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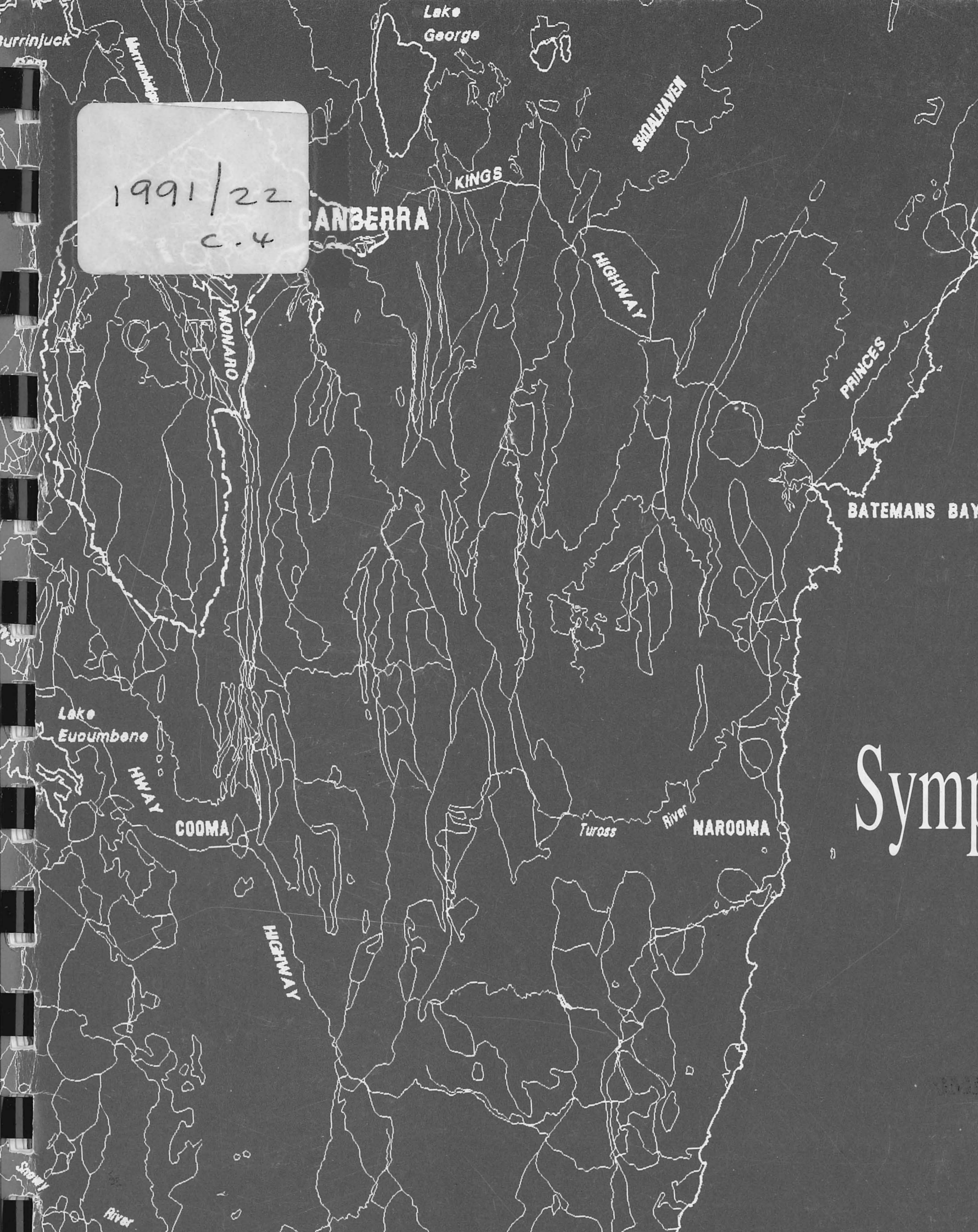

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A transverse section through granites of the Lachlan Fold Belt

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by B.W. Chappell, A.J.R. White, & I.S. Williams

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A TRANSVERSE SECTION THROUGH GRANITES OF THE LACHLAN FOLD BELT

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INTRODUCTION

That part of the Lachlan Fold Belt (LFB) exposed in southeastern Australia has a total area of close to 300,000 km^2. The full width is seen only in Victoria where it is some 750 km wide at right angles to the dominant structural trends. The belt was the site of very extensive igneous activity during late Silurian and Devonian times when abundant granites and related volcanic rocks were produced. The position of the LFB in relation to the other tectonic elements of eastern Australia can be seen in Fig. 1 of Chappell & Stephens (1988). The distribution of granites in the belt is shown in Fig. 1 of Chappell *et al.* (1988) and a more detailed and comprehensive map is now available, on a scale of 1:1 250 000 (Chappell *et al.*, 1991). All units recognized in Victoria were also listed by White & Chappell (1988a) and the location of all those units is shown on maps in that paper. Many of the regional features of the granites were discussed in the publication on the basement terrane concept of Chappell *et al.* (1988).

White & Chappell (1983) described the geological setting of the granites. Other general features of the LFB and its granites and their relation to other geological elements of eastern Australia have also been published (Chappell & Stephens, 1988). That paper also discusses the extension of the LFB to the north beneath cover rocks, and south in Antarctica. Its total extension in eastern Australia could be regarded as being from latitude 13° S in Cape York to latitude 43° S in southeastern Tasmania. In Antarctica, granites of the same age as those in the LFB are restricted to the northern part of the Transantarctic Mountains. Prior to the opening of the Southern Ocean, the granites of this belt extended through a distance of some 3600 km with a width of up to at least 750 km (Chappell & Stephens, 1988). However, the term LFB as used here will refer to that part of the belt located in southeastern Australia..

Granites outcrop over an area of 61,000 km^2 in the LFB and thus make up a little over 20% of the total area of that belt. Their distribution is not uniform, as they comprise 36% of the total area of 108,400 km^2 east of 148° E and some 12% of the central and western parts. Related volcanic rocks are also abundant, covering 15% of the area in the eastern part of the belt (White & Chappell, 1983). Radiometric ages on granites of the LFB are sparse. Most ages are in the 430 to 390 Ma interval with some plutons as young as 360 Ma in the central part of the belt north of Melbourne (see, for example, Williams *et al.*, 1975; Compston & Chappell, 1979; Richards & Singleton, 1981). The granites of western Tasmania (Taswegia Terrane) are distinctly younger than the main body of the LFB with a total range of ages from 380 to 330 Ma reported in the summary of McClenaghan *et al.* (1989). 2800 km^2 of granite of Carboniferous age (~ 320 Ma) are present in the most easterly part of the belt; this is probably more correctly related to the younger New England Fold Belt, northeast of the LFB.

White *et al.* (1974) subdivided granites according to their associated rocks into regional--aureole, contact-aureole and subvolcanic types. In the LFB, the country rocks are mostly of very low regional metamorphic grade and the plutons are generally contact-aureole types. In a few cases, the granites are regional-aureole types, and are surrounded by high-grade metamorphic rocks with which they are intimately related, e.g. at Cooma (Joplin, 1942; Pidgeon & Compston, 1965; Chappell & White, 1976; Munksgaard, 1988). The largest granite pluton in the LFB is the Bemboka

TABLE 1. LACHLAN FOLD BELT GRANITE COMPLEXES

	Batholith or complex	Area (km^2)	% of type I	S	A
1.	GULGONG GRANITES	800	100	-	-
2.	BATHURST BATHOLITH	1630	100	-	-
3.	OBERON GRANITES	390	100	-	-
4.	MARULAN GRANITES	220	100	-	-
5.	MORUYA BATHOLITH	263	100	-	-
6.	GABO ISLAND GRANITES	59	3	-	97
7.	BEGA BATHOLITH	8620	99	<1	1
8.	WOLOGORONG BATHOLITH	800	-	100	-
9.	WYANGALA BATHOLITH	3180	29	69	2
10.	MURRUMBIDGEE BATHOLITH	1470	42	32	-
11.	COOMA COMPLEX	14	-	100	-
12.	GINGERA GRANITES	260	21	79	-
13.	BERRIDALE BATHOLITH	1670	46	51	-
14.	BONANG GRANITES	435	62	16	22
15.	KOSCIUSKO BATHOLITH	4000	6	94	-
16.	YEOVAL BATHOLITH	1500	100	-	-
17.	GRENFELL GRANITES	1040	100	-	-
18.	YOUNG BATHOLITH	4090	1	99	-
19.	TUMUT GRANITES	380	89	11	-
20.	MARAGLE BATHOLITH	3940	22	78	-
21.	WAGGA BATHOLITH	13800	~5	~95	
22.	CENTRAL VICTORIA GRANITES	6400			
23.	WESTERN VICTORIA GRANITES	2060	100	-	-
24.	BASSIAN BATHOLITH	3590			
25.	TASWEGIA GRANITES (West Coast)	715	?	?	-

Granodiorite in the Bega Batholith which is 970 km^2 in area with a small additional area covered by Devonian sedimentary rocks. Volcanic equivalents of some of the granites do occur, and sometimes the intrusions are subvolcanic, e.g. near its southern end, the Young Batholith intrudes the Goobarragandra Volcanics with which it is chemically related (Wyborn *et al.*, 1981).

More than eight hundred separate lithological units of granites (≈ plutons) have been recognized in the LFB and the location of these units is shown on the map of Chappell *et al.* (1991). It has always been conventional to group these lithological units into separate batholiths, particularly in the eastern part of the LFB, and we have extended that to cover the whole belt. The term "batholith" is used for a group of plutons that are contiguous or nearly so, with a total exposed area generally in excess of 500 km^2. Smaller units are referred to as "granite complexes" or "Granites"; these are sometimes excellent "mini-batholiths", such as Marulan, Moruya and Gingera. The term "Granites" is also used for an area of dispersed plutons, e.g. Bonang and Gulgong, that are sometimes in excess of 500 km^2 in area. In some cases the batholiths are naturally well-defined, e.g. Bathurst or Young; in other cases, the boundaries are poorly defined and arbitrary, e.g. Kosciusko *vs* Maragle. Batholiths generally include some adjacent but separated plutons. Historical usage must also be considered; for example, the Cooma Granodiorite could be assigned to the Murrumbidgee Batholith but because that granodiorite has been a focus of attention, for over fifty years, as the core rock of the Cooma Metamorphic Complex, its separate identity is retained. While some aspects of this subdivision in batholiths and complexes are arbitrary it is nevertheless very useful in subdividing plutons that cover such a large area.

The composite nature of the batholiths is exemplified by the Berridale Batholith, which although relatively small, consists of about forty separate plutons ranging up to 470 km^2 in outcrop area (White *et al.*, 1976b). These structurally defined units may be grouped into twenty one distinct mappable units which appear as separate plutons, pairs of plutons, or groups of plutons. Screens of country rock hornfels often occur between adjacent plutons or between strings of plutons (White & Chappell, 1983). Contacts, where observed or inferred, are very steep.

A list of the separate batholiths and granite complexes recognized in the LFB is given in Table 1. The location of the first twenty of these is given in Fig. 2 of White & Chappell (1983). Among the additional five, the Wagga Batholith comprises the very large area of granite in the Wagga Basement Terrane, east of the Melbourne Basement Terrane, shown in Fig. 1 of Chappell *et al.* (1988), apart from the separate Maragle Batholith. Again with reference to Chappell *et al.* (1988), the Central Victoria Granites occupy the Melbourne Basement Terrane and the Western Victoria Granites occupy the Stawell and Grampians-Stavely Basement terranes. The Bassian Batholith comprises all of the granites extending from Wilsons Promontory across Bass Strait and through northeastern Tasmania to Maria Island and the small exposure on the Forestier Peninsula, shown again in Fig. 1 of Chappell *et al.* (1988). A large part of that extensive area is covered by the waters of Bass Strait, but it seems desirable to group these rocks together rather than split them into many much smaller units. Throughout much of the Bassian Batholith there are occurrences of distinctive felsic and fractionated S-type granites that sometimes contain concentrations of garnet; these rocks clearly should be grouped into one structural unit. Finally, the Taswegia Granites are those of Devonian age (and not the older Cambrian granites) in the Taswegia Basement Terrane, on the Tasmanian West Coast and King Island.

GRANITE SUITES IN THE LACHLAN FOLD BELT

The recognition of lithological units and their chemical subdivision into suites has been fundamental to granite studies in the LFB and this has been discussed by White & Chappell (1983). Granites assigned to a single suite share distinct textural, modal and chemical features. Rocks within a suite must also have the same initial isotopic composition; this is an excellent test because of the high experimental precision available and the insensitivity of isotope ratios to chemical composition, except where the age correction is large. The isotopic homogeneity of some of the suites in the LFB has been tested with Sr and Nd isotopes (Compston & Chappell, 1979; McCulloch & Chappell, 1982). Rocks within a suite either have a well-defined isotopic ratio, or if there is scatter, this is highly correlated with the parent:daughter element ratios in a way that suggests source heterogeneity. Members of a suite are consanguinous but can have no simple relationship with another suite. Each suite is considered to correspond to a specific source-rock composition, with the variation within each suite resulting from processes such as restite-unmixing and fractional crystallization.

The concept of suites is well illustrated by the Bega Batholith in which fifty three suites have been recognized, some consisting of a single pluton that has a unique compositional character, while others are made up of several plutons. The suite concept is illustrated by plotting Sr *vs* SiO_2 for the 54 samples from the 14 plutons of the low-Sr Glenbog Suite and the high-Sr Candelo Suite of the Bega Batholith (Chappell, 1984). These chemical data fall into two distinct groups with different trends that distinguish the two suites. The 43 samples of Glenbog Suite come from 12 plutons in a belt extending for 275 km along the western margin of the batholith; considering this distance, the tight chemical coherence is most remarkable. Most of the analyzed granites in the LFB have been subdivided into suites on this basis. Those suites derived from igneous source-rocks (I-type) tend to be better defined and more tightly coherent than those produced from sedimentary sources (S-type). This is thought to result from the more uniform composition of the I-type source-rocks. It is thus possible to recognize more compositional fine-structure among the I-type granites whereas the S-type suites are less numerous and individually cover larger areas. Some suites that differ in detail can be grouped with others that share broadly similar chemical features and these broader groupings are called *supersuites*. As an example, the Glenbog Suite discussed above is placed within a Glenbog Supersuite along with other suites that have similar but not precisely the same features as that suite.

The suites and supersuites are analogous to the units and super-units recognized in the Coastal Batholith of Peru by Pitcher (1978). Working in an area of excellent exposure, he emphasized relative ages determined in the field, modes, texture, and fabric, with confirmation to be sought from the chemical composition. Bateman & Dodge (1970) also emphasized age relations in applying the term sequence to related rocks in the Sierra Nevada Batholith. Granites of the LFB are not as well exposed and hence the chemical composition is emphasized in erecting suites and supersuites.

Whitten *et al.* (1987) carried out a cluster analysis of chemical data from the Bega Batholith supplied by B.W. Chappell and were not able to find a wholly objective (to them) set of criteria for identifying suites in that complex. They were able to separate five of the suites recognized by Beams (1980) using the stepwise analysis of variation diagrams for the elements Cr, Sr, K_2O and/or Na_2O, and SiO_2, but cluster analysis could not retrieve all of those suites completely and correctly. They

TABLE 2. AVERAGE COMPOSITIONS OF I-TYPE, S-TYPE AND A-TYPE GRANITES FROM THE LACHLAN FOLD BELT

	I-type	S-type	A-type
Number of samples	1078	609	42
SiO_2	68.95	70.44	73.39
TiO_2	0.43	0.47	0.30
Al_2O_3	14.31	14.07	12.88
Fe_2O_3	1.06	0.56	0.90
FeO	2.35	2.80	1.66
MnO	0.07	0.06	0.06
MgO	1.53	1.37	0.30
CaO	3.28	1.97	1.07
Na_2O	3.12	2.43	3.49
K_2O	3.39	4.01	4.61
P_2O_5	0.12	0.15	0.08
Trace elements (ppm)			
Rb	155	222	188
Sr	247	118	97
Ba	525	465	545
Zr	147	164	325
Nb	11	12	26
Y	28	32	71
Ce	64	63	131
Sc	13	12	12
V	62	54	9
Cr	25	33	2
Co	11	11	3
Ni	9	13	2
Cu	10	10	5
Zn	49	62	95
Ga	16	17	22
Pb	19	27	27
Th	18	18	24
U	4	4	5

concluded that these suites should be abandoned, or defined differently. However suites can be clearly separated in the Bega Batholith using a simple study of variation diagrams. That this can not be done "objectively" using methods of cluster analysis is more an argument against applying that technique in this way, rather than against the suite concept as used in the LFB.

Suites are the fundamental unit as far as any discussion of variation within and between different batches of granite magma is concerned. Differences among suites can be ascribed to differences in source-rock compositions. Various mechanisms can be invoked to account for the within-suite variation found in granites, including fractional crystallization, restite unmixing, magma mixing and assimilation. Within the LFB, it seems that the last two of these processes are at most only of local importance, while both fractional crystallization and restite unmixing are important.

In summary, differences between suites in the LFB are ascribed to different source-rock compositions. Variation within suites can be accounted for as follows:

(a) Dominantly by varying degrees of separation of melt from residual mafic material, or restite. A small amount of fractional crystallization may accompany restite separation in this general case, involving the removal of crystals that precipitated from the melt.

(b) Rarely, completely by fractional crystallization of a melt that separated at the source. This does sometimes occur, e.g. in the Boggy Plain Supersuite.

(c) By feldspar fractionation, after all restite has been removed by (a) or a felsic composition has been arrived at by (b).

GRANITE TYPES

Within the LFB, the first-order subdivision of suites is into those derived from igneous or infracrustal sources, and those derived from sedimentary or supracrustal sources. These I- and S-types have been discussed by Chappell & White (1984). A third very small group, the A-type granites, is also recognized in this area (Collins *et al.*, 1982). Average chemical analyses of these three types in the LFB are given in Table 2. A fourth very small group, the IS-types, that may be derived from mixed source-rocks, is restricted in its occurrence to the southern end of the Murrumbidgee Batholith and the region of the Berridale Batholith near Cooma Airport.

NOMENCLATURE

Nomenclature used for the granites follows that of Streckeisen (1976), with three exceptions. First, the boundary between quartz monzodiorite, quartz diorite, etc. and granodiorite, tonalite, etc. is taken at 25% quartz out of total quartz plus feldspars. Second, the name adamellite is used for the field containing 25% quartz and with approximately equal amounts of K-feldspar and plagioclase. Third, the term granitoid is not used here, and "granite" is used in two senses, both as a general term for this family of rocks, and specifically for those rocks between "adamellite" and "alkali granite" in composition. In that specific sense, it is either used formally as "Granite", e.g. the Mumbulla Granite, or qualified as a use, *sensu stricto,* if there could be doubt about the sense in which it used.

CENTRAL VICTORIA GRANITES

The Central Victoria Granites occur in a wide belt trending meridionally through the centre of that state, from Bass Strait to just north of the Murray River at Tocumwal, beyond which the granites are covered by younger rocks. These granites cover a total area of 6400 km^2 and include the large complexes of Tynong and Strathbogie, both of areas well in excess of 1000 km^2. Other large bodies are at Beechworth, Harcourt and Cobaw, and there are many other smaller bodies. Several of the large granite bodies have an east-west elongation. A distinctive feature of these granites is K-Ar ages close to 370 Ma, distinctly younger than the granites to both the east and west, an observation that is in accord with the stratigraphic age of the intruded rocks. Both S-type and I-type granites occur in this region. The distinctive compositional characteristics of the granites in this region, led Chappell *et al.* (1988) to distinguish the area as the Melbourne Basement Terrane.

