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EXCURSION GUIDE

THE COWRA GRANODIORITE AND ITS ENCLAVES

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GENERAL ASSEMBLY
SEPTEMBER 1993 - CANBERRA AUSTRALIA

ANCIENT VOLCANISM & MODERN ANALOGUES

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Record 1993/67
Australian Geological Survey Organisation

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: Hon. Michael Lee, MP
Secretary: Greg Taylor

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Harvey Jacka

ISSN: 1039-0073

ISBN: 0 642 19668 0

INTRODUCTION

The Lachlan Fold Belt (LFB) in southeastern Australia was the site of extensive igneous activity in Silurian and Devonian times. The Palaeozoic rocks of this belt cover an area of close to 300,000 km^2 and granites comprise a little over 20% of that area (61,000 km^2). Related volcanic rocks occur over a further 5% of the LFB and are more abundant in the eastern half of the belt. Where it is exposed over its full width, the belt is some 750 km wide. Radiometric age data on the granites are sparse, but point to most of the granites of this large area being emplaced within a restricted period of time from 420 to 390 Ma with some plutons as young as 360 Ma in the central part of the belt north of Melbourne. In the most easterly part of the belt 2800 km^2 of granite with an age ~320 Ma are present. Before the opening of the Southern Ocean the dominantly Caledonian-age granites of this belt were continuous with those of the same age in the northern part of the Trans-Antarctic Mountains. They apparently also continue north beyond present exposures, beneath younger rocks to reappear on North Queensland. Hence before the separation of Antarctica, these granites and their related volcanic rocks probably extended over a distance of at least 3600 km, with a width up to 750 km (Chappell & Stephens, 1988). By any standards this is a major petrologic province and it is fortunate that it has been exposed in a way that makes a significant part of it very accessible to earth scientists based in Canberra.

The general geological setting of these igneous rocks in southeastern Australia has been discussed by White & Chappell (1983) and Chappell *et al.* (1988). A coloured map of the granites has been published by AGSO (Chappell *et al.*, 1991) and is available for purchase at the IAVCEI Conference. Of the work that has been done in this area in the last thirty years, the best known is that which separates the granites, almost equally in terms of areas, into two groups, the I- and S-types (Chappell & White, 1974, 1992). To some extent, that subdivision drew on the model developed for much of the granite work in the LFB, the *restite model* (White & Chappell, 1977; Chappell *et al.*, 1987), which inexplicably remains controversial. Recognition of the equivalence between volcanic and plutonic suites was a significant contribution, initiated by AGSO scientists (Wyborn *et al.*, 1981). In more recent years the granite studies have lead to models for the tectonic development of the LFB that differ significantly from other models, involving the concept of basement terranes (Chappell *et al.*, 1988). It has been recognised from the earliest times that the different granite types represented in the LFB are associated with different types of mineralisation (Chappell & White, 1974), and this has recently been more completely documented for the LFB by Blevin & Chappell (1991).

This excursion is an opportunity to look at some of these aspects of the LFB. In the vicinity of Canberra, two of the related granite suites are briefly inspected. An example of a more mafic S-type granite is seen at the superb exposures of the Cowra Granodiorite. That locality also provides an opportunity to examine some of the field evidence both for the origin of granite enclaves and restite model, and to consider other supporting data. This guide is adapted from an earlier one prepared for the Second Hutton Symposium on Granites and Related Rocks by Wyborn *et al.* (1991).

PART 1 - SILURIAN VOLCANIC ROCKS OF THE CANBERRA-YASS REGION

The felsic volcanic rocks of the Canberra-Yass region are part of the extensive belt of granites and felsic volcanic rocks that make up about half of the eastern part of the LFB. The volcanic rocks can be closely compared with different suites of granites, and Wyborn *et al.* (1981) showed that there are several comagmatic volcano-plutonic associations. Two kinds of associations were recognised by Wyborn & Chappell (1986), one in which the granites and volcanic rocks are chemically equivalent and chemical variation was dominated by restite removal, and a second where the volcanic rocks formed as 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 volcanic rocks 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 volcanic rocks can be distinguished in the Canberra-Yass region, based on the mineralogy of the units. These are

(i) Hawkins Suite
(i) Laidlaw Suite
(iii) Mountain Creek Suite

Each of these suites was derived from a distinct source-rock of both different chemical composition and level in the crust, and was formed at different temperatures. The Hawkins Suite is the oldest and comes from the shallowest levels in the crust at the lowest temperatures (0.55 Gpa at 800°C). The Mountain Creek Suite is the youngest and comes from the deepest levels in the crust at the highest temperatures (1 Gpa at 1050°C). The Laidlaw Suite is intermediate between the other two. A well-constrained geothermal gradient can be constructed through the crust using P-T estimates

