairly low birefringent mineral could be manganiferous epidote.

CI-12 (Electron probe studies)

Microgranular enclave having some large quartz crystals and thought to be slightly weathered in the field; this turns out to be because it is rich in cordierite. It has a hydration rim. In thin section it is seen to have orthopyroxene and a good pseudodoleritic fabric.

Southern end of the playing fields near road within the park.

Petrographic notes

Quartz ,2-3 mm across, commonly has plagioclase laths projecting into it. Plagioclase appears as lath-shaped crystals to 2 mm that is quite calcic, up to An_{80}. Some are zoned with irregular cores (An_{80}) and patches around An_{45}. Within some of the plagioclases are rounded blebs of quartz. Orthopyroxene (mg64, but with some cores as magnesian as mg84) is seen as prisms at least 5mm in length as aggregates of smaller crystals and is also seen as rounded blebs in other minerals. Cordierite (mg76-78), mostly replaced by pinite, may occur as irregular shaped aggregates to about 8mm as well as smaller mostly irregular crystals sometimes having the appearance of coarse intergrowths with quartz. Red brown biotite (mg65-66) replaces orthopyroxene and also appears as fairly well shaped crystals. There are a few large apatites but most appear as needles. Accessory zircon is common.

CI-14 (Analysed) (Electron probe studies)

Microgranular enclave (20 X 30 cms) dark colored and even grained.

Northside of Macasser Street, at junction of Macasser and Macquarie Streets.

Petrographic notes

Quartz occurs as irregularly shaped crystals mostly 1-2 mm across, into some of which project calcic plagioclase up to An_{90}. Orthopyroxene (mg52, but with some cores as magnesian as mg87) appears as granules, prisms and as some larger stumpy irregular crystals to 2mm. Orthopyroxene is in places replaced by red brown biotite (mg53-56) which also appears are well developed crystals isolated from orthopyroxene. Altered cordierite (2mm) is rare. Tiny apatite needles are a common accessory mineral as are rods of ilmenite . There are a few small zircons.

CI-15

Microgranular enclave with unusual-looking inner zone.

Same locality as CI-14 i.e. northside of Macasser Street, at junction of Macasser and Macquarie Streets. At this locality there is also an angular "nebulite" enclave.

Petrographic notes

Quartz, calcic plagioclase and orthopyroxene dominate the rock and there is well developed pseudodoleritic fabric produced by the plagioclase laths projecting into, and enclosed within the quartz. There are also some large plagioclases (5mm) and a few quartz crystals of about the same size, the latter also having plagioclases laths projecting into their boundaries. Plagioclases and many orthopyroxenes are extensively altered. Red-brown biotite is not common and almost all grains appear to be replacing orthopyroxene. Opaques are scattered throughout but apatite needles are not conspicuous.

CI-16 (Analysed)

Microgranular enclave 50 cms across.

At water tank.

Petrographic notes

Quartz has irregular shape, is up to 3mm across and has inclusions of lath-shaped calcic plagioclase which also project into the edges of the crystals. The fabric is pseudodoleritic. There are some lath shaped orthopyroxene crystals but most are granular. Red-brown biotite is in places undoubtedly replacing orthopyroxene. Apatite needles are conspicuous. Some of the accessory opaques are rod shaped suggesting ilmenite.