S-TYPE GRANITES

Eight bodies of S-type granite are recognized in Central Victoria. These form a fairly coherent chemical group but there are differences that require their subdivision into six suites. Like the I-type granites of this area, these granites are strongly reduced and are high in Ba. By far the largest unit is the Strathbogie body (1510 km^2) which along with the Barjarg pluton (77 km^2), makes up the Strathbogie Suite. The Badaginnie Suite is a small mafic garnet-bearing intrusion north of Euroa on the Hume Highway and it has a lower Ba content than the other units. The Warburton Suite consists of the Toole-be-wong and Warburton (75 km^2) bodies which are high in Cr and extremely mafic for S-type granites. The Pyalong granite (98 km^2) occurs in the outer margin of the Cobaw Complex, and with Glenaroua (5.4 km^2) makes up the the Pyalong Suite. The Pyalong Suite is relatively high in Ba and LREE. The Bulla Suite comprises the Bulla unit which is the granite extending north from the edge of Tullamarine Airport; it is slightly higher in Na_2O.

As a group, these granites are distinctive. Relative to the S-type granites further east, these are higher in Ba at mafic compositions and the more felsic rocks are lower in Pb. Na_2O, Sr, Zr, Nb and Ga tend to be higher with some overlap in compositions, while FeO, MgO and V are generally less abundant. Fe^{3+} contents are extremely low and the ratio Fe^{3+}:Fe^{2+} is generally lower than other S-type granites. Many of these chemical features resemble those of the S-type granites of Wilsons Promontory in the Bassian Batholith to the south, but in detail they are different.

I-TYPE GRANITES

Eight I-type suites are recognised among the Central Victoria Granites of which Harcourt, Tynong and Beckworth cover the greatest areas. The most distinctive features, like the S-type granites above, are the very low Fe^{3+}:Fe^{2+} ratios and the high Ba content. Examples of these suites will not be seen on this excursion, but one representative of the very felsic I-type Beechworth Complex in the northeast, will be examined.

WAGGA BATHOLITH

The very diverse group of granites that occurs in a broad belt south from Nymagee in central New South Wales through Northeast Victoria to Bass Strait is called the Wagga Batholith. Isolated small exposures north of the Nymagee Granite, extending to Brewarrina, are also included. The area covered by these rocks includes the Wagga Metamorphic Belt, which is the most extensive area of regional metamorphism in southeastern Australia. In the northern parts, the Wagga Batholith is well separated from other granites to the east, but further south the distinction from the Maragle and Kosciusko batholiths is somewhat arbitrary. The Wagga Batholith includes the westernmost granite exposures of the LFB in New South Wales, except for the small areas of granite at Berrigan and Tocumwal that are grouped with the Central Victoria Granites. The boundary between the eastern edge of the Central Victoria Granites and the Wagga Batholith is taken to be east of the large granite complexes at Beechworth, Strathbogie and Tynong. That part of the Wagga Batholith north of the Murray River corresponds to Domain 2 of Yeates *et al.* (1982), characterized by sparse low--amplitude magnetic anomalies and common tin granites, in contrast to their Domain 1 to the east.

More than one hundred and twenty units are recognized in the Wagga Batholith, exposed over an area of 13,800 km^2, by far the largest area of any of the batholiths and complexes in the LFB. North of the Murray River in New South Wales, access is good, but because exposures are poor to very poor, most mapping and sampling has been done from very isolated exposures. South of the river, in eastern Victoria, exposures are much better but access is often difficult. Partly for these reasons, the granites of this belt have been, and remain, the most poorly known in the LFB. An exception to this is the area immediately south of the Murray River, where there are several published studies (Kolbe & Taylor, 1966; Brooks & Leggo, 1972; Price & Taylor, 1977; Price, 1983; Price *et al.*, 1983; Oates & Price, 1983).

Granites in this belt are very diverse. S-types are dominant and include mafic varieties as well as the most extensive developement of fractionated granites in the LFB. I-types are generally felsic and sometimes they are also fractionated.

S-TYPE GRANITES

The large Wantabadgery mass (2080 km^2) is the most mafic large S-type granite in the Wagga Batholith. It is indistinguishable in composition from the Tom Groggin unit of the Maragle Batholith to the east, and is placed in the Tom Groggin Suite. Within that group, Wantabadgery is separated from Tom Groggin by about 40 km of metasediments near Tarcutta. The other more mafic S-type granites, Bland (545 km^2) and Ungarie (1790 km^2), placed together in the Ungarie Suite, are north of the Wantabadgery unit while the single analysis of the Ganmain body (166 km^2) further west is very similar and quite mafic with 66% SiO_2. Granites of the Tom Groggin Suite resemble those of the Bullenbalong Suite in the Kosciusko Batholith, except for the elements Al, K, Rb, Nb, Ga and Y which are comparable at more mafic compositions, but diverge in abundance in the more felsic rocks, with the first five elements being more abundant in Tom Groggin, and Y being less abundant. This trend is carried further by some of the more felsic S-type granites in the Wagga Batholith. These more felsic units are Kikoira (209 km^2) just south of the Lachlan River, Burrandana (117

km^2), Mt Flakney (122 km^2) and Kyeamba (155 km^2) to the south of Wagga Wagga, and the units near the Murray River - Woomagarma (178 km^2), Koetong (960 km^2), Granya (361 km^2), Lucyvale (12.4 km^2) and Burrowye (290 km^2). These three groupings of more felsic granites are called the Kikoira, Kyeamba and Koetong Suites, respectively. The Grong Grong body (29 km^2) further west is similar to these more felsic granites. All thirteen units listed above form a continuous and well-defined group, the Koetong Supersuite, ranging from Wantabadgery (and Tom Groggin), the most mafic, to Mt Flakney, the most felsic. This compositional range is considered to have resulted of sequential restite separation and fractional crystallization, so that, for example, as SiO_2 increases from 64 to 73%, Rb increases from about 150 ppm to 500 ppm, and U rises to 14 ppm.

The Ardlethan Granite includes the most strongly fractionated granites in the LFB. This unit represents a more advanced stage of fractionation than the Kikoira, Kyeamba and Koetong suites. Alteration may have played a minor role in the development of these very felsic compositions, with Rb concentrations reaching around 1000 ppm.

Other S-type granites that are not part of the Koetong Supersuite occur between the Lachlan and Murray rivers. These are separated from that supersuite by the fact that while they are quite felsic, they lack high Rb and U, and other signs of fractionation. The largest of these is the Collingullie body (435 km^2) to the west of Wagga Wagga, which has compositions ranging through five per cent. SiO_2; at its more mafic compositions its chemical trend is similar to that of Koetong, while the felsic rocks diverge from that trend and are not fractionated.

The Bethanga Granite, occurring just east of the Hume Weir, is a mafic S-type granite containing abundant cordierite and garnet; it contains low abundances of Na, Ca and Sr, which suggests a derivation from melting of feldspar-poor Ordovician metasediments.

I-TYPE GRANITES

Between the Lachlan and Murray rivers, there are only four relatively small bodies of I-type granite. Barmedman (59 km^2) and Narraburra (172 km^2), east and southeast of Barmedman, are felsic bodies; Narraburra shows the larger range in composition in the analyzed samples, from 73.3 to 77.0% SiO_2. Further south, Gundibindya (40 km^2) is less felsic (71.7% SiO_2). The hornblende-bearing Yammatree body (13.3 km^2) occurs well to the east at the southern end of the Ulandra S-type mass. A fifth possibly I-type granite, Hawksview (20 km^2), containing close to 70% SiO_2, is exposed in the quarry on the northern side of the Murray River at the Hume Wier.

The Thologolong Granite (172 km^2) is the largest of the three very felsic granite bodies of the Upper Murray Valley, with the other two units, Pine Creek and Mt Mittamatite being grouped with the Maragle Batholith. Price *et al.* (1983) grouped these and rhyolite dykes and flows and ash-flow tuffs in "the Upper Murray high-Si magmatic suite". This group of rocks has aroused much interest since the study of Kolbe & Taylor (1965). We now regard them as fractionated to highly fractionated I-type granites, with at least one, the Mt Mittamatite Granite, belonging to the Boggy Plain Supersuite of Wyborn *et al.* (1987).

MARAGLE BATHOLITH

The Maragle Batholith (3940 km^2) occurs to the west of the Kosciusko Batholith and is separated from it by a narrow screen running NNE, west of Mt Kosciusko. To the north, it is bounded by the Tumut Trough and the Tumut Granites. In the west the boundaries with the Wagga Batholith are not well defined but they are taken to be the continuous screen of Ordovician metasediments, partly covered by Devonian volcanic rocks, between the Corryong unit (Maragle) and the Koetong body to the west. This batholith contains extensive areas of S-type granite and a rather diverse group of I-type rocks. Near Adelong in the north, there are several small gabbro intrusions.

S-TYPE SUITES

Two S-type suites are present in the Maragle Batholith: Tom Groggin and Geehi. The Tom Groggin Suite consists of seven units, Belmore (30 km^2), Tom Groggin (2000 km^2), Musical (51 km^2), Cemetary Creek (2.6 km^2), Rough Creek (24 km^2), Grey Mare (30 km^2), Butchers Block (42 km^2) and Corryong (740 km^2). The Wantabadgery Granodiorite (2080 km^2) in the Wagga Batholith discussed above, also belongs with this suite, giving it the largest area of any in the LFB.

The term Geehi Granodiorite is applied to the low Ca and Na (< 1% CaO, < 2% Na_2O) granites that occur within the Tom Groggin Granodiorite. It is difficult to distinguish Geehi from samples of the Tom Groggin in the field. Normally the distinction must be based on the substantial chemical differences and hence the total area of Geehi Granodiorite is unknown and separate Geehi masses cannot be mapped. This is the only member of the Geehi Suite, which is part of the Cooma Supersuite. The low Ca and Na values indicate derivation from Ordovician sedimentary source--rocks in contrast to the Tom Groggin Suite which is of more typical S-type character for the LFB, and is thought to have been derived from pre-Ordovician metasedimentary rocks (Wyborn, 1977; Wyborn & Chappell, 1983; Chappell, 1984).

I-TYPE SUITES

I-type granites are widespread in the Maragle Batholith and thirteen units are recognized, some of which belong to the Boggy Plain Supersuite. The Mt Mittamatite pluton forms the very prominent mountain just north of Corryong, and its geochemical character fits very neatly into the Boggy Plain Supersuite (Wyborn *et al.*, 1986). The Pine Mountain Granite (35 km^2) has undergone extreme feldspar fractionation, indicated by the 6 ppm Ba and 5 ppm Sr in the one sample analyzed. Price *et al.* (1983) have grouped Pine Mountain with the Jemba Rhyolite which has an initial $^{87}Sr/^{86}Sr$ between 0.709 and 0.713, a ratio that is significantly higher than that of Mt Mittamatite (0.7043).

KOSCIUSKO BATHOLITH

The Kosciusko Batholith has a total exposed area of 4000 km^2. Rocks of the eastern part of the batholith on the Berridale and Numbla 1:100 000 sheets have been described in detail by White *et al.* (1977) and White & Chappell (1989). L. Wyborn (1977) included much of the western part of the batholith in her PhD thesis. The northern parts on the Tantangara 1:100 000 Geological Sheet have been described by Owen & Wyborn (1979), and D. Wyborn (1983) studied the rocks of the Boggy Plain pluton in detail in his PhD thesis. Fifty six lithological units are recognized; S-types are dominant (94%) but some significant I-type granites are also present. A-type granites do not occur and there is one small gabbro body. In places, the S-type granites are strongly foliated and may be mylonitized, e.g. the Rawsons Pass unit at the summit of Mt Kosciusko, however the I-type granites seldom show strong foliation. This strain distribution is attributed to the S-types having higher quartz contents, a relatively weak and easily deformed mineral as compared to the abundant plagioclase that forms the framework of the I-type granites.

S-TYPE SUITES

Three S-type suites occur in the Kosciusko Batholith. The Bullenbalong Suite is dominant and covers an area of 3110 km^2. At least twenty three separate units in the Kosciusko Batholith can be placed in this suite, and also the large area assigned to the Mowambah Granodiorite (1110 km^2) is undoubtedly composite. The minimum SiO_2 value determined for the Bullenbalong Suite is 65.9% SiO_2 which is not as low as might be expected in a mafic rock containing 25% biotite. This is a general feature of S-type granites and total Fe provides a better index of general composition. For this suite, total FeO ranges from 1.95% to 5.21% (78 samples) with a median value of 4.13% nearer the more mafic end of the range in composition. The Bullenbalong Suite has been discussed in some detail by White & Chappell (1988b).

The Ingebyrah Suite is another mafic S-type suite occurring as a group of five bodies with a total area of 410 km^2, on the eastern side of the batholith north of the Snowy River. The Ingebyrah Granodiorite (370 km^2) dominates this suite. This suite is similar to Bullenbalong, but is relatively high in Ca and Sr throughout, while Ti tends to be less abundant; moreover the two suites are isotopically different (McCulloch & Chappell, 1982).

Two S-type units occurring west of Mt Kosciusko, Lady Northcotts (65 km^2) and The Ghost (38 km^2), comprise The Ghost Suite. Both units are strongly foliated and their composition may have been altered during the deformation. The Ghost is rather mafic (SiO_2 from 69 to 70%), while Lady Northcotts is felsic (~ 73% SiO_2); Ca and Na are higher than in the two suites described above.

I-TYPE SUITES

There are five I-type suites in the Kosciusko Batholith; three of these consist of only one pluton. The most extensive is the Jindabyne Suite (Hine *et al.*, 1978) which comprises eight plutons on the eastern side of the batholith and the Bugtown Tonalite in the Gingera Granites to the northeast. The total area of this suite is 120 km^2.

Four plutons in the northern part of batholith belong to the Boggy Plain Suite. The most significant chemical features of this suite are the high content of incompatible elements such as K, P, Ba, Rb, Sr and Zr (Owen & Wyborn, 1979). The Ba content usually increases with increasing SiO_2. This suite is part of the very extensive Boggy Plain Supersuite which extends for 500 km from near Dartmouth Dam to just south of Dubbo (Wyborn *et al.*, 1987). The wide distribution of this supersuite is demonstrated by the fact that it occurs in eight of the batholiths and granite complexes of the LFB, and dominates three of these, the Yeoval Batholith and the Grenfell and Tumut Granites. The Boggy Plain pluton has been studied in detail (D. Wyborn, 1983). It is a concentrically zoned body that has been cut into two parts by a wrench fault. Mafic gabbros near the contact show a progressive zonation to a more felsic sequence of granodiorites and adamellites, to aplitic granite near the centre of the pluton. Of the three smaller bodies in this suite, the Crack Hardy Point Quartz Monzodiorite is the classic "Pollocks Creek Monzonite" from Kiandra, well known because it contains the complete Discontinuous Reaction Series, excepting olivine.

The Island Bend pluton (6.6 km^2) contains relatively high concentrations of Ba and Sr like Boggy Plain but is not placed in the Boggy Plain Suite because Sr is even higher as is Ca, and it is low in Ti, K, Rb, Zr, Y, LREE, Cr and Ni. The small zoned Three Rocks body (7.8 km^2) is also not grouped in the Boggy Plain Suite, despite high Ba and Sr concentrations, since it contains much less K than that suite. Finally, the Buggary Granodiorite, pronounced Boogary (1.8 km^2), is a distinctly different rock. It is low in Al, Ca, Na and Sr relative to most other I-type granites of the Berridale and Kosciusko batholiths and the Bonang Granites. It shares those features only with the Finister Suite, from which it can be distinguished by higher Zr, Nb, Y and LREE.

BERRIDALE BATHOLITH

The Berridale Batholith has a total exposed area of 1670 km^2; Cainozoic basalt covers approximately another 300 km^2. The batholith is cut by a series of major left-lateral wrench faults, the largest of which, the Berridale Fault (Lambert & White, 1965), displaces the northern end of the batholith 11 km to the northwest. A set of conjugate right-lateral faults is also present. The large Gygederick Screen extends along the centre of much of the batholith and is part of the IS-line (White *et al.*, 1976a), the line that marks the eastern limit of occurrence of S-type granites of deep crustal origin.

Rocks of the batholith have been described in detail by White *et al.* (1977) and White & Chappell (1989). Twenty one lithological units are present; I- and S-types are approximately equally represented, with nine S-type units (893 km^2) and eleven I-type bodies (757 km^2). The IS-type Arable Tonalite (60 km^2) occurs in the northeastern part of the batholith, and is thought to have been derived from a mixed source in which the sedimentary component supplied a granitic melt and the mafic component contributed a restite fraction.

S-TYPE SUITES

Three S-type granite suites occur in the Berridale Batholith. The Cootralantra Granodiorite is the largest unit in the batholith (360 km^2) and consists of several plutons. It is the oldest S-type unit in the Berridale Batholith (monazite U-Pb age of 428 ± 3 Ma; Williams, 1978) and is sometimes strongly deformed to the extent that most samples are altered, sometimes very badly. Cootralantra is a mafic S-type granite that comprises the Cootralantra Suite.

The Dalgety Suite consists of the large Dalgety pluton (310 km^2) and the smaller Numbla Vale (49 km^2), Matong (7.8 km^2), Little Popong (7.8 km^2), Snodgrass (14.5 km^2), Merumbadgee (11.5 km^2) and Sandy Camp (0.9 km^2) plutons. Two units in the Bonang Granites to the south also belong to this suite. The Dalgety Suite is generally more felsic than Cootralantra, but in the region of overlap in general composition, Dalgety is persistently higher in Ca and Sr, and generally lower in Ti, Zr, Cr and Ni. As a result of the higher Ca content, these Dalgety rocks are not as peraluminous as the Bullenbalong or Cootralantra suites and cordierite is not as common, being absent or rare, for example, throughout the Dalgety Granodiorite; it is present in the rather felsic sample of Numbla Vale Adamellite (BB2). The Tingaringy Suite consists of a single unit, the Tingaringy Granodiorite (71 km^2) which has a unique composition. This differs from the Bullenbalong Suite in having higher Ca and Sr, and from the Dalgety Suite in its higher Mg and Cr.

ARABLE GRANODIORITE

The Arable Granodiorite (60 km^2) in the vicinity of Cooma Airport shares disinctive chemical features, such as high Cr with the Murrumbucka Tonalite, and this unit is placed in the IS-type Murrumbucka Suite. The Arable Granodiorite was not separated from Cootralantra by White *et al.* (1977).

I-TYPE GRANITES

I-type granites of the Berridale Batholith have bimodal compositions with distinct felsic and mafic groups that correspond to minimum-melt composition rocks with little restite, and non-minimum-melt compositions, respectively. Although some of the latter group are very felsic, none show compositional signs of feldspar fractionation.

The five felsic plutons are Namungo (1.2 km^2), Wullwye (39 km^2), Buckleys Lake (470 km^2), Maffra (24 km^2), and Delegate (67 km^2). Buckleys Lake is the most extensive rock type in the batholith and is very distinctive in the field, generally being coarse-grained and porphyritic in pink K-feldspar; the other units are fine to medium even-grained. Namungo is a very felsic body containing andalusite altering to muscovite. Wullwye is felsic, extremely homogeneous and distinct from the other units with higher Na, Sr and LREE and lower K, Rb, Pb, Th and Y. The other three units are somewhat similar in composition but Buckleys Lake can be separated by its low Na and high K, Rb and Th. Maffra is a very felsic body (75 - 76.5% SiO_2) but there is no overlap with Delegate (73 - 75% SiO_2) so it is difficult to be certain that the two are consanguinous. Maffra may have slightly lower Y levels, but both are placed together in the Delegate Suite, and along with Buckleys Lake are assigned to the Buckleys Lake Supersuite.