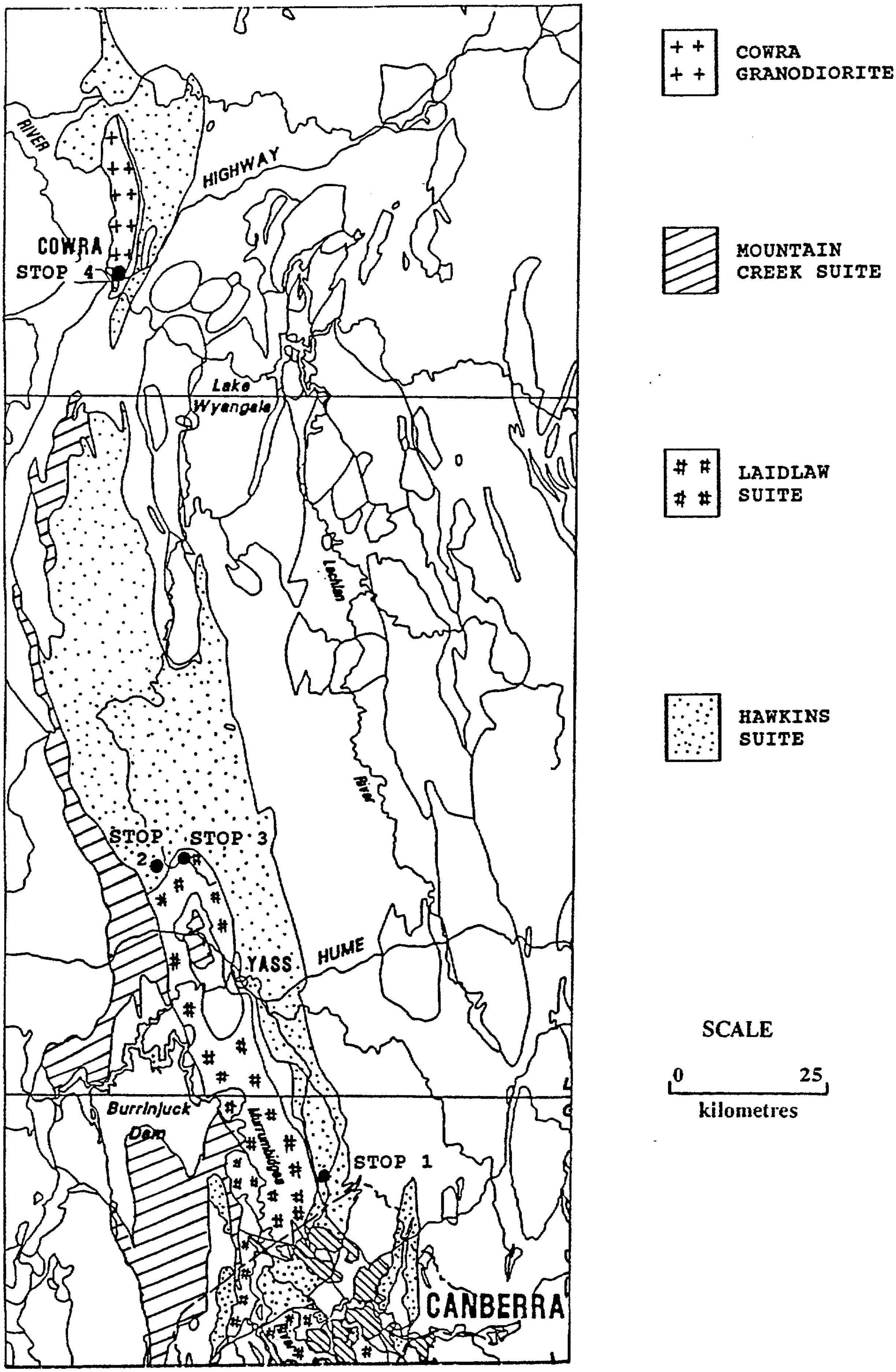

Figure 1. Generalised geology - Canberra to Cowra

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 with a value of a little under 20°/km (Wyborn *et al.*, 1991; Wyborn, 1993). The gradient 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 these three volcanic suites between Canberra and Cowra is shown in Fig. 1.

(i) HAWKINS SUITE

The Hawkins Suite of volcanic rocks is part of the Bullenbalong Supersuite, the most extensive group of igneous rocks in southeastern Australia. The extrusive and intrusive rocks of this supersuite are comagmatic and chemically equivalent, belonging to the first kind of volcano-plutonic association described above. The volcanic rocks extend for a distance of over 250 km, from Dubbo in the north to Kiandra in the south. Granites of the Bullenbalong Supersuite are even more extensive, extending over 350 km 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, as a result of their derivation 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 have been derived from the Ordovician sediments.

In the Canberra district 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 volcanic rocks, 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 were new. The volcanic rocks 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 albitised by burial metamorphism), biotite, cordierite, orthopyroxene (Mg_{45-50}) and xenocrysts of garnet. Where the plagioclase is unalbitised, it is relatively unzoned with a composition close to An_{50}. Orthopyroxene is absent in the equivalent granites, 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 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 volcanic rocks 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, as it there contains the largest and greatest abundance of lithic and flattened pumice fragments. The ignimbrite extends north for over 60 km to an extensive area of poorly mapped Hawkins Suite volcanic rocks northeast 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 as early Ludlovian, the earliest part of the late Silurian (Link & Druce, 1972). Eruption of the Hawkins Suite fits a pattern equivalent to the eruption of a single granite pluton with a volume of about 1000 km^3. Earliest eruptions from the top of the magma body were crystal poor and rhyolitic in composition. These were followed by numerous small eruptions of crystal rich dacitic ignimbrite and lava culminating in a climactic ignimbritic eruption of some 500 km^3 that essentially evacuated 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 the Yarralumla Formation, but the mineralogy of the volcanic rocks was different from the underlying Hawkins Suite. Cordierite and garnet are absent and sanidine and allanite are present. These volcanic rocks, 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 (An_{70}-An_{35}) 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,

TABLE 1. AVERAGE COMPOSITIONS OF SOME VOLCANIC UNITS

Unit	Hawkins	Mt Painter	Laidlaw	Mtn Ck
no anals	13	9	26	11
SiO_2	67.82	66.30	70.00	71.89
TiO_2	0.56	0.59	0.43	0.53
Al_2O_3	13.99	13.93	14.17	13.93
Fe_2O_3	1.85	0.68	1.01	0.83
FeO	2.65	4.33	2.10	1.39
MnO	0.06	0.09	0.05	0.12
MgO	1.92	2.63	1.31	0.60
CaO	1.17	2.28	2.86	1.86
Na_2O	2.28	1.86	2.74	3.62
K_2O	4.49	3.58	3.31	4.29
P_2O_5	0.12	0.11	0.09	0.07
H_2O+	2.18	2.47	1.23	0.53
H_2O-	0.19	0.10	0.11	0.05
CO_2	0.37	0.57	0.14	-
rest	0.22	0.20	0.20	0.20
	99.88	99.73	99.74	99.31
Trace elements (ppm)				
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

sodic plagioclase and biotite have also crystallised from the melt during ascent and cooling. The Laidlaw Suite is thought to have been derived from a feldspathic greywacke source beneath the Hawkins Suite source.