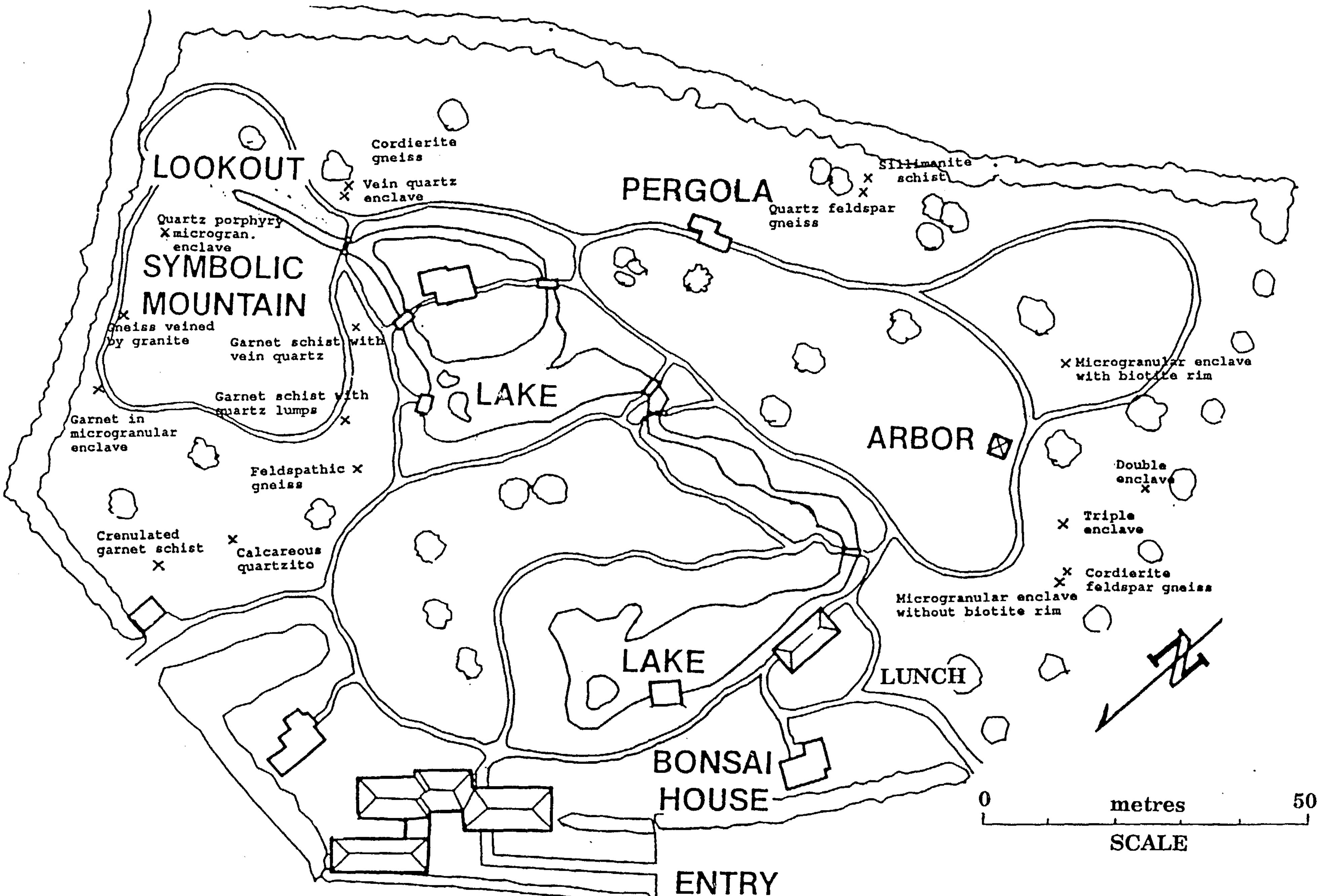
CI-17 (Analysed)

Microgranular enclave (large) containing large crystals of quartz and feldspar.

At water tank.

Petrographic notes

Quartz has irregular shape, is up to 3mm across and in this rock is crowded with inclusions of lath-shaped calcic plagioclase which also project into the edges of the crystals and which are mostly only 0.5mm long. There are also some large crystals of plagioclase. Orthopyroxenes, red-brown biotites and small rods of opaque mineral also occur as inclusions within the quartz, so that the quartz appears as a matrix in which the other minerals are set. The red-brown biotite is scattered throughout the whole rock. Apatite needles are accessory.



STOP 4 - Cowra Granodiorite in Japanese Gardens