The more mafic units are Tara (24 km^2), Finister (33 km^2), Merumbago (15.0 km^2), Currowong (42 km^2), Bimbimbie (12.5 km^2) and Iona (29 km^2). Tara has a unique composition, being relatively high in Na, Mn and Sr, and low in K, Rb, Th, LREE and Cr. Finister and Merumbago are identical rocks, differing from the other suites for most elements, but most distinctively it contains low Na, Sr and Al, and high Fe, Mg, and the trace transition metals; they are placed in the Finister Suite. This suite is the oldest in the batholith (Williams *et al.*, 1975) and also has very old model isotopic ages for Sr and Nd ~ 1500 Ma (Compston & Chappell, 1979; McCulloch & Chappell, 1982) implying very old source-rocks despite its distinctive I-type chemical character (it contains abundant hornblende). Currowong, Bimbimbie and Iona are grouped in the Currowong Suite, along with the Bonang and Brodribb units from the Bonang Granites to the south.

THE COOMA COMPLEX

The Cooma Granodiorite has an outcrop area of 14.0 km^2. The main interest since it was first studied by Browne (1914) has been in the surrounding metamorphic rocks of pelitic and quartzofeldspathic composition (Joplin, 1942) which are about 9 km wide where exposed on the western side. The eastern side of the complex is covered by basalts of the Monaro Province and on the western side the metamorphic grade increases towards the granodiorite and the following zones can be recognized (Chappell & White, 1976):

1. *Chlorite zone* in which the slates have the assemblage quartz + muscovite + albite + iron oxides or quartz + albite + calcite + chlorite.
2. *Biotite zone* of schists or phyllites containing the assemblage quartz + albite + biotite + muscovite ± chlorite ± iron oxides.
3. *Andalusite zone* defined by the presence of andalusite and the absence of sillimanite. At the lower grades spotted schists probably contain relict andalusite or cordierite. The higher grade part of this zone includes assemblages quartz + cordierite + orthoclase + biotite + muscovite + plagioclase + andalusite.
4. *Sillimanite zone* defined by the presence of sillimanite with the mineral assemblages being mainly quartz + orthoclase + cordierite + biotite + muscovite + sillimanite + andalusite.
5. *Migmatite zone* in which abundant granitic dykes occur in a sillimanite-andalusite biotite gneiss.

The Cooma Granodiorite is a regional-aureole granite which is sometimes foliated, but more often massive. The pluton has a distinctive mineralogical and chemical composition. It is extremely quartz-rich (~ 50%) and contains cordierite, andalusite and sillimanite. It is very low in Na_2O and CaO which is thought to result from its derivation from the clay-rich Ordovician sediments. Such an origin is supported by isotopic data (Pidgeon & Compston, 1965; McCulloch & Chappell, 1982). The Cooma Granodiorite is grouped with the Gap unit of the Murrumbidgee Batholith in the Cooma Suite. That suite, together with the Geehi Suite in the Maragle Batholith further west, make up the Cooma Supersuite. Members of that Supersuite differ from the more abundant S-type granites of the LFB (the "batholithic S-types" of White & Chappell, 1988b), which are higher in Na_2O and CaO and are thought to have been derived from less mature, pre-Ordovician sedimentary rocks (Chappell, 1984; White & Chappell, 1988).

For a sketch map of the Cooma Complex, see page xx.

GEOCHRONOLOGY OF THE COOMA COMPLEX

Browne (*in* David, 1950) divided the granites of southeastern Australia into three groups based on textural grounds, and interpreted each as the product of a particular orogenic episode. He considered the granite gneisses to be Ordovician, those granites with a partly cataclastic foliation to be Silurian, and the granites which are massive and unstressed to be Devonian or younger.

While the Cooma Granodiorite exemplifies the 'Ordovician' type, the weight of evidence collected over the last thirty years has been that the granodiorite and its metamorphic aureole cooled through the blocking temperature for most geochronological systems in the mid to late Silurian. However, the most recent thinking, based on ion-probe analyses of zircon, is that, in fact, Browne might have been right, and the emplacement age of the Cooma Granodiorite might be latest Ordovician, about 440 Ma.

Minerals and whole rocks from the Cooma Granodiorite, its regional metamorphic aureole, and its large amphibolite enclave, the Soho Street Amphibolite, have been dated by a number of techniques, Rb-Sr, K-Ar, Ar-Ar, Sm-Nd and U-Pb. The three isotopic studies that have been directed specifically at the granodiorite and its associated rocks are: [1] Pidgeon & Compston (1965), principally a Rb-Sr whole-rock and mineral study of the relationship between the granodiorite and its surrounding metamorphic rocks, [2] Tetley (1979), a K-Ar and Ar-Ar study of the cooling history of the granodiorite itself, and [3] Munksgaard (1988), a chemical and Sr and O isotopic study of the granodiorite and its host metasediments.

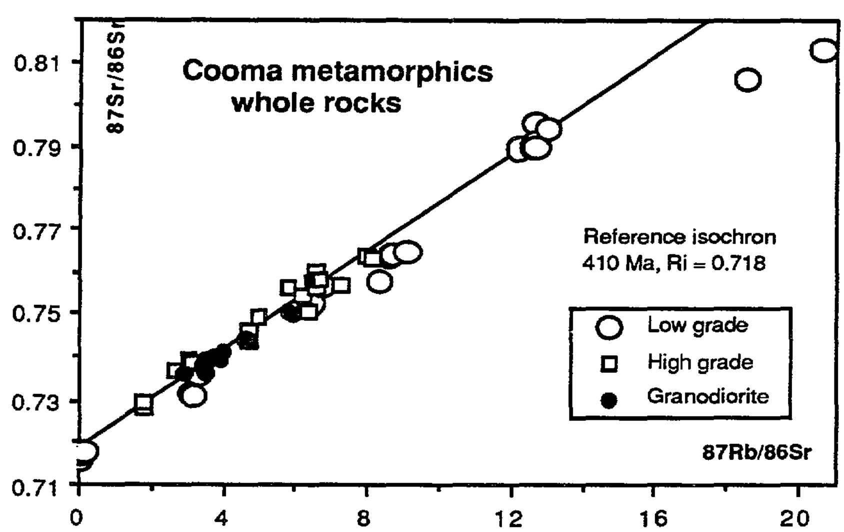


Figure 1. Whole-rock Rb-Sr analyses of the Cooma Granodiorite, and high and low grade sediments in its regional metamorphic aureole.

The combined Rb-Sr whole-rock data for the Cooma Granodiorite and its surrounding metasediments (Pidgeon & Compston, 1965; Tetley, 1979; McCulloch & Chappell, 1982; Munksgaard, 1988) are plotted in Fig. 1. Pidgeon & Compston (1965) interpreted their data to indicate that the granodiorite and high grade metasediments shared the same age and initial $^{87}Sr/^{86}Sr$, but that the low grade rocks were older and had a lower initial $^{87}Sr/^{86}Sr$. The additional analyses of the metasediments by Munksgaard (1988) did not support this interpretation, suggesting instead that the slopes of the isochrons for the three rock types are comparable. What is clear from the combined data is the progressive averaging of Rb/Sr and Sr isotopic composition that took place as the metamorphic grade increased and the metasediments finally partly melted. A corollary to this is that the higher the grade, the less is the scatter about the isochron.

The whole-rock data are not suitable for a precise determination of the age of the Cooma

Granodiorite since, despite partial homogenization during metamorphism and melting, the initial isotopic heterogeneity of its source was too great. The reference isochron shown in Fig. 1 is that calculated from the whole-rock and feldspar analyses of the granodiorite by Tetley (1979), but there is no evidence to suggest that the alignment of the array of all available whole-rock analyses is significantly steeper, i.e. that the whole-rock age is significantly greater than 410 Ma. A composite isochron of all the available whole-rock and feldspar analyses from the granodiorite itself and an associated microgranite dyke (Pidgeon & Compston, 1965; Tetley, 1979; McCulloch & Chappell, 1982; Munksgaard, 1988) is shown in Fig. 2. As in Fig. 1, the isochron for the mineral and whole-rock data of Tetley (1979) is shown for reference.

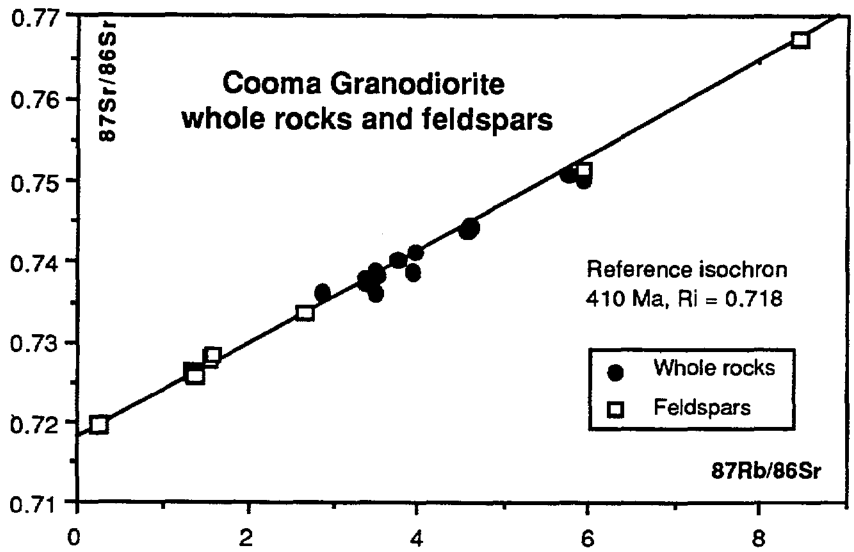


Figure 2. Whole-rock and feldspar Rb-Sr analyses from the Cooma Granodiorite and an associated microgranite dyke.

Fig. 2 illustrates the difficulty in determining the Rb-Sr age of the Cooma Granodiorite, caused by initial isotopic heterogeneity and the relatively small dispersion in the whole-rock Rb/Sr. Pidgeon & Compston (1965) originally combined whole-rock and mineral analyses to calculate an age of 406 ± 12 Ma, with an initial $^{87}Sr/^{86}Sr$ of 0.7179 ± 0.0005. Munksgaard (1988), on the other hand, used the whole-rock analyses alone to conclude the age was 362 ± 77 Ma, and the initial $^{87}Sr/^{86}Sr$ 0.7203 ± 0.0043. He considered the difference between the latter age and the mineral age to be significant, which requires that the Cooma sediments had a negative correlation between $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ at the time of magmatism. While there are processes that could cause this, such as variable isotopic exchange between the sediments and sea water, the evidence for a young whole-rock age remains tenuous.

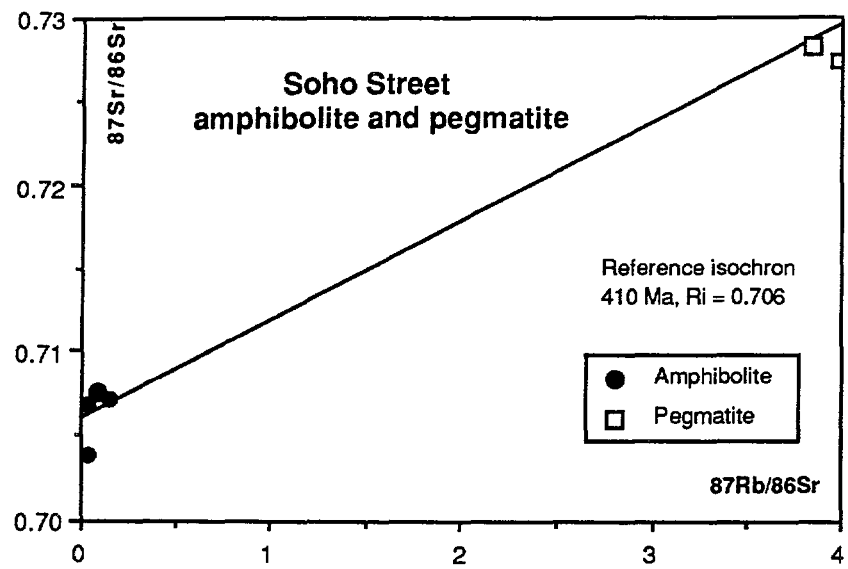


Figure 3. Rb-Sr whole-rock analyses from the Soho Street pyroxene amphibolite enclave in the Cooma Granodiorite, and an associated pegmatite.

Rb-Sr analyses of the large (50m) diameter Soho Street amphibolite enclave in the Cooma Granodiorite, probably originally a gabbro or norite, contribute little age information (Fig. 3), but do show very clearly its low initial $^{87}Sr/^{86}Sr$, consistent with a possible mantle origin. The great importance of the amphibolite from a geochronological viewpoint, however, is that it is one of the few sources of hornblende in the Cooma Complex suitable for Ar dating.

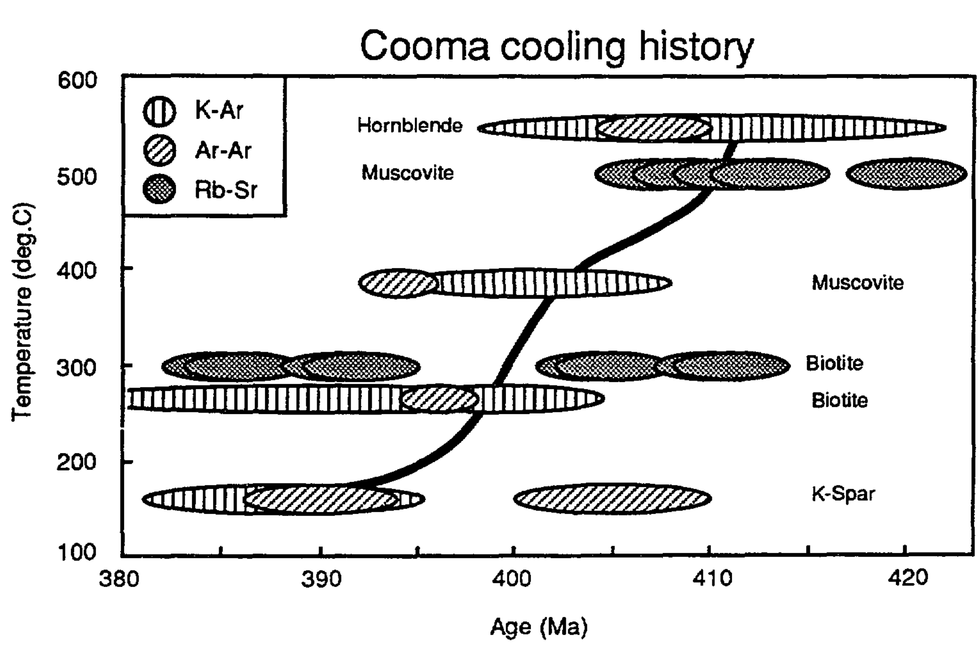


Figure 4. Mineral ages measured on the Cooma Complex plotted against their effective closure temperatures.

The mineral ages measured on the Cooma Complex are listed below in Table 3 and illustrated in Fig. 4. Where necessary, they have been recalculated to the constants recommended by Steiger & Jäger (1977).

TABLE 3. MINERAL AGES FROM THE COOMA COMPLEX

Mineral		Method^	Age (Ma)*	Reference
Cooma Granodiorite				
GA 239	biotite	K-Ar	390 ± 13	Evernden & Richards (1962)
C5	biotite	Rb-Sr	385 ± 3	Pidgeon & Compston (1965)
C5	biotite	Rb-Sr	386 ± 3	"
C2	biotite	Rb-Sr	411 ± 3	"
C2	biotite	Rb-Sr	404 ± 3	"
76-3A	biotite	Rb-Sr	391 ± 3	Tetley (1979)
76-3A	biotite	Rb-Sr	392 ± 3	"
76-3A	biotite	K-Ar	399 ± 5	"
76-3A	biotite	Ar-Ar	396 ± 2	"
C2	muscovite	Rb-Sr	420 ± 3	Pidgeon & Compston (1965)
C2	muscovite	Rb-Sr	413 ± 3	"
76-3A	muscovite	Rb-Sr	409 ± 3	Tetley (1979)
76-3A	muscovite	Rb-Sr	411 ± 3	"
76-3A	muscovite	K-Ar	401 ± 7	"
76-3A	muscovite	Ar-Ar	394 ± 2	"
76-3A	K-feldspar	K-Ar	388 ± 7	"
76-3A	K-feldspar	Ar-Ar	390 ± 4, 405 ± 5	"
Microgranite dyke				
GA 293	biotite	Rb-Sr	410 ± 3	Pidgeon & Compston (1965)
GA 293	biotite	Rb-Sr	405 ± 3	
	"			
GA 293	muscovite	Rb-Sr	407 ± 3	
	"			
Amphibolite				
75-102	hornblende	K-Ar	410 ± 12	Tetley (1979)
75-102	hornblende	Ar-Ar	407 ± 2	
	"			

^ Rb-Sr ages are based on $R_i = 0.718$.
* Uncertainties are 2σ estimates.
$^+$ Two plateaux in the Ar release spectrum

The heavy black line in Fig. 4 is the cooling history for the Cooma Complex inferred by Tetley (1979). His interpretation of the shape of the curve was that there was early rapid cooling due to the thermal contrast between the magma and its host rocks, followed by slow cooling resulting from regional uplift.

The most recent isotopic work on the Cooma Granodiorite is an ion-probe zircon U-Pb study currently underway (Williams and others). Preliminary results show several features of interest. First, the zircon population is dominated by inherited grains. Zircon that precipitated from a silicate melt is limited to thin, micron-scale mantles on older grains. Even with an ion microprobe, dating this zircon has proved to be extremely difficult. The few mantles that are thick enough to date have yielded ages about 30 Ma greater than the 410 Ma recorded by hornblende K-Ar, sufficientl to show that even hornblende probably has not recorded the emplacement age of the granodiorite. This being so, the details of the cooling history proposed by Tetley (1979) might require some revision, with cooling having been slower, and possibly at a more even rate, than he suggested.

Secondly, most of the interpreted ages of the inherited grains cluster bimodally between 450 and 600 Ma and slightly above 1000 Ma. Some cores are early to mid Proterozoic and late Archaean. Zircons have yet to be dated from the lower grade rocks in the aureole immediately around the granodiorite, but very similar zircon age groups already are known from several samples of the southeastern Australian Ordovician flysch sediments surrounding the Bega Batholith to the east. The same age groups also are found in the rare inherited zircons in the Bega Batholith granites themselves (Williams *et al.*, 1988), and in the inherited zircons in the granites of the Berridale and Kosciusko batholiths. In no other analyzed granite, however, is the inherited zircon as abundant as in the Cooma Granodiorite. This strongly supports the contention that the Cooma Granodiorite formed by the ultrametamorphism of local sedimentary rocks with a very low degree of partial melting. It remains to be seen whether the inherited zircons can be used to distinguish between derivation of the granodiorite from metasediments the same as those presently at the surface, or derivation from somewhat different metasediments at depth.