The volcanology of the Laidlaw Suite is somewhat similar to the 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 500 m thick, and can be mapped from southern Canberra to north of Yass (**STOP 3**) and has a total strike length of about 100 km. It appears to represent a single ignimbrite eruption with a volume of nearly 1000 km^3 that once covered an area of at least 2000 km^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 *Neoprioniodus excavatus* 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 volcanic rocks, 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 to northwest of Canberra, and are distinctly different from the Silurian volcanic rocks. 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 volcanic rocks are I-types 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 recognised by Wyborn & Chappell (1986), in which the volcanic rocks represent the complementary fraction of intrusive cumulates that separated by convective fractionation. The volcanic rocks belong to a suite of intrusive and extrusive rocks that extend in a meridional belt from eastern Victoria for over 500 km to Dubbo in central New South Wales (Wyborn *et al.*, 1987). They will not be examined on this excursion.

CHEMICAL COMPOSITION

The three volcanic suites, although similar in silica content (Table 1) are mineralogically distinct, and this is mainly reflected in the relative abundance of Al and alkalis, which is in turn related to the composition of the source-rocks. The Hawkins Suite has an excess of Al (peraluminous) reflecting its pelitic sedimentary source, the Laidlaw Suite is close to saturated in Al, and the Mountain Creek Suite is metaluminous, reflecting its mafic igneous lower crustal source.

PART 2 - COWRA GRANODIORITE AND ASSOCIATED ROCKS

The Cowra Granodiorite is an elongate intrusion of mafic garnet-cordierite granodiorite outcropping over an area of 95 km^2 in the northern part of the Kosciusko Basement Terrane of Chappell *et al.* (1988). S-type granites are here not as extensive as are 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 volcanic rocks of equivalent composition (Wyborn *et al.*, 1981). Despite its mafic character, contact metamorphic affects are only discernible within about 1 m of the contact of the Cowra Granodiorite. This rock is medium- to coarse-grained containing crystals of quartz, plagioclase, K-feldspar and cordierite up to 3-mm across and smaller sometimes perfectly shaped red-brown biotite crystals commonly 0.5-1 mm across. Large garnet crystals surrounded by cordierite are present but not in sufficient abundance to normally be seen in thin-sections. Their compositions are virtually identical to the garnet in the Hawkins Volcanics, that is they have *Mg* values of 20-25, and contain 1-2% MnO and CaO. Plagioclase, which may also occur 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 sericitised 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 ten samples of the Cowra Granodiorite are shown in Table 2, arranged in order of decreasing FeO* content. The pluton is one of the most mafic S-types from the LFB and is part of the Bullenbalong Supersuite. The analyses in Table 2 are illustrative of the most significant features of the more mafic S-type granites of the LFB. Thus, while they are rather mafic granites with average FeO* and MgO contents of 4.47% and 2.02%, and relatively high abundances of the trace transition metals, the SiO_2 content is also relatively high. That high SiO_2 abundance, combined with the low CaO and very low Na_2O contents, accounts for the high normative Q (Table 2) and modal quartz abundances. Low Ca, Na and Sr are the most distinctive features of S-type granites of the LFB relative to the I-type granites and is a result of their derivation from source rocks from which those elements had been lost during an earlier weathering event. The low Ca and Na levels of these rocks are also responsible for their strongly peraluminous nature, with normative C values from 2.9% to 3.8% (Table 2). Another feature of the analyses in Table 2 which is consistent with their S-type character is the generally low Fe_2O_3:FeO ratios.

Within the Bullenbalong Supersuite there are systematic small differences in composition, corresponding to separate suites. Compared with Bullenbalong Supersuite rocks from the southern part of the Kosciusko Basement Terrane, the Cowra Granodiorite or Suite 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. Differences such as these are ascribed to corresponding small differences in source-rock compositions.

CANOWINDRA VOLCANICS

The Canowindra Volcanics ("porphyry") are intruded by the northern end of the Cowra Granodiorite (Fig. 1). These volcanic rocks are almost certainly part of the Hawkins Suite as they show the same mineralogical features, but they were extruded into a shallow marine environment and are rather more altered than the subaerial volcanic rocks to the south. However Stevens (1952) reported "sparsely-distributed red garnet" in these rocks. Pseudomorphs of cordierite and orthopyroxene are also recognisable. Hence the Cowra Granodiorite is a subvolcanic intrusion.

ENCLAVES IN THE COWRA GRANODIORITE

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) granitised.