BEGA BATHOLITH

The Bega Batholith (8620 km^2) is the largest in the LFB. It was originally named and briefly described by Brown (1933) who recognized it as a composite body. More recent field data from theses, with additional mapping by Beams (1980) and by Wyborn & Owen (1986) have shown that the batholith consists of more than 130 separate lithological units, ranging in area up to 970 km^2. The country rock is mainly Ordovician sandstones and shales (quartz-rich flysch) but in a few localities the granites intrude Silurian limestones. The batholith is overlain unconformably by Upper Devonian (Frasnian) volcanic and sedimentary rocks in a few places.

The Moruya Batholith (263 km^2) has traditionally been separated from the Bega Batholith despite its small size and its close compositional association with the larger complex. It consists of nine lithological units of granite (Griffin *et al.*, 1978), one of which, the Tuross Head Tonalite, extends out to sea. On the basis of aeromagnetic data, there is at least one other pluton under the Tasman Sea to the southeast. There are two small areas of exposure of mafic rocks, the Bingie Bingie Gabbroic Diorite, on the southeastern edge of the batholith, at Bingie Bingie Point and at Tuross Head. The Gabo Island Granites consist of nine small plutons with a total area of 59 km^2 in the southeastern corner of mainland Australia. These rocks have been described by Collins *et al.* (1982).

The rocks of the Bega and Moruya Batholiths and the Gabo Island Granites will here be considered together. Those rocks are dominantly I-type, with a small amount of A-type granite and four plutons that have been analyzed but are unassigned. Those are the highly fractionated Whipstick pluton and three which may be S-type: Stanton Rock, Myocum and Mila. All of those four bodies contain more than 2% muscovite. Other very felsic granites of the batholith may contain small amounts of muscovite, less than 1%, and are then weakly peraluminous. Cordierite or aluminosilicate minerals, typical of S-type granites, are never found; hornblende is always present in the more mafic rocks, in contrast to mafic S-types.

Seven I-type supersuites have been recognized in these granites. Rocks covering a total of 83% of the area of the Bega Batholith can be placed into these supersuites. The small and generally felsic plutons occurring along the western edge of the batholith (6% of area) and Whipstick, Stanton Rock, Myocum and Mila have not been assigned. Plutons not sampled for chemical analysis, either because of inaccessibility or because of lack of fresh exposures, make up 9% of the total area. A-type granites make up the remaining 2% of the total area.

For both suites and supersuites, Na and Sr are the most useful discriminants. The batholith has a striking chemical asymmetry with a significant decrease in both Na and Sr westward across the batholith (Table 4). The other two elements that decrease fairly regularly, at constant SiO_2, are Al and P. Ca and Sc increase significantly to the west, while Rb, Y and V increase slightly. There is no detectable systematic change in K. The Moruya Supersuite lies on these trends when they are extrapolated to the east, and chemically that supersuite is part of the Bega Batholith story. It is significant that these changes occur in a short distance (55 km) across the batholith whereas no systematic changes have been observed along the axis of the batholith (300 km).

TABLE 4. SUPERSUITES IN THE BEGA BATHOLITH

Name	Number of units	Number of suites	Area (km^2)	At 68% SiO_2 % Na_2O	ppm Sr
1. Moruya	9	2	263	4.04	321
2. Cobargo	7	4	370	3.63	384
3. Kameruka	6	5	1354	3.44	299
4. Candelo	9	7	1199	2.65	315
5. Bemboka	13	8	1850	2.51	188
6. Glenbog	17	6	1752	2.67	136
7. Tonghi	7	4	573	2.41	191

The dominant I-type rock in the Bega Batholith is granodiorite with lesser adamellite and tonalite. One sample plots in the field of granite in the strict sense (c.f. the A-type granites of Collins *et al.*, 1982). Quartz-poor granites, that is quartz monzonites, quartz monzodiorites and quartz diorites are present but uncommon. The batholith is dominated by moderately quartz-rich rocks spanning the adamellite-granodiorite-tonalite range of feldspar proportions. Gabbroic diorites (53-57% SiO_2) and gabbros (<53% SiO_2) are very minor in amount; only 5.6 km^2 (0.06% of the total area) has been mapped in these groups. Other small bodies will presumably be found with extensive searching but the total amount will still be very small. This situation in a large Palaeozoic batholith is in complete contrast to the amount of mafic rock in the large Mesozoic Cordilleran batholiths, e.g. in southern California (Larsen, 1948) and in the Coastal Batholith of Peru where Cobbing & Pitcher (1972) report that gabbro makes up "about 16%" of the plutonic rocks.

The petrographic and chemical features of the Bega Batholith, under supersuites and suites, east to west across the batholith, will now be described. This can be done in more detail than for most of the other granites of the LFB because of the detailed studies of Beams (1980).

MORUYA SUPERSUITE

Granitic rocks of the Moruya Batholith are subdivided into two suites, Moruya and Nelligen. Griffin *et al.* (1978) described this batholith and grouped all of these rocks together as a single Moruya Suite but they pointed out that the most northerly Nelligen pluton is slightly different in composition from the other bodies, containing higher K and the related trace elements Rb, Pb, Th and U. This difference was confirmed by Compston & Chappell (1979) who showed that Nelligen has a slightly higher initial $^{87}Sr/^{86}Sr$ than the other Moruya rocks. For these reasons the two suites are distinguished but they are grouped in the same supersuite on the basis of similarity of other elements, particularly the high Na contents. All rocks in the Moruya Batholith are I-type. Compston & Chappell (1979) give Rb-Sr total-rock ages of 389 ± xx Ma for the Moruya Tonalite and 395 ± xx Ma for the Nelligen Granodiorite. The ion-probe zircon age of the Moruya Tonalite is about 395 Ma.

TABLE 5. ISOTOPIC COMPOSITION OF BEGA BATHOLITH SUPERSUITES

	ε_{Nd}		$^{87}Sr/^{86}Sr$		$\delta^{18}O$	
MORUYA	3.5	(3)	0.7040	(2)	8.2	(8)
CANDELO	0.6	(6)	0.7047	(6)	8.8	(12)
KAMERUKA	-1.7	(4)	0.7058	(3)	8.9	(11)
CANDELO	-2.9	(5)	0.7059	(5)	9.1	(9)
BEMBOKA	-6.3	(12)	0.7087	(6)	9.6	(19)
GLENBOG	-6.6	(17)	0.7094	(13)	8.7	(14)
TONGHI	-6.1	(11)	0.7082	(5)	9.1	(15)
TONGHI without BOMBALA	-6.7	(8)	0.7084	(4)	10.0	(5)

The Moruya Supersuite is the most easterly in the southern part of the LFB and it has been described in detail by Griffin *et al.* (1978). The Nelligen Suite consists of a single pluton (69 km^2) that is rather felsic (SiO_2 = 70.7 - 74.1%). The Moruya Suite consists of eight separate units (total area 194 km^2), containing rocks with a very wide and continuous range in composition, from 58.9% to 74.9% SiO_2. Griffin *et al.* (1978) ascribed this range to varying degrees of retention of material residual from partial melting, or 'restite', in a felsic melt, so that the more felsic rocks are relatively restite-free, and the more mafic rocks relatively restite-rich. White & Chappell (1977) again discussed these rocks in proposing the restite model in granite genesis (see also Chappell *et al.*, 1987). There are no fractionated rocks in the Moruya Batholith and the most felsic rocks are close to minimum-temperature melt composition. Relative to other granites in the LFB, the rocks of the Moruya Supersuite are particularly high in Na and Sr. Griffin *et al.* (1978) compared in detail the composition of these rocks with those of the Jindabyne Suite that lies 150 km to the west across the fold belt; they showed that the K contents of the two suites are indistinguishable and the most significant differences are in Ti, Na, P, Zr and Nb, all of which are more abundant in the Moruya rocks.

COBARGO SUPERSUITE

The Cobargo, Merricumbene, Brogo and Wangarabell Suites on the eastern margin of the Bega Batholith, and the Xmas Suite in the Gabo Island Granites constitute the Cobargo Supersuite. Specific chemical characteristics that together distinguish this supersuite are high Na and Sr, Cr, Ni, Mg:Fe and low total Fe, Y, Sc, V, Mn and Zn.

The Xmas Quartz Monzonite (1.0 km^2) and Stringy Road Granodiorite (0.7 km^2) constitute the Xmas Suite. Rocks of this suite are similar to the Cobargo and Brogo Suites but, compared with those two suites, the Xmas Suite is lower in Ti, Mg, K, Rb, Th, Zr, Sc and Zn and higher in Fe^{3+}, Na, Ba and Sr. The Sr content of these rocks (~ 800 ppm) is higher than in any other Silurian-

-Devonian granite thus far analyzed from the LFB, except for some samples from the Boggy Plain Suite in the Kosciusko Batholith (Wyborn *et al.*, 1987). The Carboniferous Wuuluuman Granite in the northeastern part of the LFB has Sr contents in excess of 1200 ppm.

The Cobargo Suite is represented by the Coolagolite Granodiorite, Cobargo Quartz Monzonite, Quaama Granodiorite and Murrabrine Quartz Diorite. The Coolagolite Granodiorite (25 km^2) is an elliptically-shaped pluton occurring east of Cobargo. It ranges from quartz monzodiorite to granodiorite. Mafic inclusions up to 200 mm across are common throughout the unit. Plagioclase is the dominant mineral and it displays prominent oscillatory zoning. Magnetite is the opaque phase, and apatite occurs as tiny needles scattered through all minerals. The Cobargo Quartz Monzonite (23 km^2) is a more felsic member of the Cobargo Suite in which mafic inclusions are rare. The mineral assemblage is the same as for Coolagolite but the proportions are different: hornblende with inclusions of quartz and magnetite is more abundant than biotite. Biotite appears either as ragged flakes intergrown with hornblende and magnetite, or as perfect crystals enveloped by interstitial K-feldspar. Again the plagioclase has irregularly shaped cores with rare inclusions of clinopyroxene, magnetite, hornblende and apatite, surrounded by a rim of oligoclase giving the crystals a tabular outline; oscillatory zoning of plagioclase is prominent in the outer zones. The Quaama Granodiorite (159 km^2) is the largest pluton in the Cobargo Suite. It contains large crystals (up to 15 mm) of the complexly zoned plagioclases typical of the suite. Quartz is more abundant in the Quaama body as compared to other members of the Cobargo Suite. The Murrabrine Quartz Diorite (1.4 km^2) is a small body occurring 500 m west of Cobargo. The compositional range of the Cobargo Suite is from 59% SiO_2 (Murrabrine Quartz Diorite) to 73% SiO_2 (Cobargo Quartz Monzonite). On Harker Diagrams, all members of the suite lie along one line for Ti, K, Ba, Sr, Zr, Nb, Sc, V, Mn, Ni, and Ga. These elements distinguish the suite from all others in the batholith. For other elements there are differences between plutons that might become more significant with more intensive sampling. Thus the Cobargo Suite is not as well constrained as most other suites.

The Merricumbene Suite is a single pluton, the Merricumbene Granodiorite (8.4 km^2), 35 km southeast of Braidwood. Irregular quartz and K-feldspar grains are interstitial to a framework of complexly zoned plagioclases. It contains perfectly shaped crystals of hornblende and less well--shaped biotite crystals. Compared with the Cobargo Suite, the Merricumbene Suite contains more Al, Fe^{3+}, Na and Sr and less Ti, K, Rb, Th, U, Zr, Nb, Y, La, Ce, Nd and Sc.

The Brogo Suite consists of a single pluton, the Brogo Granodiorite (127 km^2), an elliptical pluton outcropping around Bega. The pluton is slightly zoned from a moderately mafic margin to a more felsic interior, with a SiO_2 range from 66.4% to 70.7%. Rocks at the margin contain abundant, complexly-zoned plagioclase, interstitial quartz and K-feldspar plus hornblende and biotite which are either perfectly shaped or are clots within hornblende intergrown with minor biotite, irregularly shaped sphene, magnetite, and fine apatite needles. Equant prisms of apatite also occur. From the margin to the centre of the pluton, there is a decrease in the number of mafic inclusions and in the amount of plagioclase with calcic cores and a decrease in the hornblende:biotite ratio, concomitant with an increase in the amount of quartz and K-feldspar and in the proportion of well-shaped crystals of hornblende and biotite and of squat prisms of apatite. Compared with the Cobargo Suite, the Brogo rocks contain lower Ti, Rb, Th, Zr and La, and higher Na, Sr, Ba, Mg and Mn.

The Wangarabell Suite consists of a single pluton, the Wangarabell Granodiorite (26 km^2); it is a medium-grained, quartz-poor granodiorite, 10 km west of Genoa. It has many of the petrographic features of the Brogo Suite. Chemically this pluton is very similar to the Cobargo Suite rocks; differences include slightly higher Fe^{3+} and slightly lower Ti, Th and Zr in this suite.

The Xmas Suite in the Gabo Island Granites is part of the Cobargo Supersuite.

KAMERUKA SUPERSUITE

Included in the Kameruka Supersuite are the Kameruka, Jingo Creek, Wallagaraugh, Pericoe and Betka Suites. These suites occur near the eastern edge of the batholith and they are more felsic and coarser grained than rocks in the more easterly Cobargo Supersuite

The Kameruka Suite consists of two plutons, the Kameruka Granodiorite and the Illawambra Adamellite. The Kameruka Granodiorite (570 km^2) is very coarse-grained porphyritic and distinctive. It is cut by two northeast-trending, right-lateral wrench faults. Pink K-feldspar crystals, commonly 20 to 80 mm across, are abundant in this unit. Some of the K-feldspars are mantled by plagioclase in a typical rapakivi texture. The virtual absence of hornblende, even in the mafic samples, distinguishes the Kameruka Granodiorite from all other Bega Batholith granites of similar SiO_2 content. Mafic inclusions are fairly common in the Kameruka Granodiorite. The Illawambra Adamellite (60 km^2) occurs at the northern end and apparently intruded the Kameruka pluton. It is again coarse-grained but more equigranular than the Kameruka Granodiorite and K-feldspar is distinctly more abundant. Relative to other granites of comparable SiO_2 range in the Bega Batholith, the Kameruka Suite is higher in Ca and lower in K and Al. It is also higher in Na than all other granites except members of the Moruya and Cobargo Supersuites. Ga is higher than any other I-type granites of similar SiO_2 content in the batholith. The Illawambra Adamellite contains slightly more Ba and Sr than the Kameruka Granodiorite but this is insufficient to justify it being regarded as a separate suite.

The Jingo Creek Adamellite 6.4 km^2) is the only member of the Jingo Creek Suite. It is a small body 2 km east of the southern part of the Kameruka Granodiorite. In contrast with that body, mafic inclusions are absent and K-feldspar occurs as irregularly-shaped grains (up to 10 mm) rather than as large well-shaped crystals. This suite shares many chemical characteristics with the Kameruka Suite but can be distinguished by its slightly higher Na, Nb, Mn and Cu, and lower Ti, K, Pb, Th and Zr.

The Pericoe Adamellite (134 km^2) comprises the Pericoe Suite. It is characterized by prominent outcrops of large tors and it occurs to the north of the Wallagaraugh Adamellite, where it is intruded by the Kameruka Granodiorite. It is an even and coarse-grained adamellite, petrographically similar to the Croajingalong Adamellite. The Pericoe Adamellite differs from the rest of the Kameruka Supersuite by having higher Ba, Ti, Zr, La and Rb:Sr, and lower K, Na, Rb, Th and Nb.

The Wallagaraugh Suite forms most of the eastern arm of the southern part of the Bega Batholith. Several rocks types are present, ranging from the moderately mafic Yambulla and Croajingalong Adamellites to the extremely felsic Wallagaraugh Adamellite. Each of these rock types may form several distinct intrusions however they have not been completely mapped. The Wallagaraugh Adamellite (210 km^2) is a coarse-grained, pink, felsic granite covering an extensive area on the eastern side of the batholith, south of Mt Imlay. The Croajingalong Adamellite (315 km^2) is coarse to very coarse-grained, outcropping both north and south of Genoa. The unit has a variable composition and more than one intrusion may be present. It is more mafic than the Wallagaraugh Adamellite. The Yambulla Adamellite (55 km^2) occurs to the west of the Wallagaraugh Adamellite. The chemical composition of the Wallagaraugh Suite lies near the felsic end of the Kameruka Suite. However, the Wallagaraugh rocks contain less Ti, Sc, P and Ga, and more Pb, Th and Y, than Kameruka Suite rocks of similar SiO_2 content. Rocks of this suite provide an excellent example of extensive feldspar fractionation with progressive changes including the prominent decrease in Ba and Sr and increase in Rb. Other elements vary in a concomitant way.

The Betka Suite consists of the Betka Granodiorite (3.6 km^2), a small body 5 km south of Genoa. It is similar petrographically to the Kameruka Granodiorite but can be distinguished from that unit by the presence of small amounts of hornblende and prominent accessory sphene. Chemical analysis of one sample of Betka Granodiorite shows that it lies between the trends defined by the Kameruka and Wallagaraugh Suites. Lower K, Rb and higher Na distinguish it from other members of the Kameruka Supersuite.

CANDELO SUPERSUITE

Granites of the Candelo Supersuite occupy much of the central part of the Bega Batholith. The constituent suites include Candelo, Braidwood, Warri, Jinden, Belowra, Hopping Joe and Nungatta. These are characterized by being much more mafic than the Kameruka Supersuite and are higher in K and lower in Na.

The members of the Candelo Suite form a zoned pluton offset by the Burragate Wrench Fault. The more mafic Candelo Tonalite (45 km^2) is marginal to the Yurammie Granodiorite (245 km^2), and the two share a gradational contact. The Candelo Tonalite is dominated by a framework of well formed tabular plagioclase crystals, the majority of which are complexly zoned. The coarse to very coarse-grained Yurammie Granodiorite can be distinguished from the Candelo Tonalite by an increase in quartz and K-feldspar and associated decrease in plagioclase and mafic mineral content. Brick-red sphene (up to 5 mm across) and allanite are prominent accessory minerals in some samples. The boundary between the Yurammie Granodiorite and the Candelo Tonalite has been mapped in the field as the first appearance of pink K-feldspar. The Candelo Suite is distinguished from the other Bega Batholith suites by relatively high Sr, light rare earth elements (LREE), Cu, K, Ba, Rb, Th and U, moderate Na, Sc, Zn, V, Mn, Cr, and low FeO, Ca, Ca:Al and Rb:Sr. The comparatively large amount of K is reflected in the high K-feldspar content. For example, at 67% SiO_2, samples of the Candelo Suite contain ~ 20% K-feldspar, whereas at the same SiO_2 content the Kameruka Suite contains ~ 6%, the Why Worry and Bemboka Suites ~ 5% and the Glenbog Suite contains ~ 10% K-feldspar. The high LREE contents of the Candelo Suite is consistent with the occurrence of two REE-rich mineral phases, sphene and allanite.

The Braidwood Granodiorite (590 km^2) forms the Braidwood Suite. It is a large, meridionally-trending body centred on the town of Braidwood. It has many of the same petrographic features as the Candelo Suite. Magnetite is abundant and amounts to 1 to 1.5% of most specimens. On the basis of twelve chemical analyses, this unit has a rather restricted compositional range (61 - 67% SiO_2), like that of the Candelo Suite. It is also similar to the latter suite in having high K and moderate Na. It can, however, be distinguished from the Candelo Suite by slightly lower Al, Fe^{3+}, Ba, Sr and higher Fe, Mg, Ca and Ga:Al. The compositions are, however, sufficiently similar for these two large suites to be distinguished from all other Bega Batholith suites, and to be grouped within the same supersuite.