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, derived from the adjacent Silurian sediments and they are not discussed further here. 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. Table 3 gives a list of assemblages in these enclaves modified from Stevens (1952). 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 to be more surmicaceous than they really are, although red-brown biotite dominates the mineral assemblage in many and variation of biotite abundance outlines the banding seen in some rocks. In some enclaves, large garnets up to 30 mm 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 having

TABLE 2. CHEMICAL ANALYSES OF COWRA GRANODIORITE

	WB151	WB97	WB143	WB2	WB118	WB127	WB116	WB150	WB96	WB117
Grid ref.	570607	569605	572584	565555	573571	567552	572768	567639	557551	565672
SiO_2	67.87	67.46	68.21	67.52	67.67	67.71	67.77	68.28	67.69	68.01
TiO_2	0.68	0.65	0.65	0.64	0.65	0.66	0.65	0.65	0.61	0.62
Al_2O_3	14.59	14.40	14.48	14.38	14.39	14.40	14.46	14.50	14.44	14.39
Fe_2O_3	0.81	0.98	0.46	1.30	0.57	0.66	0.78	0.66	1.08	0.75
FeO	4.02	3.77	4.18	3.34	3.92	3.81	3.69	3.76	3.35	3.58
MnO	0.11	0.09	0.08	0.08	0.07	0.06	0.07	0.06	0.06	0.05
MgO	2.13	1.96	2.10	2.04	2.02	2.05	2.03	2.06	1.85	1.92
CaO	2.37	2.34	2.24	2.37	2.29	2.45	2.47	2.41	2.23	2.30
Na_2O	1.80	1.98	1.92	1.93	2.05	2.06	2.13	1.98	2.02	2.26
K_2O	3.60	3.53	3.60	3.47	3.52	3.47	3.52	3.62	3.79	3.62
P_2O_5	0.15	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.14	0.15
S	0.03	<0.02	0.02	<0.02	<0.02	<0.02	0.03	<0.02	<0.02	<0.02
H_2O+	1.98	2.16	1.61	2.23	1.78	1.96	1.76	2.29	2.18	2.23
H_2O-	0.26	0.13	0.20	0.24	0.17	0.17	0.16	0.33	0.15	0.18
CO_2	0.13	0.25	0.15	0.24	0.08	0.05	0.08	0.20	0.16	0.09
O=S	-0.01		-0.01				-0.01			
SUM	100.52	99.84	100.03	99.92	99.33	99.66	99.74	100.95	99.77	100.15
Trace elements (ppm)										
Ba	500	535	505	510	520	530	525	520	500	495
Rb	175	180	177	177	176	171	173	178	195	184
Sr	136	128	128	131	131	133	128	130	121	121
Pb	25	27	27	27	38	22	26	20	27	16
Th	21.5	20.5	19.8	20.5	21.5	20.5	20.5	21.0	20.0	21.0
U	3.6	3.0	4.0	3.6	3.4	3.8	3.2	4.2	3.6	2.4
Zr	196	193	189	194	194	191	187	195	192	189
Nb	12.0	11.5	13.0	12.0	12.5	12.5	12.5	13.0	12.0	13.0
Y	31	29	31	29	30	31	33	32	29	32
La	33	29	32	30	32	32	31	30	30	33
Ce	72	71	72	70	67	70	69	70	69	73
Nd	27	26	26	26	25	26	25	25	25	28
Sc	16	13	15	14	16	16	16	15	13	14
V	80	73	79	79	79	82	78	82	68	72
Cr	50	48	48	52	50	50	47	51	47	45
Co	13	16	16	15	15	16	14	15	14	16
Ni	21	19	20	19	21	21	22	22	17	20
Cu	17	24	17	18	18	16	21	3	18	32
Zn	155	104	104	81	96	59	69	53	58	38
Ga	17.0	17.2	17.4	17.8	18.0	17.4	17.6	17.8	16.8	17.4
As	4.5	5.0	5.0	3.0	2.5	1.5	1.0	5.0	2.5	1.5
Sn	6	7	8	6	7	6	7	6	8	7
CIPW normative minerals										
Q	33.15	32.52	32.83	33.40	32.14	32.07	31.65	32.64	32.31	31.35
C	3.78	3.40	3.69	3.48	3.40	3.16	3.01	3.30	3.30	2.93

TABLE 3. MINERAL ASSEMBLAGES IN PELITIC ENCLAVES OF THE COWRA GRANODIORITE

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

been 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 volcanic rocks. Quartz lumps similar to those found in all other LFB S-type granites are common although not mentioned by Stevens (1952). One oval-shaped quartz lump 450 mm 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 epidotised around the enclave but there is no sign of the amphibole that would be expected if there was contamination to any great extent. The typical mineral assemblage in the enclave is epidote (or clinozoisite) + plagioclase + quartz. Actinolitic amphibole, calcite and rarely minor K-feldspar may also occur. Rounded zircons, sphene and chunky crystals of apatite are minor components.

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 nine such enclaves are given in Table 4. They are generally fine-grained and massive but include what was considered in the field to be a metapelite 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 pseudodoleritic fabric taken by others as evidence of an igneous origin. The sample has the least calcic normative plagioclase composition is the most peraluminous of all the analysed samples (Table 4).

Many of the microgranular enclaves have a clearly defined reaction rim about 20% 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 characterised by pseudodoleritic fabric in which lath-shaped plagioclase crystals 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}. 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 crystals 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 "granitised 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 containing calcic plagioclase that almost certainly were derived in a similar way to the Cowra enclaves. The Jillamatong enclaves do not, however, contain fresh orthopyroxene.

ENCLAVES IN S-TYPE GRANITES OF THE LACHLAN FOLD BELT

Mica-rich schistose and surmicaceous enclaves and lumps of milky quartz are common in all S-type granites of the LFB becoming progressively less abundant when the host rocks are more felsic. When present, microgranular enclaves in S-type granites from different environments within the LFB have many

TABLE 4. CHEMICAL ANALYSES OF MICROGRANITIC ENCLAVES

	CI-1	CI-4	CI-5	CI-7	CI-9	CI-10	CI-14	CI-16	CI-17
Grid ref.	567552	567553	566554	566554	564557	564557	564556	571569	571569
SiO_2	60.14	59.67	58.23	63.07	61.90	65.45	61.13	61.83	61.58
TiO_2	0.74	0.61	1.07	0.85	0.50	0.47	0.65	0.93	0.99
Al_2O_3	16.38	16.12	18.26	15.75	14.99	13.87	16.00	15.24	15.65
Fe_2O_3	1.55	1.53	1.51	1.28	1.03	0.98	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	0.11	0.13	0.09	0.11	0.12	0.11	0.12	0.13	0.11
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
Na_2O	0.91	0.70	3.31	2.04	0.96	1.57	1.16	1.51	1.96
K_2O	1.52	0.92	2.46	1.26	1.25	1.17	1.21	1.05	1.50
P_2O_5	0.09	0.07	0.22	0.14	0.09	0.10	0.11	0.14	0.13
S	0.09	0.05	0.03	0.04	0.08	0.06	0.08	0.07	0.06
H_2O+	1.79	1.82	2.35	1.01	1.84	1.28	1.65	1.17	1.43
H_2O-	0.30	0.30	0.38	0.26	0.38	0.31	0.33	0.35	0.30
CO_2	0.26	0.21	0.23	0.19	0.30	0.23	0.16	0.31	0.22
O=S	-0.04	-0.02	-0.01	-0.02	-0.04	-0.03	-0.04	-0.03	-0.03
SUM	99.84	99.73	99.72	99.94	99.71	99.60	99.88	99.48	99.85
Trace elements (ppm)									
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	2.2	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
Sc	40	39	23	26	34	27	33	32	32
V	197	182	162	184	166	126	158	196	143
Cr	25	19	<1	23	155	127	43	15	89
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
As	4.5	3.5	3.0	1.5	5.0	3.5	5.5	7.5	2.5
Sn	5	3	8	3	3	3	4	3	6
CIPW normative minerals									
Q	25.20	25.77	14.09	26.63	27.35	32.07	25.63	27.12	23.49
C	0.51	0.32	1.97	0.71	0.60	1.17	0.45	0.48	0.73

similarities but their differences are considered to shed some light on the problem of their origin (White *et al.*, 1991). Those at Cowra are the most primitive found to date and are the most informative with respect to their origin.

Mica-rich schistose and surmicaceous enclaves

The Cooma Granodiorite (Joplin, 1942) occurs within regionally metamorphosed rocks with migmatites near the contacts (regional-aureole granite) and clearly it has been derived from rocks equivalent to those 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 and Berridale Batholiths, e.g. Jillamatong and Cootralantra Granodiorites (White *et al.*, 1977; White & Chappell, 1988; Chen *et al.*, 1989) have narrow contact aureoles. 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 sillimanite and cordierite crystals in the mica-rich schistose and surmicaceous enclaves, suggests that these are derived from depths 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 i.e. 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 those 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 volcanic rocks of the same composition and it is therefore a subvolcanic granite. The mica-rich schistose and surmicaceous enclaves in the near surface intrusion of the 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-type granites of the LFB 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 did not melt to any appreciable extent during partial melting 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 pre-existing melt phase.

Quartz lumps

The origin of the quartz lumps that are relatively rare but ubiquitous in all of the more mafic S-type granites of the LFB 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". Vernon & Flood (1982) state that milky and smoky quartz occur near xenoliths of pegmatite in the Cooma Granodiorite and they suggested 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, can leave 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 were derived.

Microgranular enclaves

According to Didier (1964, 1973) microgranular enclaves in general are fine-grained, massive and rounded and have mineralogical and chemical characteristics reflecting those of the host granite. Many have fabrics suggestive of igneous rocks (pseudodoleritic 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 Wyllie *et al.* (1962) to support this suggestion.

In the regional-aureole Cooma granite, there are no microgranular enclaves having pseudodoleritic 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 contact-aureole and subvolcanic granites. Because of the igneous-looking fabric and the 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 seed of the magma mingling hypothesis presently in vogue. Based on the mineralogical and chemical coherence with the host he also suggested that early crystallisation of granite on the walls and subsequent reincorporation into the magma is a possible explanation.

In the contact-aureole and subvolcanic granites of the Bullenbalong Supersuite such as the Cowra Granodiorite, 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-type granites adjacent to the Jillamatong Granodiorite again suggests that they were derived from the source rocks or were at least part of the Jillamatong magma. Also the fact they are peraluminous "rules out the possibility that they could represent crystallised blobs of an extraneous mingling magma such as basalt or andesite" (Chen *et al.*, 1989), unless metasomatic alteration (the granitisation 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 "crystallised pieces of Cootralantra Granodiorite that have been reincorporated in the magma". However, for the Jillamatong Granodiorite, Chen *et al.* (1989) argue that because certain elements lie off the geochemical trends shown by the host granite then they cannot be early crystallisation 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 critical melt fraction 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 were arrested in the process of modification by the granite and modified rims that resemble those in more deep-seated granites of the Bullenbalong Supersuite. 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 pseudodoleritic 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 P_2O_5 content. They are also lowest in Zr and Nb and least peraluminous. Rare earth element analyses of selected samples are similar to the host granodiorite, except that the rather large negative Eu anomaly of the granodiorite is not present in the enclaves. The Eu anomalies of the enclaves are slightly positive for samples CI-5 and CI-10, nonexistent for CI-7 and negative for CI-14. From these limited data it appears that the rocks with the lowest anorthite contents have the highest Eu (CI-5), and those with the highest anorthite content have the lowest Eu (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 rheological critical melt fraction extracted from them. The granite magma itself formed from the bulk of the source which melted to the critical melt fraction 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 Eu 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 Eu anomaly of CI-14 is thus not too different from the original feldspathic sedimentary source rock, and not too different from the granite itself.