The Warri Suite is composed of two small plutons, the Glenrossal Granodiorite (7.2 km^2) and Warri Granodiorite (0.7 km^2) which occur north of the Braidwood Granodiorite. Both are similar petrographically and chemically to the felsic parts of the Braidwood Granodiorite. In general the Warri Suite has similar chemical features to those of the Braidwood Suite but it can be distinguished by lower Sr.

The Jinden Granodiorite (183 km^2) and Belowra Granodiorite (63 km^2) are coarse- and even-grained felsic granodiorites, occurring south of the Braidwood Granodiorite, and form the Jinden and Belowra Suites. Two analyses from each pluton are close to the felsic end of the compositional range of the Braidwood Suite. The Jinden Granodiorite is lower in Sr and the Belowra granodiorite lower in Cr than that suite. Despite their relatively felsic compositions, rocks of these suites contain hornblende.

The Hopping Joe Granodiorite (10.5 km^2) occurs to the west of the Yurammie Granodiorite. It is similar to the more felsic Candelo Tonalite samples in composition but it is regarded as a distinct suite. The unit is close to the Burragate Fault and is strongly deformed.

The Nungatta Granodiorite (55 km^2) forms the Nungatta Suite and is the most southerly member of the Candelo Supersuite. Although the Nungatta Granodiorite has very similar characteristics to the Candelo Suite, it can be distinguished by slightly lower Sr, Al, Ba, Zn and Mn.

BEMBOKA SUPERSUITE

The Bemboka Supersuite is the most extensive in the Bega Batholith and it includes those suites (Bemboka, Why Worry, Drummer, New Building, Hyde Creek, Coolangubra, Tamboon and Everard) that occupy the central western part of the batholith.

The major component of the Bemboka Suite is the Bemboka Granodiorite (970 km^2), the largest body of granite recognized in the LFB. On the western side it is in contact with the Brown Mountain Screen which occurs as a continuous strip 25 km long; further remnants of that screen occur intermittently both to the north and south along most of the batholith. Where the screen is breached, south of Brown Mountain, the Bemboka Granodiorite comes into contact with rocks of the Glenbog Suite and with more felsic members of the Bemboka Supersuite. The Wadbilliga Adamellite (75 km^2) is the second member of the Bemboka Suite. It occurs as a separate unit north of the Bemboka Granodiorite, and has a similar petrography and chemistry to felsic samples from that unit.

There are two members of the Why Worry Suite, the Why Worry and Pretty Point tonalites, which are separated by a narrow discontinuous screen of metasediments. The Why Worry Tonalite (60 km^2) is a coarse-grained mafic tonalite (average colour index of 25) containing abundant mafic inclusions, particularly near the margins of the intrusion. The Pretty Point Tonalite (17.5 km^2) has a similar field appearance, modal mineralogy and petrography to the Why Worry Tonalite, except that it has a strong, probably protoclastic, foliation parallel to the margins of the pluton.

The Bemboka and Why Worry Suites can be distinguished from others in the Bega Batholith by their high Fe, Ca, Sc, V, Mn, Co and Zn and their low Na and Sr. However, differences in detail occur between the trends exhibited by the Bemboka and Why Worry Suites. Samples from the Bemboka Suite produce a "tight" straight line trend on a Harker Diagram for almost all elements with continuous variation from 67.5% to 73.5% SiO_2. Samples of the Why Worry Suite, although more scattered, lie at the mafic end of the Bemboka Suite trend for many elements, e.g. Na, P, Fe, Mg, Ti, Sc, V, Cr, Mn, Ni and Zn. However, for other elements the Why Worry Suite has a distinctly flatter trend than the Bemboka Suite. These elements include K, Rb , Ba, Th, U, Zr, Nb, Y, LREE, Ca, Sr, Al and Ga.

The New Building Granodiorite (6.4 km^2) is located in the central part of the batholith and forms the New Building Suite; one analyzed sample is very similar to Bemboka in composition, except for lower Sr and slightly higher K contents.

The Hyde Creek Granodiorite (12.0 km^2) is a medium-grained hornblende-free granodiorite occurring north of the Burragate Fault on the southeastern margin of the Bemboka Granodiorite. Chemically it is similar to felsic samples of that pluton, but it is distinguished by a higher Sr content and is assigned to the Hyde Creek Suite.

The Coolangubra Suite consists of three felsic adamellites, Coolangubra (72 km^2), Loomat (80 km^2) and Beehive (163 km^2). All are coarse-grained with prominent but poorly-shaped K-feldspars. For certain elements the Coolangubra Suite samples plot at the felsic end of the Bemboka Suite trend but it can be distinguished from that suite by lower Ca and higher K, Rb, Th and U.

A zoned body consisting of three medium to coarse-grained units constitutes the Drummer Suite. The marginal Drummer Granodiorite (50 km^2) and Thurra Granodiorite (54 km^2) are hornblende-bearing whereas the central pluton, the Future Trail Granodiorite (23 km^2) is hornblende-free. These rocks are similar to the Bemboka Granodiorite and chemical and modal analysis of two samples from the Drummer Suite show that it shares many of the chemical characteristics which distinguish the Bemboka Suite from other suites of the Bega Batholith, such as higher Fe, Ca, Sr, V and Co, and low Na and Sr. However, it can be distinguished from the Bemboka Suite by higher K, Rb, Th, U, Cr and Ni, and lower Ba, Zr, Mn and Zn.

The Tamboon Adamellite (87 km^2), forming the Tamboon Suite is felsic, even-grained and pink-coloured. It is similar chemically to felsic Bemboka Suite samples but can be distinguished by higher Na, V and Y.

The Everard Suite consists of one large unit, the Everard Adamellite (180 km^2), an even-grained felsic rock. It is partly covered by Cainozoic and Recent sediments adjacent to Bass Strait. Chemical data show that it is similar to felsic members of the Bemboka Suite, but in detail it differs from that suite.

GLENBOG SUPERSUITE

The Glenbog Supersuite extends along the western edge of the Bega Batholith. It is dominated by the Glenbog Suite which comprises 1507 km^2 of the total area of 1752 km^2. This supersuite is distinguished from all others in the batholith by its low Na and Sr contents.

The Glenbog Suite occurs over a distance of 265 km along the western edge of the Bega Batholith (see Fig. 1 in Chappell *et al.*, 1987). The more mafic members of this suite, the Anembo (157 km^2), Frogs Hollow (92 km^2), Yalgatta (74 km^2), Glenbog (335 km^2), Towamba (181 km^2), and Weeragua (21 km^2) plutons are all granodiorites and are very similar rock types. They are coarse-grained and a most conspicuous textural feature of these rocks is the occurrence of quartz as large equidimensional grains (10 - 20 mm), commonly surrounded by a rim of hornblende and generally with embayed margins. Larger lumps of quartz, 40 mm across, are occasionally present. The Boro Granodiorite (135 km^2) is the northernmost member of the Glenbog Suite sampled to date. It is very coarse-grained and slightly more felsic than the Glenbog and Anembo Granodiorites. The Ballallaba Granodiorite (240 km^2) occurs south of the Boro Granodiorite. The Towneys Creek (85 km^2), Nimmitabel (131 km^2), Cannabul (7.8 km^2) and Cann Mountain (48 km^2) adamellites are the felsic members of the Glenbog Suite. Within this suite there is a continuous range in composition from 63% to 74% SiO_2, although each individual pluton has a relatively narrow compositional range. In spite of the significant range in composition of this suite and the large area from which the samples come, the whole suite displays the most remarkable chemical coherence, e.g. for Sr (see Fig. 1 in Chappell *et al.*, 1987). Compared to the other Bega Batholith Suites the Glenbog Suite is characterized by high Fe, Ca, Rb, Sc, V, Mn and Co and low Na, P, Ba, Sr, Nb and Ni.

The Blue Gum Suite consists of two mafic bodies, the Blue Gum Tonalite (14.5 km^2) and the Buldah Gap Granodiorite (19.5 km^2), which occur at the southern end of the Glenbog Supersuite. The Blue Gum Suite differs from mafic members of the Glenbog Suite in that it does not contain the large quartz grains typically found in the latter. The Blue Gum Suite is more mafic than the Glenbog Suite but for most elements, such as Sr, it is chemically very similar to values that Glenbog would have if extrapolated to these SiO_2 contents.

The Lake Bathurst Suite consists of the Lake Bathurst Adamellite (34 km^2) that occurs north of the Boro Granodiorite. It has many of the petrographic features of felsic members of the Glenbog Suite, and chemically it is again very similar to members of the Glenbog Suite, but is distinguished by having slightly higher Na, Sc and lower Sr.

The Badja Granodiorite (148 km^2) forms the Badja Suite and occurs east of the Glenbog Granodiorite and is similar to the Anembo and Glenbog Granodiorites. The composition of rocks in this suite is very similar to that of the Glenbog Suite; differences include slightly higher Na and Sr and lower Nb.

Two felsic plutons, the Myocum Adamellite (23 km^2) and Throsby Adamellite (4.9 km^2) make up the Myocum Suite. Chemically, the samples of the Myocum Suite plot at the felsic end of the Glenbog Suite trend but they can be distinguished by their lower Ca, Th and Zr and higher Na, Sc and Ga.

The Cathcart Adamellite (1.1 km^2) is a small body occurring 10 km east of Bombala, making up the Cathcart Suite. For most elements, this unit lies at the felsic end of the Glenbog Suite trend. It can be distinguished by higher Y and Sc, and lower Ba, Sr, Th and LREE.

Wyborn & Chappell (1986) have described the occurrence of volcanic equivalents of the Glenbog Supersuite. The Kadoona Dacite occurs east of the Glenbog Suite south of Braidwood. The Kadoona Dacite has slightly higher contents of Sr, Ba, Zr and Ga than the Glenbog Suite. The dacite also has a restricted range in SiO_2 content, 64 to 67%, near the lower end of the range of SiO_2 values of the Glenbog Suite.

TONGHI SUPERSUITE

Four suites, Tonghi, Bombala, Nalbaugh and Bukalong, make up the Tonghi Supersuite, occurring in the southwestern corner of the batholith between Bombala and Bass Strait.

The Tonghi Suite consists of four plutons which extend for 100 km along the western edge of the batholith. The more mafic members of this suite, the Tonghi Granodiorite (245 km^2), the Rockton Granodiorite (147 km^2), and the Noorinbee Granodiorite (38 km^2), are all very similar and the felsic member of this suite is the Buckle Trail Adamellite (37 km^2).

The Bombala Granodiorite (37 km^2) comprises the Bombala Suite, occurring within and immediately southwest of the town of Bombala; it is separated from the main body of the Bega Batholith to the east by a 15 km wide strip of metasedimentary rocks.

Granites from the Tonghi and Bombala Suites have a wide range in composition with SiO_2 ranging from 60 to 75%. The chemical characteristics that distinguish these suites from others in the Bega Batholith further east are high Mg, Ca, Sc, V, Cr, moderate Fe, Sr, Ni and low Ti, Al, P, Ba, Zr, Cu, Zn and Na. The Bombala Suite can be distinguished from the Tonghi Suite by its slightly higher Sr, Na, and lower K.

The Nalbaugh Suite comprises a single rock unit, the Nalbaugh Granodiorite (33 km^2), which consists of several small bodies southeast of Bombala. It has a restricted range in composition, from 67% to 70% SiO_2. It shares many of the chemical features of the Tonghi Suite, such as high Mg, Sc, V, Cr, moderate Sr, Ni, and low Al, Ba and Na; it differs from that suite in having higher Ti, Pb, Fe, Y, Cu, Zn and Zr, and lower Ca and slightly lower Na. The lower Na and Ca contents result in this rock being slightly peraluminous.

Several bodies of generally pink felsic adamellite intrude the Bombala Granodiorite northeast of Bombala. These share many of the chemical characteristics of the Bombala and Tonghi Suites, such as low Ti, Al, P and Ba, and moderate Fe, Mg, Ca and Sr. The major difference is their higher Na content. On this basis, they have been grouped in the Bukalong Suite and placed in the Tonghi Supersuite.

UNASSIGNED SUITES

Many small plutons, generally rather felsic, occur along much of the western edge of the batholith. These include the Rock Flat (37 km^2) and Mila (29 km^2) plutons which are strongly peraluminous and contain abundant muscovite. They are not strongly fractionated, as Ba contents are in the range 405 to 495 ppm and Sr contents between 81 and 148 ppm; their status is uncertain but they may be S-types.

The Stanton Rock body (4 km^2) occurs near the centre of the batholith. It has a unique composition, including 43 ppm Pb, the highest value in the Bega Batholith. It is strongly peraluminous, contains more than 5% muscovite; it is probably S-type. This is supported by unpublished istopic data for O, Sr and Nd.

The status of the small Whipstick pluton (16 km^2) is uncertain; three analyses are available and they contain as little as 10 ppm Ba and 7 ppm Sr, values indicating a high degree of feldspar fractionation; this rock is is strongly peraluminous with up to 8% muscovite. It could have been derived by the fractionation of either an I-type or an A-type magma. In the context of the Bega Batholith it is unusual.

A-TYPE SUITES

Six of the plutons are A-type and are grouped in the Gabo Suite. These are Watergums (28 km^2), Naghi (3.5 km^2), Nagha (5.3 km^2), Carlyle (4.6 km^2), Howe Range (14.5 km^2) and Gabo Island (1.6 km^2). These rocks are even medium to fine-grained and felsic, ranging from granite (*sensu stricto*) to adamellite. K-feldspar is the most abundant mineral, with zoned oligoclase and quartz making up more than 95% of the rock. Biotite (annite) and hastingsite are the mafic silicates, both minerals being generally interstitial. Zircon, fluorite and magnetite are constant accessories. Apatite and allanite are less common and relicts of fayalite are rare (Collins *et al.*, 1982).

Chemical analyses are available from all plutons except Carlyle. These are not particularly felsic for A-type granites and they contain from 71.5 to 73.6% SiO_2. They are a very uniform group with the distinctively high Zr, Nb, Y, rare earth elements (REE), Sc and Zn and Ga characteristic of A-type granites. There are four suites of A-type granite in the Bega Batholith and the Gabo Island Granites. The largest is the Mumbulla Suite, consisting of the Mumbulla (56 km^2) and Dr George Mountain (13.0 km^2) plutons on the eastern side of the batholith, immediately northeast of Bega. The second suite consists of the Monga pluton (24 km^2) approximately 120 km to the north. The third, on the western side of the Bega Batholith, the Wangrah (24 km^2) and Danswell Creek plutons (4.4 km^2) occur northeast of Bredbo. The Mumbulla Suite has been studied in detail by Beams (BSc thesis, 1975) and Collins *et al.* (1982) but the other suites have not been examined thoroughly, although chemical data are available

Rocks of the Mumbulla Suite are very felsic granites (*sensu stricto*) dominated by K-feldspar and quartz, with lesser amounts of greenish plagioclase. Biotite (<5%) is the sole primary mafic mineral and is commonly interstitial. Accessory minerals include magnetite, fluorite, zircon, apatite and allanite. The granites are very rich in SiO_2, ranging from 76.8 to 77.8%. The Mumbulla Suite has many of the very distinctive trace element features of A-type granites, as do the less felsic A-type granites of the Gabo Suite, discussed earlier. Thus the REE and Ga contents are high but Zr and Nb are only a little higher than felsic I-type granites. Ba contents are high for such felsic rocks, from 500 to 655 ppm, and so the rocks do not seem to have undergone any significant feldspar fractionation. The compositions are probably very close to primary A-type melts.

Five samples of the Monga Granite show a large range in composition, with SiO_2 varying from 62.1 to 76.4%, in contrast to the very uniform Gabo and Mumbulla suites. Outcrops of this body are poor. The most felsic rocks are the most abundant but are generally more altered and difficult to sample so that only one felsic rock has been analyzed. The most mafic sample is from near the northern contact and this implies a zoned the body. Three samples contain very close to 71% SiO_2. Features characteristic of A-type chemistry are high Zr and LREE.

On the western side of the batholith, the Danswell Creek body is close to Monga in composition while Wangrah is very felsic. The two analyses of Danswell Creek show that this body has particularly high Zr, Nb, REE and Ga. Wangrah contains a little less SiO_2 than Mumbulla; its most distinctive A-type features are the high Ga values, 20.6 to 24.2 ppm, and Y from 70 to 125 ppm while Zr, Nb and LREE are not particularly high.

OVERVIEW OF ISOTOPIC STUDIES

The granites of southeastern Australia are part of a worldwide Caledonian (~ 400 Ma) magmatic episode, the products of which are found throughout the length of eastern Australia (from Tasmania to northern Queensland), and in Southeast Asia and eastern China, the eastern United States, the British Isles, Europe and Antarctica. A consistent feature of this episode is that it appears to have involved crustal redistribution rather than the generation of new crust, and most of the magmas seem to be the products of partial melting of pre-existing crustal rocks. The result of the Caledonian-age episode is a generation of igneous rocks with a geochemical and isotopic character which is distinctive, reflecting their generally evolved and complex sources.

The study of the granites in southeastern Australia began with the mapping and petrologic work of Browne and Joplin in the early part of this century. By 1960, through their efforts and those of others such as Dallwitz, the broad extent of the batholiths had been established and a start made on distinguishing individual intrusions. Dallwitz suggested that in the Snowy Mountains there were two petrographically distinct groups of intrusions, one of which consistently appeared to predate the other. In the early 1960's Joplin claimed that the two groups were different geochemically, for example in CaO, Na_2O and K_2O/Na_2O, but a more comprehensive study by Kolbe & Taylor (1966) could not substantiate this. It was only following a concerted program of mapping and geochemistry, principally by staff and students from the Australian National University, that the presence of two distinct groups of granites (now called I- and S-types) was confirmed. Their principal petrographic and geochemical features, attributable to their derivation from ***Infracrustal*** and ***Supracrustal*** sources respectively, were first detailed by Chappell & White (1974, 1984).

The current theories for the genesis of the granite magmas are strongly influenced by the geology of a small area of regional metamorphism at Cooma, 150 km south of Canberra. There, a 2 km-wide body of strongly peraluminous granite sits at the centre of a roughly elliptical metamorphic aureole in which, over a distance of about 10 km, the relatively homogeneous sequence of mature shales and sandstones of the Ordovician Adaminaby Beds has been metamorphosed progressively from chlorite to biotite to andalusite to sillimanite grade, passing then through migmatites to the granite. Far from being the cause of the metamorphism, the granite appears to be the product of *in situ*, or virtually *in situ*, partial melting of the sedimentary pile.

In a Sr isotopic study of the Cooma metamorphics, Pidgeon & Compston (1965) showed that not only did the Cooma granite have an elevated initial $^{87}Sr/^{86}Sr$ ratio, as would be predicted for a magma produced from the partial melting of sediments, but also that the same was true of all but the lowest grade of the surrounding metasediments. The field-based conclusion that the granite had been produced by the ultrametamorphism of the sediments was confirmed.

Since the early 1970s much additional work has been done on the eastern Australian granites, to the extent that they are now one of the most intensively chemically analyzed provinces anywhere.

The first indications of the temporal pattern of granite emplacement were provided by the K-Ar study of the more easterly batholiths by Evernden & Richards (1962). They recognized two principal periods of felsic magmatism, the first Siluro-Devonian and the second Carboniferous in age. In another wide ranging study, using both K-Ar and Rb-Sr, Richards & Singleton (1981) extended the area sampled to include the full 650 km width of the LFB in Victoria.

The K-Ar and Rb-Sr data suggest that plutonism in the southern LFB appears to have started in the late Ordovician with batholiths being emplaced along a roughly north-south line just west of the Snowy Mountains. Through the Silurian and early Devonian the axis of major plutonism moved eastwards by about 100 km, but scattered plutons also were emplaced to the west, both adjacent to the Ordovician axis and in a separate terrane in western Victoria, 400 km away. By the late Devonian, most activity was in central Victoria, the exception being a few small intrusions near the present east coast at the eastern margin of the early Devonian batholiths. During the Carbonifeous several isolated plutons were emplaced northeast of the main batholiths.

Most recent isotopic work has been concentrated on the batholiths of southeastern New South Wales, where mapping and geochemical studies had been concentrated beforehand. The petrographic and geochemical work of Snelling (1960) and Joyce (1973), which showed the Murrumbidgee batholith near Canberra to have formed largely by the melting of sediments, was followed by the Rb-Sr study of Roddick & Compston (1976, 1977). They were the first to identify a feature of the granites that has subsequently been found to be ubiquitous - the partial preservation of the isotopic heterogeneity of their source-rocks. This was manifest in the Murrimbidgee Batholith as excess scatter in the Rb-Sr whole-rock isochrons, and in mineral ages commonly being less than the whole-rock ages. Further, the whole-rock ages in some cases exceed the stratigraphic age of the granite host rocks. The same features are even more clearly seen in the granites of the Berridale and Kosciusko Batholiths to the south.

The aims of subsequent radioisotopic studies of the granites have naturally become twofold, to determine emplacement ages, and to place some constraints on the age of the granite source materials. Inevitably the question repeatedly arises as to whether individual ages are too young because of resetting or are too old because of inheritance.

Roddick & Compston (1976, 1977) concluded from both Rb-Sr whole-rock and mineral analyses that the Murrumbidgee Batholith was emplaced between 405 and 415 Ma, possibly all at 415 Ma, if some of the mineral ages have been reset.

Williams *et al.* (1975) measured Rb-Sr mica ages on a dozen plutons from the Berridale Batholith and found a range in age between 420 and 411 Ma which was wholly consistent with the known intrusive sequence. In that case the concern was that the older ages might have been partly reset. Subsequently Tetley (1979; published Williams *et al.*, 1982) measured K-Ar ages on many of the same mineral separates and for every sample obtained the same as the Rb-Sr age. On the other hand, Tetley found that the Rb-Sr and $^{40}Ar/^{39}Ar$ ages did not agree in all cases - two of the older, and one of the younger plutons gave anomalous Ar release patterns which suggested they might be as old as 429 Ma. The problem was only partly solved by the zircon and monazite U-Pb study undertaken concurrently by Williams (1978) and Williams *et al.* (1983) - the zircon populations in the granites are so dominated by inheritance that in most cases measuring emplacement ages proved impossible. However, where monazite was present, ages equal to or older than the mica results (up to 440 Ma) were obtained, suggesting again that the micas in some of the older plutons might have been reset.

Much effort has been put into constraining the ages of the granite sources. For several of the plutons of the Murrumbidgee batholith, Roddick & Compston (1977) obtained Rb-Sr whole-rock ages of 480 Ma, well in excess of the granites' interpreted maximum emplacement age of 417 Ma. Although they specifically attached no significance to that age, it does indicate that the source is at least as old as early Ordovician.

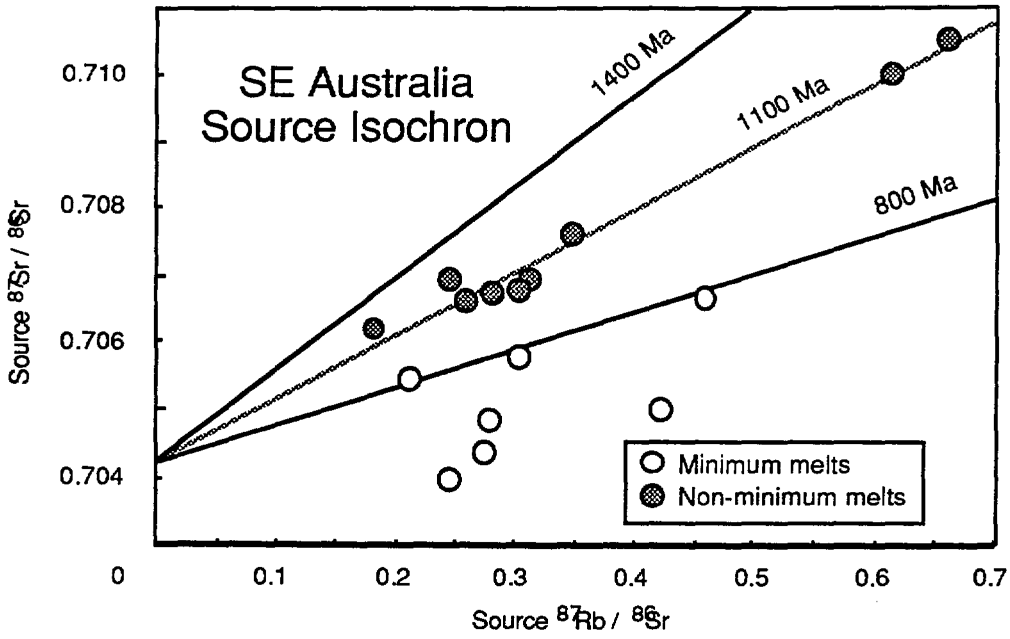


Figure 5. Source isochron for granites of the Berridale and Kosciusko batholiths constructed by inferring the source Rb/Sr for a number of plutons and plotting that against the plutons' initial $^{87}Sr/^{86}Sr$.

Compston & Chappell (1979) specifically addressed the question of Rb-Sr in the granite source-rocks. By using the major and trace element compositions of many samples from several plutons of I-type granite from the two easternmost batholiths (Bega and Berridale), they calculated the average Rb/Sr for the source of each magma (Fig. 5). Using then the initial $^{87}Sr/^{86}Sr$ for each, they constructed a source-rock isochron, concluding that the granites might postdate their sources by about 350 Ma. Extending the analysis to include granites from the Kosciusko batholith to the west, and considering only granites that were non-minimum melts, a well-defined mean source age of 1100 Ma (relative to the present day) was obtained. Here was an indication that at least some of the granite sources were Precambrian in age.

The inherited zircons in the granites of the Berridale and Kosciusko Batholiths told a very similar story (Williams, 1978; Williams *et al.*, 1983), but as with the Sr studies, they provided only tantalizing indications of the possible average ages of their source-rocks. In the I-type granites, inherited zircon is rare, but even so, in one case (the Finister Granodiorite) clear evidence of inheritance at least as old as 1100 Ma was found. Inheritance is much more abundant in all the S-type granites, and well-defined mean inheritance ages of 1340 to 1960 Ma were measured.

McCulloch & Chappell (1982) investigated the Berridale and Kosciusko granites using Nd isotopes. Analysing both I- and S-types they demonstrated the now well-recognized strong correlation between increasingly radiogenic initial Sr and increasingly negative ε_{Nd}, the principal dispersion being along a mixing curve between the isotopic compositions of depleted mantle and evolved crust (Fig. 6). As expected, the S-type granites have compositions closer to the crustal end member. In remarkable accord with the ages inferred from the earlier Sr and zircon work, the Nd depleted mantle model ages of the sources of the I-type granites were calculated to be a little over 1000 Ma, and those of the S-types to be 1250 to 1550 Ma.

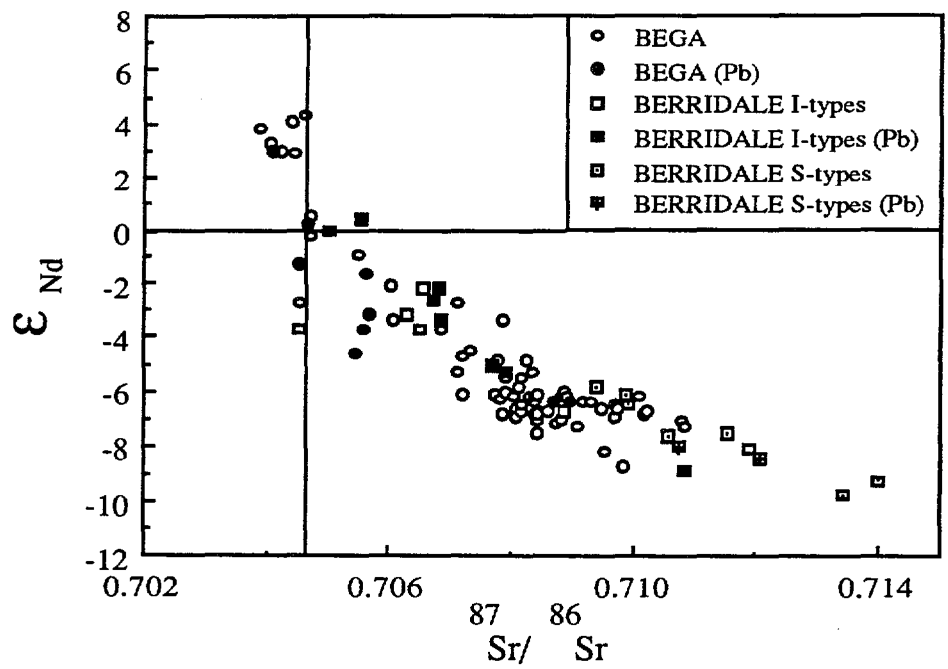


Figure 6. Initial Nd-Sr isotopic compositions of Palaeozoic I- and S-type granites from the Bega and Berridale Batholiths. Solid symbols indicate samples for which Pb isotopic analyses have been undertaken (from Chappell *et al.* (1990).

The most recent work on the LFB granites (as yet unpublished) has been concentrated on the easternmost, almost exclusively I-type, Bega batholith. There, chemical analyses by Chappell have revealed a systematic shift in the composition of the granites from east to west, consistent with a westward increase in the chemical maturity of their sources. In a study of Nd and Sr isotopic compositions (Fig. 6), McCulloch & Chappell are showing that there is also a marked westward progression in ε_{Nd} and ε_{Sr}. The depleted mantle model ages of the granites range relatively systematically from a little over 700 Ma near the coast, to about 1700 Ma farthest inland. Questions remain however: does the progression in model ages in the Bega batholith, and the difference in model ages between the I- and S-type granites in the Berridale and Kosciusko batholiths, reflect sources of truly different ages or greater and lesser contributions to the granite magmas from sources of essentially the same ages?

In an attempt to answer such questions Williams is dating the inherited zircons by ion microprobe. That way it has been possible to measure the age of individual components from the granites' sources directly, not only dating the sources but also estimating their relative contributions to individual magmas. Three main inherited zircon age populations have been distinguished (Williams *et al.*, 1988); the first up to 600 Ma old, a second about 1000 Ma old and a third 1200 to 3300 Ma old. The youngest population dominates nearly all granites, particularly those on the eastern side of the batholith; it probably dates the granites' immediate igneous protolith. Westwards the amount of inheritance increases and the two older populations become more abundant. In the S-type granites of the Berridale and Kosciusko Batholiths, every zircon crystal contains inheritance, but the ages and relative proportions of the three inherited components are basically the same as in the I-types of the westernmost Bega Batholith.

Dating zircons from the granites' Ordovician country rocks has turned up the same three age populations, but with the youngest population relatively less abundant than in the granites. It appears that about 1000 Ma ago, and again about 600 Ma ago, plutonism and volcanism built up the crust in southeastern Australia. Erosion largely removed the volcanic rocks to form a massive Ordovician flysch wedge, that are now the host-rocks to the Siluro-Devonian batholiths. The plutonism underplated the crust, forming the I-type granites' protolith and its source. The contribution of the Proterozoic and older central Australian craton to the sediments was not very great, but the presence of some such zircons in the granites strongly suggests that a small amount of sediment formed part of their sources. The amount of sediment and 1000 Ma material in the sources increases westwards.

In contrast to the highly systematic behaviour of Sr and Nd isotopic compositions, McCulloch & Woodhead are finding a remarkable uniformity in the common Pb isotopic composition of feldspars throughout the region. The Pb isotopic composition of the Bega and Berridale Batholiths has a far more restricted composition than for example modern subduction related magmas found in for example the Marianas Island Arc or the Andes, suggesting later rehomogenization of the Pb isotopic compositions in the granites sources on a large scale. These Pb isotope data have been discussed in the ICOG-7 excursion guide by Chappell *et al.* (1990).

Oxygen and hydrogen isotopic compositions of the granites from the Berridale batholith, on the other hand, are strongly heterogeneous (O'Neil & Chappell, 1977). $\delta^{18}O$ in the S-types is significantly higher than in the I-types and δD is somewhat less negative. The former probably reflects differences in source materials, but the latter is more likely due to interaction with meteoric water early in the history of the batholith.

EXCURSION NOTES

This excursion travels from Melbourne to Canberra, and examines a variety of granites in the Lachlan Fold Belt. It aims to present an integrated account of extensive field, petrogaphic, chemical, isotopic, and age studies that have been made on these rocks during the last 20 years. There are three principal scientific goals:

1. To look at a cross-section of plutonic rocks formed near an old (~ 400 Ma) active continental margin. In doing this, a section through approximately 500 km out of the total width of the belt of 800 km is examined, comprising four distinct granite provinces and basement terranes.
2. To compare and contrast the mineralogical, chemical, and isotopic properties of I- and S-type granites, and to see a variety of both types of granite. In this regard, the extensively-developed cordierite granites are of particular interest.
3. To examine the compositional changes across the compositionally asymmetrical I-type Bega Batholith, in the easternmost part of the belt, so that a comparison can be made with younger batholiths that exhibit systematic compositional changes, e.g. in the Cordillera.

The route to be followed by the excursion is shown on Fig. 1, below. For further information on the geographical distribution of granites in the belt, consult the recently published map of Chappell et al. (1991).

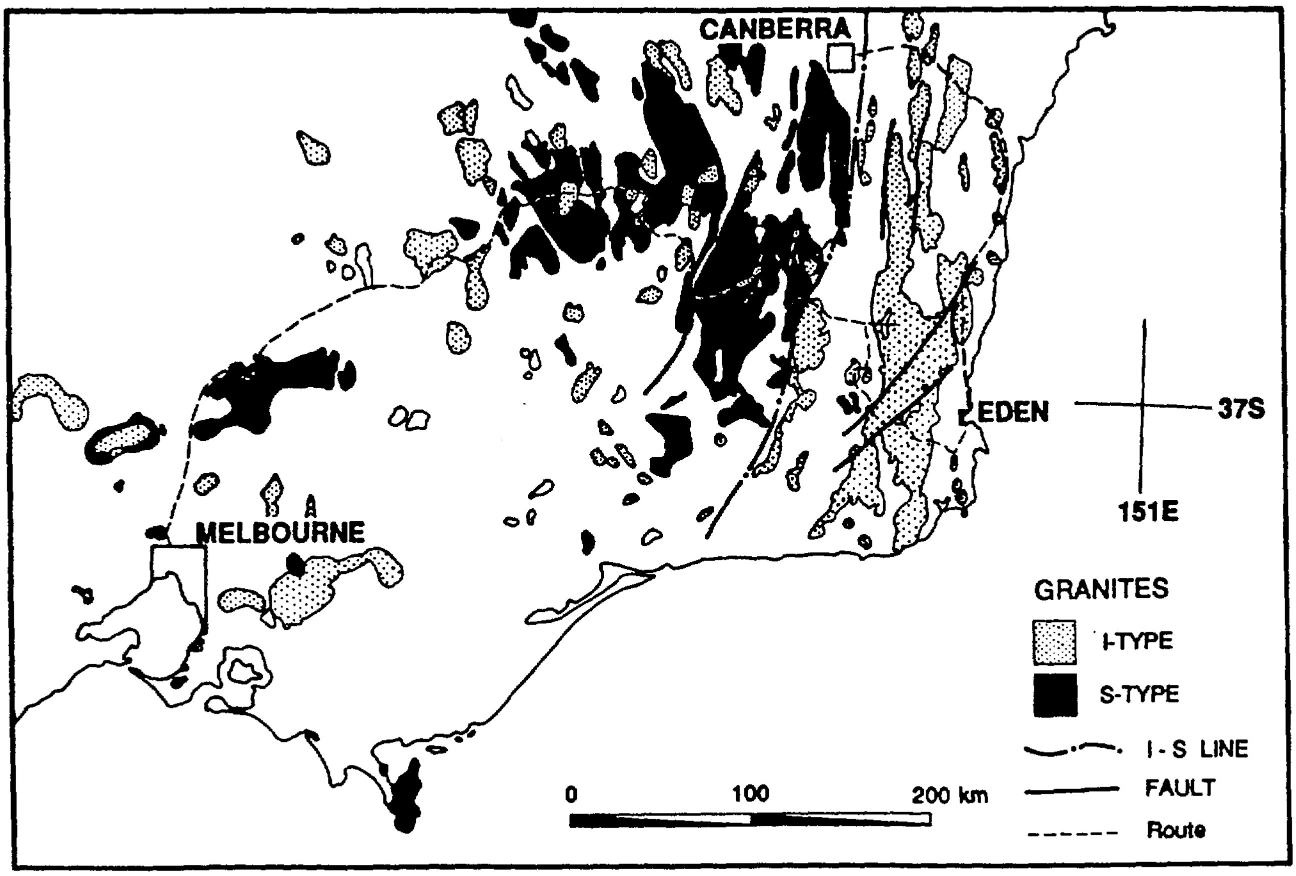


Figure 1. Showing the distribution of granites in part of the Lachan Fold Belt, and the excursion route

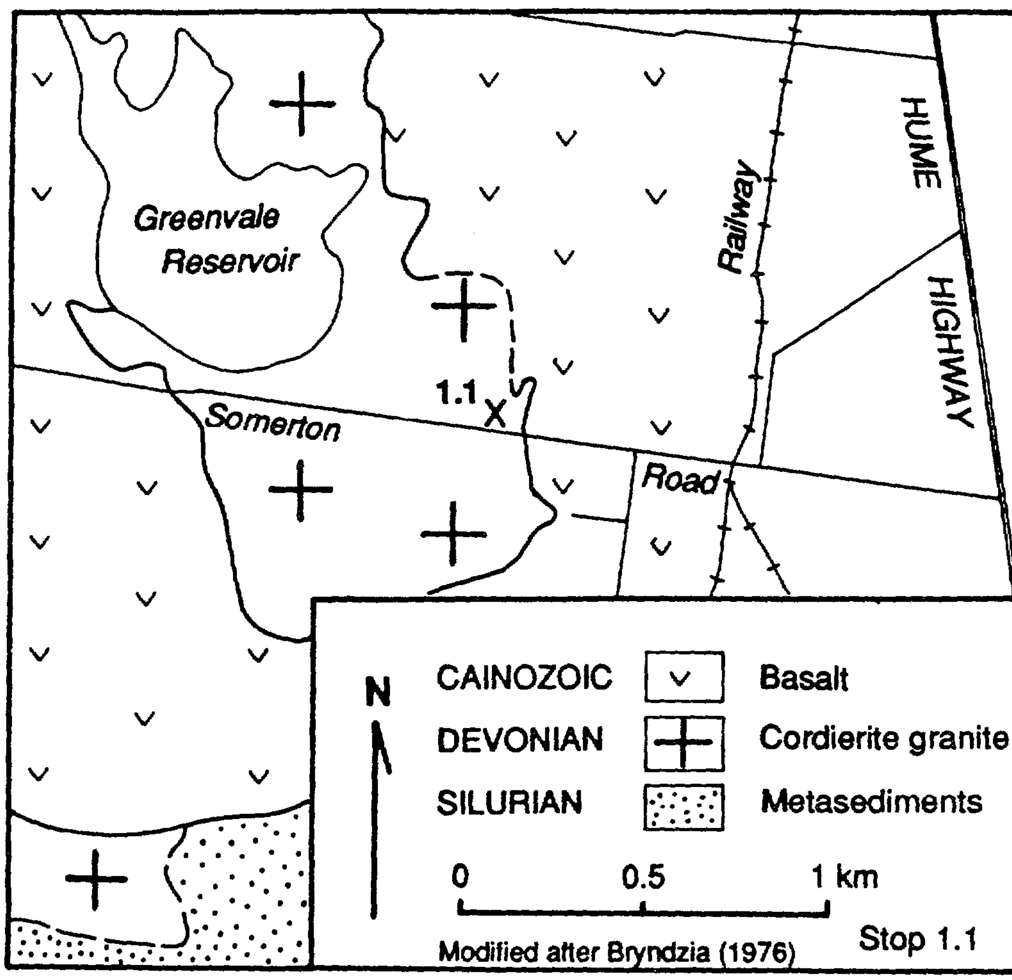


Figure 2. Map of the Bulla Granodiorite locality CV108

DAY 1: S-TYPE GRANITES OF THE MELBOURNE BASEMENT TERRANE (CENTRAL VICTORIA GRANITES)

The first day of the excursion involves travel north from Melbourne to Beechworth. Several stops are made to examine a variety of S-type granites and one S-type volcanic rock in the Melbourne Basement Terrane. Both S-type and I-type granites are widely developed in that area, although this excursion only visits S-type granites on the first day. Both types share high Ba contents and low Fe^{3+}:Fe^{2+} ratios that distinguish them from all other rocks of the LFB (see p. 9 for a discussion of this area). As a consequence of the low oxidation ratio, all granites of this terrane apparently contain ilmenite and not magnetite. Analyses of rocks from this area are listed in Table 6.