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 pseudodoleritic fabric (cf. 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 mobilisation of most of the source rocks into the magma when the critical melt fraction is reached. These refractory residues would have been entrained in the mobilised magma as enclaves. The mineral assemblage orthopyroxene + anorthitic plagioclase + quartz ± cordierite is probably stable up to about 700 MPa, 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 crystallisation of the host granite. 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 other Bullenbalong Supersuite granites, the process is so advanced that only possible pseudomorphs of orthopyroxene remain but pseudodoleritic fabric is still recognisable. In the even more deep-seated environment of the Cooma Granodiorite, either all traces of the original fabric has disappeared, or these residues never formed because the biotite breakdown curve was never reached.

It is concluded that all enclaves in S-type granites of the LFB, except those clearly recognisable as local country rock origin, are restites of various types. More rapid crystallisation in near surface environments such as that at Cowra, results in the preservation of microgranular enclave compositions as well as fabrics.

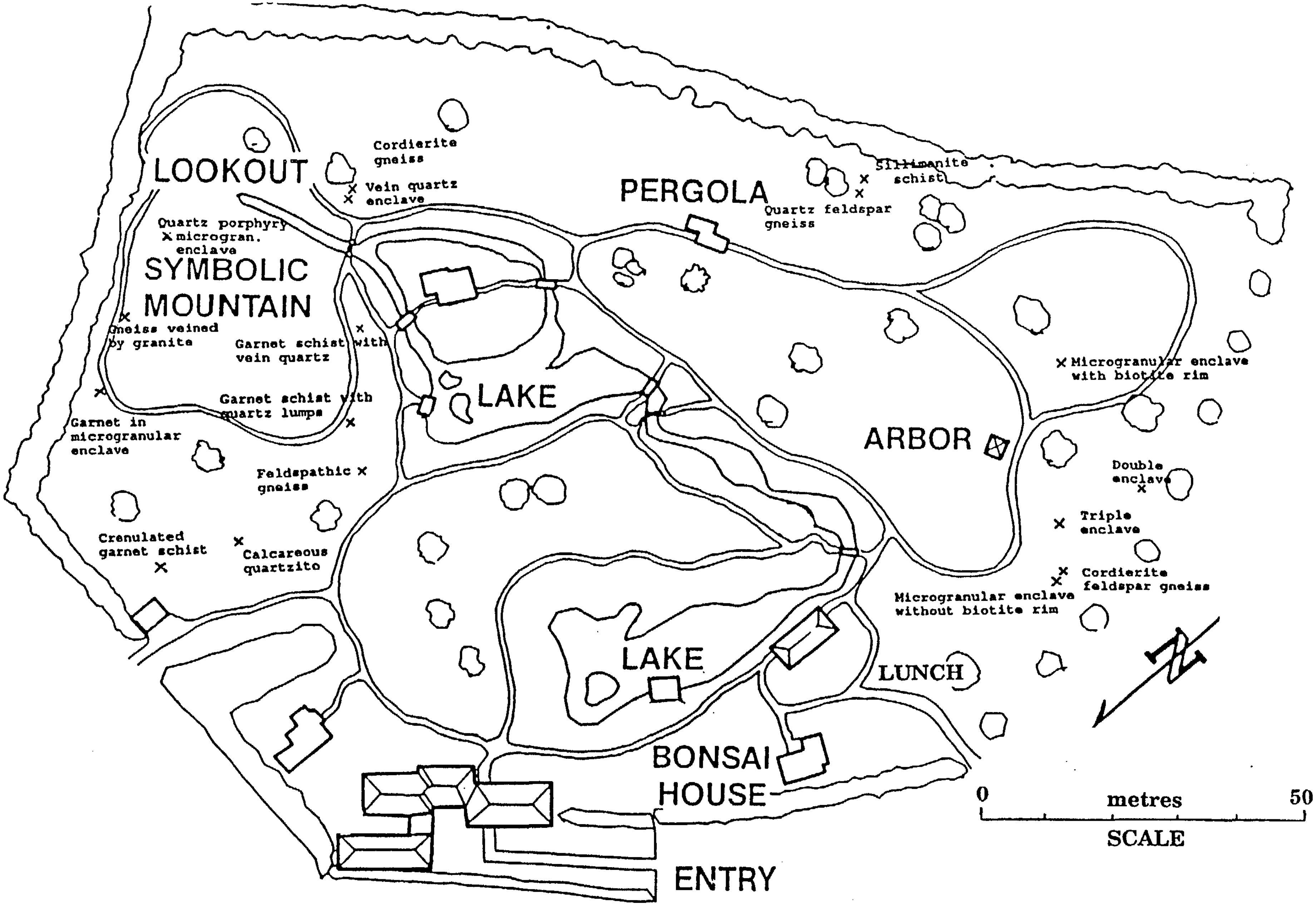

Figure 2. Cowra Granodiorite in the Japanese Gardens

PART 3 - EXCURSION STOPS

STOP 1: Mount Painter Volcanics north of Nanima Road (Canberra 868118, Fig. 1)

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

STOP 2: Hawkins Volcanics on Bendenine Road (Yass 622622, Fig. 1)

This locality contains boulders of the freshest and least metamorphosed lavas of the Hawkins Volcanics. Primary mafic minerals and unalbitised plagioclase phenocrysts are preserved. Chemical and modal analyses are shown in Table 5 (p. 16). Compared with the average Hawkins Suite (Table 1), the analysis from this locality is less oxidised and higher in CaO reflecting its more pristine composition. The analysis from this locality and that of the Cowra Granodiorite at Stop 5 (Table 5) are remarkably similar, apart from the higher Fe_2O_3:FeO ratio in the volcanic rock.