Take the Sydney Road (Hume Highway) north from Melbourne. Continue for 11.3 km north from Bell St near Pentridge Gaol and then turn left into Somerton Road. Continue along that road for 2.8 km and stop near the quarry on the north side of the road. At the present time (1991), Somerton Road represents the northern limit of Melbourne suburban development. A flat-lying tholeiitic basalt flow (Epping Flow) forms a plateau from the highway to this locality and overlies the Bulla granite exposed in the creek (Map 2). The flow is part of the "Newer Basalts" of Victoria.

Stop 1-1: Bulla Granodiorite (Melbourne 164321; map 1 in this guide) sample CV108

This is a mafic S-type granite that contains large stumpy prismatic cordierite crystals up to 10 mm in length. The reduced nature of the rock can be deduced in the field by its grey colour, the red-brown colour of the biotite, and the low magnetic susceptibility. Microgranular inclusions are fairly common, as they are in most more mafic granites. Cordierite was first recorded in this granite by Tattam (1925) who also described cordierite in the adjacent hornfels and hence thought that the cordierite in the granite was derived by contamination by those sediments. He considered that cordierite was not stable in the granite but that its micaceous alteration products were. The contamination model was supported by Bryndzia (1976) who found that in the central part of the Bulla pluton was a unit without cordierite, which he considered uncontaminated. He considered the outer unit of the pluton examined at this locality to be the most contaminated because it contains cordierite and because its inclusions commonly contain garnet. Bryndzia thought that the well-shaped cordierites resulted from recrystallization of metamorphic cordierite. However, we consider that recrystallization is unlikely because the complexly and delicately zoned plagioclase crystals were not affected. The specimens that we have examined from the central unit are considerably different from those of the outer unit. For example, they are porphyritic, probably as a result of pressure quenching, and the apparent sharp contact (it is not exposed) indicates that it is a separate intrusion of a granite, probably of another suite.

Petrographic description: In thin-section, quartz occurs as large aggregates, 6-7 mm across, consisting of several individuals with weak undulose extinction and triple junctions. Plagioclase cross-sections are crudely rectangular with good crystal shapes when in contact with K-feldspar. There are no well-defined cores but compositions range from near An_{60} down to outer zones near An_{20}. Superimposed oscillatory zones are as abundant as any seen in the LFB, with at least 25 oscillations being seen in one crystal. The K-feldspar is microperthitic and appears as large crystals up to 10 mm across that include other minerals. Biotite crystals (α = pale straw, $\beta = \gamma$ = foxy red-brown) are mostly 1-2 mm across, rarely show any crystal shape, and are mostly unaltered. Crystals that are altered are commonly almost completely changed to a pale green chlorite that may contain rods and needles of rutile. Large, crudely rectangular cross-sections of cordierite (10 mm long) are widely scattered and altered to sericitic aggregates with cores of pale yellow pinite. There are some sheaves of muscovite, in which individual well-defined crystals are up to 0.5 mm in length, and these are considered to be secondary. Apatites are stumpy prisms averaging 0.1 mm across

TABLE 6. CHEMICAL ANALYSES: CENTRAL VICTORIA GRANITES

	CV108	CV142	CV114	CV125	CV126	CV115	CV116	CV143
Stop	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-9
SiO_2	68.48	70.13	76.35	75.32	70.54	73.65	74.52	65.14
TiO_2	0.65	0.52	0.08	0.12	0.49	0.36	0.19	0.71
Al_2O_3	14.81	14.23	12.88	13.01	13.90	13.08	13.43	15.12
Fe_2O_3	0.06	0.18	0.02	0.08	0.21	0.16	0.09	0.71
FeO	3.61	3.09	1.01	1.11	2.93	2.27	1.55	3.38
MnO	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.07
MgO	1.33	1.04	0.16	0.25	1.01	0.61	0.42	1.57
CaO	2.45	1.96	0.54	0.78	1.66	1.20	0.96	2.96
Na_2O	2.66	2.53	3.02	2.92	2.43	2.58	2.74	2.62
K_2O	3.57	4.11	4.82	4.58	4.27	4.60	4.91	3.41
P_2O_5	0.20	0.16	0.13	0.13	0.18	0.17	0.13	0.18
H_2O+	1.13	1.03	0.54	0.66	1.01	0.90	0.68	2.16
H_2O-	0.13	0.13	0.11	0.23	0.16	0.16	0.10	0.37
CO_2	0.37	0.02	0.01	0.01	0.01	0.09	0.08	0.03
total	99.50	99.18	99.72	99.25	98.86	99.88	99.85	98.43
Trace elements (ppm)								
Rb	167	185	326	299	237	244	249	150
Sr	154	126	17.5	31.0	102	79	53	213
Ba	1050	860	64	115	700	755	295	985
Zr	228	184	54	69	182	183	102	261
Nb	13.0	12.0	7.0	7.5	11.5	11.5	8.0	14.5
Y	30	36	20	21	34	35	26	35
Ce	67	59	14	18	59	58	26	76
Sc	12	11	4	5	11	7	6	14
V	61	42	3	7	41	25	15	77
Cr	29	22	2	5	25	13	8	38
Ni	13	10	1	2	11	7	3	18
Zn	79	65	41	42	67	67	48	80
Ga	19.6	18.8	16.2	16	18.6	17.8	16.4	20.2
Pb	24	23	24	24	23	25	26	17
Th	16	15	6	7	15	16	10	17
U	4	3.4	9.4	10.2	3.8	5.8	6.2	3.4
Norm. C	2.59	2.44	2.02	2.14	2.69	2.08	2.17	2.17
Modes								
Quartz	35.7	30.9	29.2	33.4	26.3	21.8	29.2	14.5*
K-feldspar	16.2	24.5	44.3	46.3	33.2	45.9	42.9	30.4
Plagioclase	34.1	26.3	19.8	16.6	22.0	20.1	19.0	36.3
Biotite	9.5	11.2	2.4	1.4	12.5	10.2	6.0	12.0
Hornblende	-	-	-	-	-	-	-	-
Cordierite	2.9	2.5	1.2	1.0	3.3	1.5	1.7	1.0
Muscovite	1.1	4.0	3.1	1.2	1.7	-	2.0	0.3
Opaques	0.2	0.3	<0.1	<0.1	0.2	0.2	<0.1	0.1
Sphene	-	-	-	-	-	-	-	-
Apatite	0.2	0.3	<0.1	<0.1	0.2	0.2	<0.1	0.1
Allanite	-	-	-	-	-	-	-	-
Tourmaline	-	-	<0.1	-	0.2	-	<0.1	-

* includes 2.0% garnet and 0.4% calcite

and opaque minerals are seen to be common, particularly in biotites. Many of the crystals of opaque minerals have hexagonal cross-sections and a few have rod-shaped sections suggesting that ilmenite predominates. Crystals of zircon are prominent.
Chemistry: This is a moderately mafic composition with the extremely low Fe_2O_3:FeO ratio and high Ba content (1050 ppm) characteristic of granites of the Melbourne Basement Terrane. Na_2O at 2.66% is higher than the mafic S-type granites of the Kosciusko region further east. The rock is strongly peraluminous, containing 2.59% normative C.

Return on the Somerton Road to the Hume Highway and turn north. The hill on the west side of the road (Mt Ridley), 9.1 km north of Somerton Road, is made of nephelinite, and two other volcanic centres can be seen to the north. The wooded hills to the east include the Mt Disappointment granite which intrudes Silurian sediments. Further to the west is Mt Macedon which includes Devonian porphyritic dacite and is an ash-flow. 11.8 km north of Mt Ridley, Bald Hill to the east is an old scoria cone being quarried on the south side; nephelinite float occurs near the summit. The Great Divide is crossed 11 km beyond Bald Hill (32 km from Somerton Road), at an altitude of 357 m. This divide between coastal rivers and inland-flowing rivers is one of the longest physiographic features on Earth, extending from Victoria to Cape York. Beyond the divide, the rolling hills comprise Silurian mudrocks which are very mature and contain no feldspar, in contrast to the Ordovician rocks seen later in the excursion. Gently dipping and folded Silurian mudrocks may be seen in road cuttings from 25 to 35 km past the divide. Close to Seymour, some of the sediments are almost flat-lying and may be Devonian in age. The granites of the Melbourne Basement Terrane are younger than all of these sediments. The Goulburn River is crossed 79 km north of Somerton Road.

9.3 km north of the Goulburn River, the highway crosses the contact of the south-western lobe of the Strathbogie Batholith. Stop at the boulders on the north-west side of the highway 45.6 km north of the river where the highway first enters granite exposures 5 km south-west of Euroa.

Stop 1-2: Strathbogie granite (Euroa 682294; map 3) sample CV142

This is typical of the more mafic parts of the Strathbogie granite. It is a coarse-grained granite with some K-feldspar crystals up to 20 mm long and buff-coloured quartz up to 5 mm in longest dimension. K-feldspars are grey to white in colour. Biotite crystals, some with good shapes, have the characteristic red-brown colour of a reduced granite. Cordierites are prominent but are altered to a dull dark grey colour, in contrast to the biotites. Rare garnets, surrounded by altered cordierite, are present. There are some patches of biotite + quartz (? altered orthopyroxene). Sheaves of black tourmaline are present.

Petrographic description: Plagioclase crystals have more-or-less rectangular cross-sections that are mostly zoned from An_{35} to An_{20} with much superimposed oscillatory zoning. K-feldspar is microperthitic and is interstitial or includes other minerals. Biotite (α = pale yellow, $\beta = \gamma$ = red-brown) appears as crystals mostly 1-2 mm across with few crystal faces. A few crystals are altered to pale green chlorite with rare strips of fluorite and rare low birefringent moderately high relief purple-pink pleochroic material that may be an epidote group mineral. Cordierite crystals are rectangular in shape and up to 20 mm across in hand-sample but commonly seen down to about 1 mm in thin-section. All cordierites seen in the thin-section examined are pinite or sericitic mica pseudomorphs (some large muscovite flakes are seen in the larger peudomorphs), rarely with an irregularly-shaped core of garnet. Opaque minerals are relatively common as rods and hexagonal cross-sections occur mainly in biotite and these appear to be ilmenite. Apatite prisms are up to about 0.8 mm in length. Zircon crystals are common in biotite but recognizable monazites are rare.

Chemistry: While this represents the more mafic compositions in the Strathbogie Batholith, it is more felsic than the Bulla Granodiorite CV108 of the previous stop. Again, it is strongly corundum-normative (2.44%).

Isotopic composition: Gray (1990) reported an initial $^{87}Sr/^{86}Sr$ ratio of 0.7115 for the Strathbogie granite.

Continue on the Hume Highway to Euroa. Turn right on the Strathbogie road, 250 m beyond the bridge in Euroa (before completion of the freeway bypass). Outcrops on the hills to the east seen for the next few kilometers are Violet Town Volcanics. These are intruded by the granite and the contact lies 8 km from the highway.

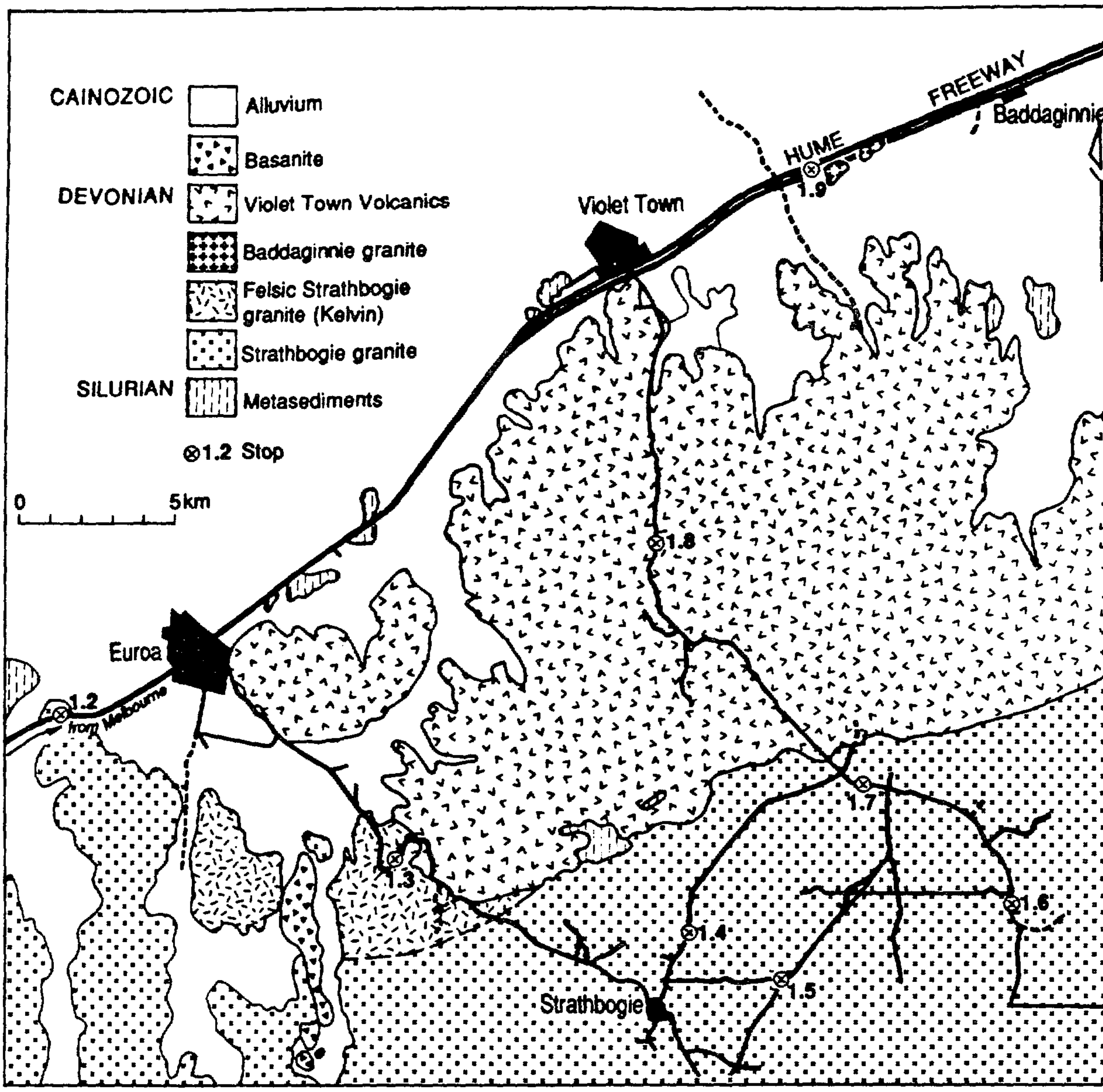


Figure 3. Map showing part of the Strathbogie Batholith east of Euroa, modified from White (1954)

Stop 1-3: Felsic Strathbogie granite of Kelvin View (Euroa 787246; map 3) sample CV114

This is the most felsic intrusion studied from the Strathbogie Batholith and this and the sample CV142 of the previous stop encompass almost all of the compositional variation within that complex. Large crystals of well-shaped cordierite up to 20 mm in length, as well as quartz, feldspar and biotite are set in a fine-grained aplitic matrix of the same minerals. There are irregular patches and rosettes of tourmaline 10 mm across. At the southern end of the outcrop the rock is slightly coarser grained. Notice the grey colour of the feldspars and the red-brown colour of the biotites, again indicating that the rock is reduced. Kelvin View is a small felsic intrusion on the northern margin of the batholith.

Petrographic description: In thin-section the bulk of the rock is seen to consist of perthitic orthoclase that may be graphically intergrown with quartz and plagioclase (mostly An_{25}-An_{20}), all of which have irregular shapes. The scattered ferromagnesian minerals are ragged biotites (α = pale yellow, $\beta = \gamma$ = red-brown), altered cordierites, and muscovite which appears as a replacement product of cordierite. Muscovite occurs as isolated ragged flakes, and as veinlets and optically continuous patches within some K-feldspar crystals. There are a few, apparently late, andalusite crystals (0.03 mm), also partly replaced by muscovite. It is suggested that all the muscovite in the rock is sub-solidus. Zircon, monazite, apatites and a few opaque minerals are accessory. The rock is from a near-surface intrusion, as seen in the field by the association with volcanic rocks, by the pressure-quenched porphyritic fabric, and the graphic intergrowths seen in thin-section.

Chemistry: This is very felsic and slightly fractionated. The high Rb (326 ppm) and low Sr and Ba (17.5 and 64 ppm) show, that there has been some feldspar fractionation involved in the production of this rock composition.

Continue 13 km to Strathbogie town and turn north immediately after crossing Spring Creek. The next stop is a granite pavement on the western side of the road 2.5 km from this turn-off.

Stop 1-4: Pressure-quenched Strathbogie granite (Euroa 881224; map 3) sample CV125

This is another felsic phase of the Strathbogie Batholith, consisting of crystals of buff to smoky quartz and large feldspars up to 20 mm long, cordierite and biotite, in a fine-grained matrix. This is a typical pressure-quenched rock.