The garnets from the Hawkins Volcanics are almandine with a *Mg* range of 22-31 (46 analyses), and 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 0.55 GPa and 800°C (Wyborn *et al.*, 1981), thought to represent conditions in the source during melting.

STOP 3: Laidlaw Volcanics at Boorowa River Crossing (Yass 665626, Fig. 1)

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 (analysis and mode, 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 they are perfectly preserved. Biotite has been used to date the unit by K-Ar and Rb-Sr methods at 420.7 ± 2.2 Ma and has been used as an important age constraint on the geological time scale.

STOP 4: Cowra Granodiorite at Japanese Gardens (Cowra 569555, Figs 1 and 2)

This locality contains magnificent exposures of the Cowra Granodiorite in an idyllic garden setting. The gardens have been maintained by the Cowra Tourist and Development Corporation since 1978 to commemorate the fateful day in August 1944 when 231 Japanese prisoners and 4 Australians died during a mass breakout 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 Fig. 2 indicating the localities of some of the more significant enclave types. On arrival, lunch will be provided on the lawns to south of the Bonsai House. The purpose of this stop is while wandering leisurely around the gardens, to establish spirited discussions on the origins of the various types of enclaves. Once satisfied that all has been resolved we will walk over to the lookout south of the gardens where further excellent exposures are present.

STOP 5: Cowra Granodiorite at Cowra Lookout (Cowra 567552)

Samples of the granodiorite are obtainable from this locality if required (analysis, Table 5). The view from the lookout shows the old Tertiary erosion surface about 200 m above the present Lachlan River plain. The hills to the south are part of a Late Devonian terrestrial sequence that is widespread over the LFB (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 volcanic rocks and unroofed high-level granites. This in turn implies that there was virtually no continental crustal addition during magmatism, in contrast to active continental margins today. Rather the magmatism involved continental reworking and overturning without significant new continental growth.

The flat topped hills to the southwest 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 - DETAILS OF ANALYSED ENCLAVES

CI-1 (Wall below parking space at lookout, Cowra 567552 - Stop 5)

Collected close to the edge of a zoned enclave showing a hydration rim. A general observation in the Cowra area is that many of the enclaves are zoned whereas in other regions of the LFB zoned enclaves are rare. The enclave sampled here is about 150 mm in diameter.

Petrographic notes: Quartz appears as large crystals but these are enclosed and pierced by laths of very anorthitic plagioclase and orthopyroxene, both of which are quite altered in this rock. Red brown biotite crystals 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-4 (Within the kangaroo enclosure on top of ridge, 80 m N of lookout, Cowra 567553)

The field identification was "quartzite showing bedding". In thin-section this is a typical microgranular enclave.

Petrographic notes: The mineral assemblage is quartz, plagioclase, orthopyroxene, biotite (red-brown and replacing orthopyroxene), accessory apatite as needles, and opaques. There is much secondary alter ation with sericitisation of plagioclase and the formation of montmorillonite or bastite around the orthopyroxene.

CI-5 (Within the kangaroo enclosure on top of ridge, 130 m N of lookout, Cowra 566554)

This sample was called "microgranite" 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 pseudodoleritic fabric.

Petrographic notes: The irregular grey and white coloured patches seen in the hand sample are seen in thin-section to result from sericitization, chloritisation and epidotisation bleaching the white portions. In places replacement by these secondary minerals is complete. Quartz grains are up to 2.5 mm 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 coloured, $\beta = \gamma$ = red-brown). K-feldspar is up to 2.5 mm 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 (Within the kangaroo enclosure on top of ridge, 130 m N of lookout, Cowra 566554)

This is a microgranular enclave that appears in hand sample to be coarser than CI-5. It has pseudo-doleritic fabric and contains orthopyroxene.

Petrographic notes: Calcic plagioclase crystals project into quartz. 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 (2 mm) 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 also are tiny rods of ilmenite.

CI-9 (From the centre of the large microgranular enclave 500 mm across, first boulders at south end of the playing fields 500 m NW of the lookout, Cowra 564557)

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

CI-10 (From a microgranular enclave 250 mm across having no visible rim, boulders at S end of the playing fields 500 m NW of the lookout, Cowra 564557)

Petrographic notes: Contains 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-14 (From dark coloured and even grained 200 x 300 mm microgranular enclave, north side of junction of Macasser and Macquarie Streets, Cowra 564556)

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 (Mg_{52}, but with some cores as magnesian as Mg_{87}) appears as granules, prisms and as some larger stumpy irregular crystals up to 2 mm across. Orthopyroxene is in places replaced by red brown biotite (Mg_{53-56}) which also appears as well developed crystals isolated from orthopyroxene. Altered cordierite (2 mm) is rare. Tiny apatite needles are a common accessory mineral as are rods of ilmenite. There are a few small zircons.

CI-16 (Microgranular enclave 500 mm across, at water tank, Cowra 571569)

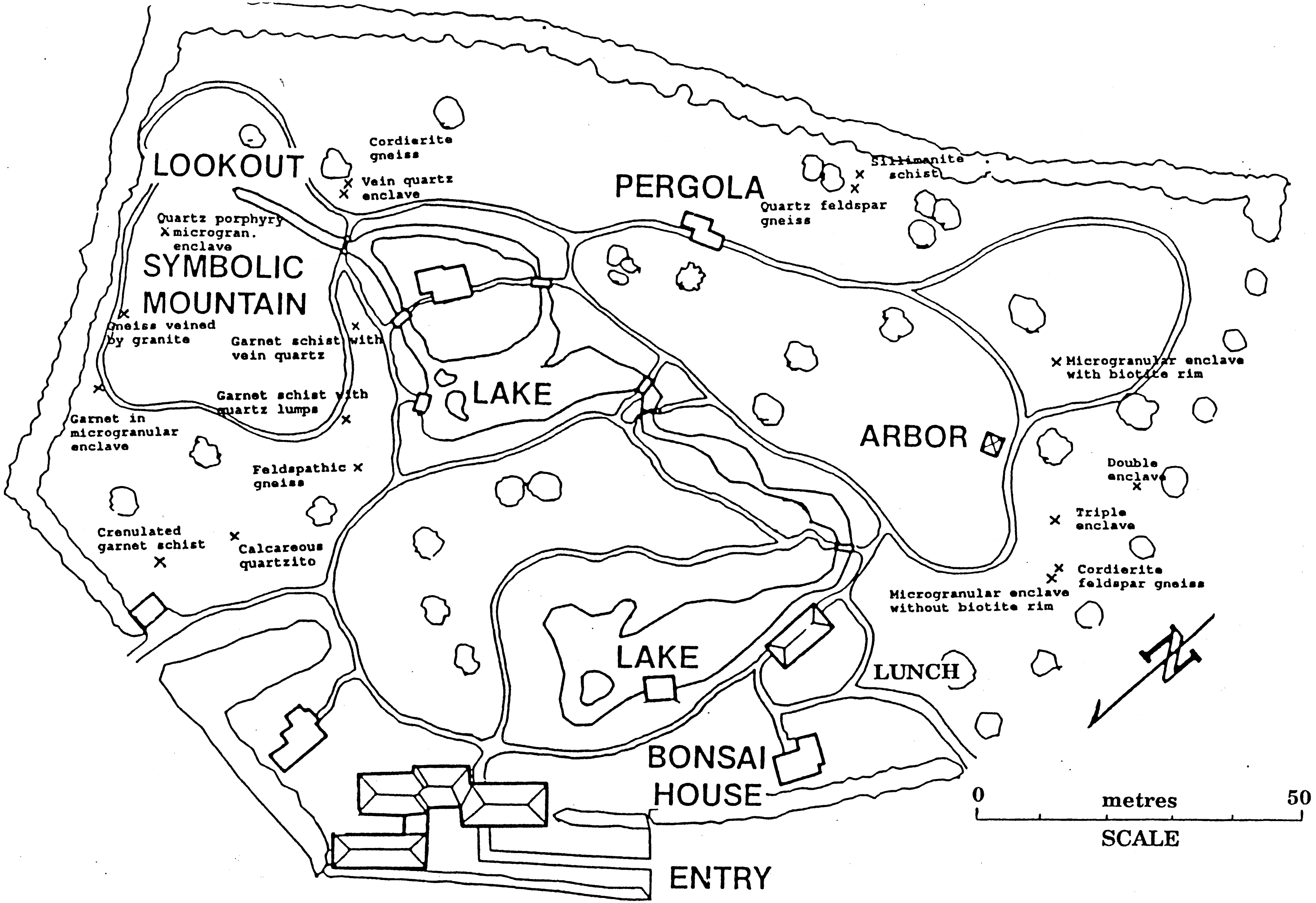
Petrographic notes: Quartz has an irregular shape, is up to 3 mm across and contains inclusions of lath-shaped calcic plagioclase which also project into the edges of the crystals (pseudodoleritic). There are some lath shaped orthopyroxene crystals but most are granular. Red-brown biotite is in places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

CI-17 (From large microgranular enclave containing large crystals of quartz and feldspar at water tank, Cowra 571569)

Petrographic notes: Quartz has irregular shapes, is up to 3 mm 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 0.5 mm 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.

TABLE 5. ANALYSES FROM EXCURSION STOPS

Unit Locality	Hawkins Stop 2	Laidlaw Stop 3	Cowra Stop 5
SiO_2	68.05	70.05	67.71
TiO_2	0.61	0.50	0.66
Al_2O_3	14.41	14.03	14.40
Fe_2O_3	0.86	1.00	0.66
FeO	3.57	2.32	3.81
MnO	0.06	0.03	0.06
MgO	2.05	1.31	2.05
CaO	2.68	2.48	2.45
Na_2O	2.03	2.26	2.06
K_2O	3.58	4.09	3.47
P_2O_5	0.15	0.13	0.15
H_2O+	1.12	1.37	1.96
H_2O-	0.15	0.17	0.17
CO_2	0.24	0.08	0.05
	99.56	99.82	99.66
Trace elements (ppm)			
Ba	510	605	530
Rb	166	177	171
Sr	136	134	133
Pb	27	37	22
Th	19.0	22	20.5
U	3.8	3.6	3.8
Zr	180	180	191
Nb	12.0	11.5	12.5
Y	32	34	31
La	32	26	32
Ce	74	64	70
Sc	15	12	16
V	84	67	82
Cr	55	41	50
Ni	21	15	21
Cu	15	14	16
Zn	70	59	59
Ga	17.4	16.6	17.4
Modes			
quartz	17.4	26.8	
plagioclase	19.3 (An_{51})	21.0 (An_{70-35})	
biotite	9.6 (mg_{55})	8.7 (mg_{52})	
orthopyroxene	4.2 (mg_{48})	4.3 (mg_{55})	
cordierite	5.4		
K-feldspar		3.2	
opaques	0.4	tr	
garnet	tr (mg_{25})		



STOP 4 - Cowra Granodiorite in Japanese Gardens