Petrographic description: The porphyritic fabric of this rock is considered to have been produced by pressure quenching (Phillips *et al.*, 1981); there are large crystals of all the common granite minerals, quartz crystals commonly 10 mm across, K-feldspar up to 20 mm and plagioclase crystals up to 10 mm, as well as large cordierite and biotite crystals in a matrix of the same minerals having a much smaller grain size (averaging about 0.4 mm). The K-feldspar is perthitic orthoclase, which in this rock is more than twice as abundant as plagioclase. The large crystals of plagioclase mostly show normal zoning with a range in composition from An_{45} to An_{20} and that in the matrix is in the composition range An_{25} to An_{20}. Quartz is less abundant than that in more mafic cordierite-bearing granites such as those of the Bullenbalong Suite. Cordierite is variously altered, with some being replaced completely by an aggregate of greenish biotite and muscovite and some being pseudomorphed by both micas and pinite. Both the large cordierites and those in the matrix may occur as perfectly-shaped crystals. A few isolated muscovite flakes also occur throughout the matrix and are considered secondary. Biotite (α = pale yellow, $\beta = \gamma$ = red-brown) appears as ragged crystals commonly including tiny zircons and monazites around which are prominent pleochroic haloes. Apatites are relatively large stumpy prisms up to 0.5 mm long, whereas rare opaque minerals pyrrhotite and ilmenite are small and are also commonly included in biotite.

Chemistry: This rock is high in SiO_2 (75.3%) and has experienced a small degree of feldspar fractionation (Rb = 299 ppm; Sr = 31.0 ppm; Ba = 115 ppm). The very low (0.08%) Fe^{3+} content of this rock is typical of S-type granites of the Melbourne Basement Terrane and differs from all others in the LFB; f_{O_2} is about 2 log units below QFM (Phillips *et al.*, 1981), an exceptionally low value.

At the present time (1991) the most direct route to the next locality is closed to traffic. Return to Strathbogie and follow the road through the township, crossing the small bridge after 900 m, past Aberdeen, and continue as the road goes left to the Tame's road intersection. Continue across that intersection for 1.8 km and then turn left on the road to Violet Town. Stop at the boulders on the left side of the road.

Stop 1-5: Garnet-bearing Strathbogie granite (Euroa 913211; map 3) sample CV126

This contains large crystals of K-feldspar commonly 50 mm across in which zoning may be seen, consistent with the high Ba content of the rock (700 ppm). Also present are crystals of rounded buff-coloured quartz, 10 mm across, inconspicuous plagioclase, prismatic cordierite up to 10 mm in longest dimension and sometimes with perfect shapes and generally altered to dull black aggregates. Biotites up to 5 mm across have hexagonal shapes and foxy red-brown colour in thin flakes. Garnets are common in this rock and they are always surrounded by altered cordierite. There are a few microgranular inclusions up to 200 mm across; some finer-grained types have hydration rims, whereas the coarser varieties with a grain size of 0.5 to 1 mm have no rims.

Petrographic description: This rock is similar to CV142 (Stop 1-2) but is coarser grained. In thin-section a few unaltered cordierite cores are seen to have remained within some of the pinite aggregates. Some of the foxy red-brown biotites are well-shaped and up to 5 mm across. There are a few rosettes of muscovite and patches of blue tourmaline, both of which are either isolated or associated with altered cordierite. Stumpy apatites, zircons and rare monazites are accessory minerals.

Chemistry: This is very similar in composition to the first occurrence of Strathbogie granite CV142 at Stop 1-2, except for a somewhat higher Rb content, and is typical of the more mafic rocks of this complex.

Continue along the Violet Town road to the Watkins Road intersection, and then turn sharp right along that road for 5.5 km to a T-junction and then to the right for 200 m to the granite exposure on the west side of the road.

Stop 1-6: Strathbogie granite (Euroa 985238; map 3) sample CV115

This is the rock studied experimentally by Clemens & Wall (1981). Some very large K-feldspars up to 30 mm across and smaller phenocrysts of buff-coloured quartz and good cordierites, mostly altered, and some biotites up to 5 mm across are seen in hand-samples. Rare garnet up to 10 mm across is surrounded by cordierite that is mainly altered.

Petrographic description: The large crystals listed above are set in a matrix consisting mostly of quartz, K-feldspar, plagioclase and lesser biotite and altered cordierite with a grain size mostly around 0.2 mm. There is a weak development of graphic intergrowths around some of the large K-feldspars. This porphyritic fabric is typical of that produced by pressure-quenching with large crystals of all the common granite minerals in a matrix of the same minerals with a much smaller grain size (Phillips *et al.* 1981). The K-feldspar is perthitic orthoclase which, in this rock, is more than twice as abundant as plagioclase. The large crystals of plagioclase mostly show normal zoning with a range in composition from An_{45} to An_{20} while that in the matrix is in the range An_{25} to An_{20}. Quartz is less abundant than that in more mafic cordierite-bearing granites such as those of the Bullenbalong Suite of the Kosciusko Batholith. Cordierite is variously altered. Some is replaced completely by an aggregate of greenish biotite and muscovite, some is mostly pseudomorphed by micas but has pinite cores, and yet other crystals are fresh except that the crystals are surrounded by and traversed by veinlets of pinite. Some cordierite pseudomorphs near 0.5 mm in diameter appear in the matrix. A few isolated muscovite flakes of about the same size also occur throughout the matrix and are considered to be secondary. Biotite (α = pale yellow, $\beta = \gamma$ = foxy red-brown) appears as ragged crystals commonly replaced, or partly replaced, by chlorite. Tiny zircons and (?) monazites occuring as inclusions in the biotite are surrounded by prominent pleochroic haloes. Apatites are relatively large stumpy prisms up to 0.5 mm long, whereas rare opaque minerals, pyrrhotite and ilmenite, are small crystals and commonly included in biotite. Tourmaline has a patchy distribution and it is pleochroic in shades of brown or blue.

Chemistry: This rock is is relatively high in SiO_2 (73.65%) but not fractionated and it is probably close to a felsic S-type melt in composition. However, its petrographic features suggest that it might have contained a small amount of restite.

Follow the road to Boho. Examine the outcop on the south side of road 800 m after crossing the junction of Chapmans and Seimes roads.

Stop 1-7: Strathbogie granite with fresh cordierite (Euroa 937275; map 3) sample CV116

This is a moderately felsic porphyritic Strathbogie granite, notable because many of the large prisms of cordierite up to 15 mm long are remarkably unaltered and have the characteristic cordierite pale blue colour in hand-sample. This rock is similar to CV125 in that it is felsic and porphyritic with large crystals of K-feldspar (up to 20 mm), buff coloured quartz (10 mm), plagioclase (up to 10 mm), biotite and cordierite in a fine-grained matrix of the same minerals that average only about 0.3 mm across.

Petrographic description: In thin-section some of the large K-feldspars have an outer zone rich in small blebs of quartz some of which are in optical continuity and which look a little like granophyric intergrowths. Many of the smaller cordierite crystals seen in thin-section are also unaltered.

Chemistry: This is slightly more felsic than sample CV115 at the previous stop, and again it is unfractionated. It is probably very close to a primary melt composition, both restite-free and unfractionated, and certainly closer to that situation than any other rock examined from the Strathbogie Batholith on this excursion. In that context, note the normative C content of 2.17%.

Continue along the road towards Violet Town past Boho hall and Boho South where the granite contact is crossed and outcrops of Violet Town Volcanics are encountered. Turn north on the main Strathbogie to Violet Town road to an exposure of Violet Town Volcanics on the west side of the road 5 km north of this junction.

Stop 1-8: Violet Town Volcanics (Euroa 870348; map 3) sample CV218

In hand-sample, this volcanic rock is dark grey and even-grained. Crystals of garnet, some as large as 5 to 10 mm across, may be found in hand-samples.

Petrographic description: There are large crystals, mostly 0.5 to 2 mm across, of quartz, plagioclase, biotite, orthopyroxene, cordierite and garnet, set in a fine-grained matrix consisting dominantly of small but more-or-less equigranular grains of quartz and alkali feldspar about 0.03 mm in diameter. Scattered small crystals of biotite are easily recognized in the matrix, but it is impossible to identify cordierite and there appears to be no matrix orthopyroxene. The large plagioclase crystals may be surrounded by alkali feldspar sieved with matrix-sized quartz grains, and large quartz grains may be surrounded by a rim of quartz sieved with matrix-sized alkali feldspar. Quartz, which dominates the phenocryst assemblage, may be in crystals 5 mm across; it is mostly irregular or angular in shape, although rarely there are crude hexagonal shapes. Embayments indicative of resorption are present on some quartz crystals. Plagioclase crystals display many faces, but many crystals have clearly been broken, as indicated by irregular boundaries on part of a perfect crystal, or by the abrupt termination of zones present within some crystals. Although oscillatory zoning is seen on some sections of plagioclase, that mineral appears to be mostly uniform with a composition near An_{50}-An_{55}. Biotite (α = pale yellow, $\beta = \gamma$ = red-brown) is irregular in shape. Most of the larger biotite crystals have a paler-coloured outer zone that is crowded with tiny grains of opaque mineral. The orthopyroxene crystals are irregular in shape and commonly show evidence of partial replacement by biotite. Cordierite is remarkably unaltered and hence it is very difficult to distinguish it from quartz, except for the presence of tiny veinlets or cracks, particularly around the grain boundaries, in which the normal colourless cordierite shows a slight greenish discolouration; rare cordierite crystals contain tufts of sillimanite needles. The garnets seen in thin-section are small (about 1 mm) and irregularly-shaped; they are always surrounded by unaltered cordierite in which there is an intergrowth of wormy orthopyroxenes. Some accessory apatites, zircons, and opaque minerals are distinctly larger (up to 0.3 mm) than the matrix grains. At least some of the opaque mineral grains have the hexagonal shape of ilmenite. Monazite is an accessory mineral.

The broken crystals are the only evidence for this rock being an ash-flow. There are no relict shards and the matrix appears to have been recrystallized, perhaps as a result of metamorphism by the Strathbogie granite. The mineral assemblage, except for orthopyroxene, is like that of the Strathbogie granite; in the latter the orthopyroxene has reacted to form biotite.

Isotopic composition: An initial $^{87}Sr/^{86}Sr$ ratio of 0.7084 has been reported for the Violet Town Volcanics (Gray, 1990). This is significantly lower than the corresponding figure for the Strathbogie granite of 0.7115 referred to earlier, a surprising observation in view of the close association in the field and the petrographic and chemical similarities between the volcanic and plutonic rocks.

Outcrops of similar volcanic rocks may be seen beside the road until the Hume Freeway is reached at Violet Town. Travel to the north-east along that freeway for 6.9 km to Stony Creek and examine garnet-bearing granite in the banks of the creek between the freeway and the railway, alongside the large red gum tree. This material was dumped from an isolated outcrop in the nearby cutting in the south-bound lane of the freeway, that was completely used in road construction.

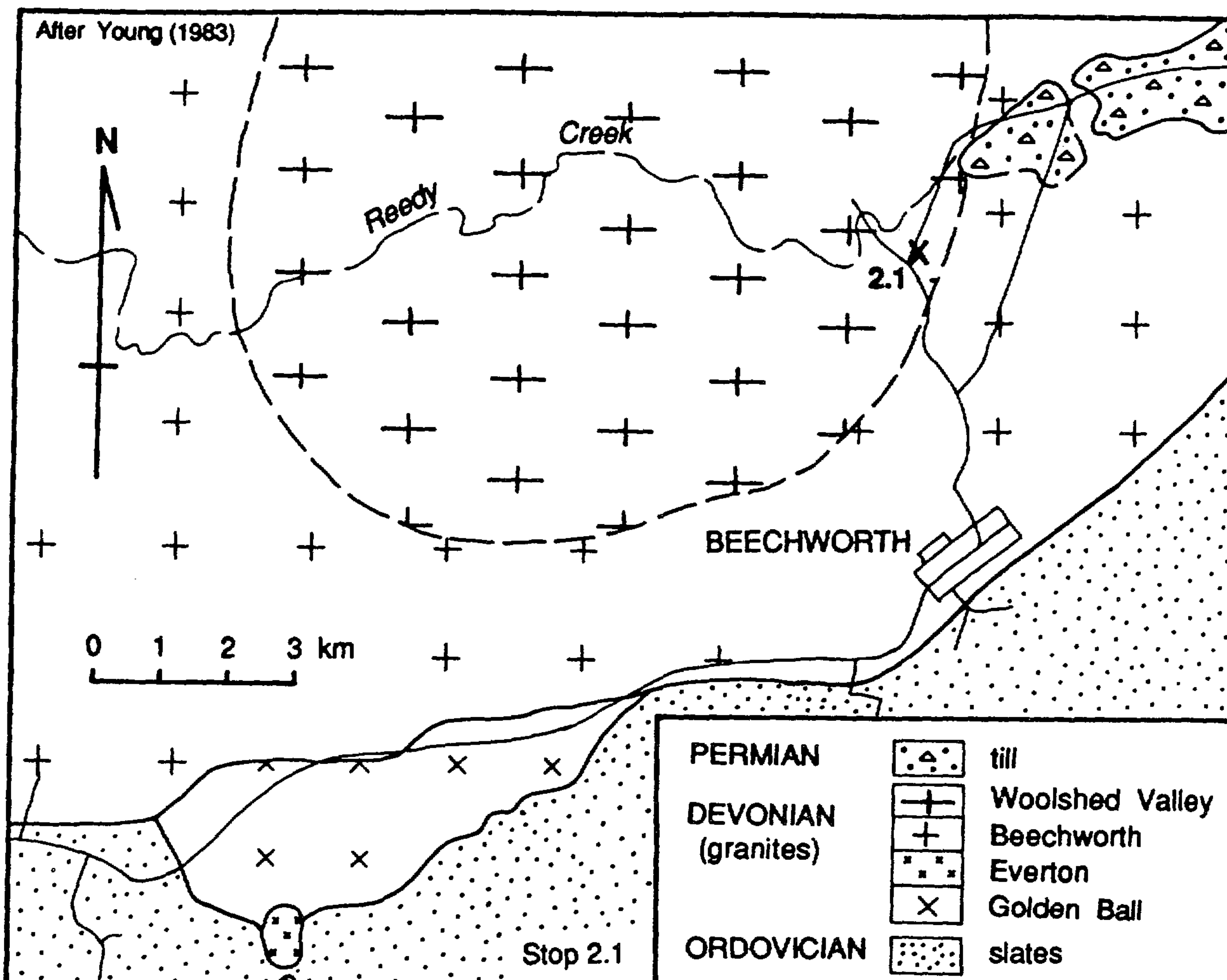
Stop 1-9: Badaginnie granite with garnet (Euroa 919471; map 3) sample CV143

Large crystals of garnet up to 10 mm in diameter, K-feldspar, smaller plagioclases, quartz and cordierite occur in a fine-grained matrix. Inclusions of hornfels, microgranular inclusions and lumps of quartz are fairly common. This intrusion is separated from, and more mafic than, any rocks of the Strathbogie Batholith.

Petrographic description: This is a very porphyritic rock in which there are large crystals in a fine--grained matrix consisting mainly of a graphic intergrowth of quartz and alkali feldspar. The large crystals are well-shaped albitized plagioclases up to 4 mm across, rounded quartz up to 5 mm, partly embayed and with no undulose extinction, and red-brown biotite in the rare unaltered grains included in quartz, but otherwise as pale green chlorite pseudomorphs with much secondary sphene and calcite. Crystals of garnet are up to 4 mm across and some have partial rims of green chlorite and sericite patches that may have been cordierite. Aggregates, mostly of fine sericite but rarely with larger muscovite flakes and rarely showing crude rectangular cross-sections, are thought to have been cordierites. There are some large (0.4 mm) prisms of zircon, and apatite appears as stumpy prisms. There are scattered large (3 mm) lumps of secondary calcite and many small calcite grains occur throughout the plagioclase. Some aggregates of green phyllosilicate may have been original orthopyroxene grains.

Chemistry: This is an altered rock, with high H_2O and a high Fe_2O_3 for granites of this basement terrane. It is also the most mafic composition that has been examined so far on this excursion. It has typical Y and Ce abundances relative to shaley rocks (35 ppm and 76 ppm). It is therefore unlikely that it is a cumulate rock since such a rock containing garnet would have a high Y:Ce ratio (such cumulate rocks do have high Y:Ce ratios elsewhere in the LFB). It is probably close to the original source-rock composition of the Strathbogie granites and the associated volcanic rocks, allowing for the fact that it is relatively altered and may have therefore undergone some open-system chemical changes.

Continue along the Hume Highway. After 10 km, near the exit to Warrenbane, a good view of the Violet Town Volcanics may be seen to the south-east. Further on at Glenrowan, the road passes through the low hills at the southern end of the Warby Range consisting mostly of felsic I-type granites and here we cross out of the Melbourne Basement Terrane. Glenrowan was the site of the bushranger Ned Kelly's last stand. At the Myrtleford-Bright exit, 6 km beyond Glenrowan, turn right onto the Snow Road. The mountain in the distance, snow-covered in winter, is Feathertop. Take this road 17 km to Milawa and end the day sampling Brown Bros wines. Continue to Beechworth.



Map 4. Figure showing the location of the Woolshed Valley granite north of Beechworth

DAY 2: GRANITES OF THE WAGGA AND MARAGLE BATHOLITHS

During the second day of the excursion visits an I-type granite of the Central Victoria Granites near Beechworth, and then examines a variety of S-type and I-type granites in the Wagga and Maragle Batholiths of the Wagga Basement Terrane (see pp 11-13 for a discussion of this area). Analyses of rocks from this area are given in Table 7.

From the Beechworth Post Office follow the Wadonga road through the town noting the outcrops of granite as well as the houses and gaol built of granite. Take the Chiltern road turn off after 2.9 km. After a further 2.5 km, turn right and examine the outcrops on the right-hand side of the road 200 m north of this junction (Map 4).

Stop 2-1: Woolshed Valley granite (Albury 712807; map 4) sample CV224

This is a central intrusion within the Beechworth granite complex. On average it is coarse-grained but it has distinct phenocrysts of white K-feldspar up to 30 mm across, lesser epidotized greenish plagioclases commonly 20 mm across, prominent smoky quartz (5-10 mm) and fairly ragged red-brown biotites (5 mm) indicative of a reduced rock. These are all set within a fine-grained matrix. There are no inclusions.

Petrographic description: This is a felsic porphyritic rock in which there are large (up to 30 mm long) crystals of white K-feldspar seen to be perthitic in thin-section, lesser partly altered plagioclases with a composition mostly in the range An_{25}-An_{20} (up to 20 mm), smoky quartz (5-10 mm) and a few ragged red-brown biotites in a fine-grained matrix of the same minerals having a grain size mostly in the range 0.5 mm to 0.1 mm. There is a suggestion of graphic intergrowths of quartz and feldspar around some of the large crystals. Some patches of muscovite occur in sheaves or as isolated flakes. In thin-section most of the biotites (α = pale brownish yellow, $\beta = \gamma$ = foxy red-brown) are seen to be altered to a pale greyish green chlorite accompanied by chunks of fluorite. Ilmenite and irregularly-shaped patches of what appears to be secondary monazite. A few isolated tiny crystals have the shapes of monazite. Some biotites appear to be recrystallized to a green brown variety and in these there are tiny peudohexagonal crystals. Also within the altered biotite are strips of what could be chlorite or an epidote, which is pleochroic from brownish red to a very pale bluish or greenish tint. Zircon and apatite are both very rare accessory minerals.

Chemistry: This is a rather felsic granite (73.9% SiO_2), probably very close to an unfractionated minimum-temperature melt composition (Rb = 267 ppm; Sr = 93 ppm; Ba = 405 ppm). It is slightly corundum-normative (1.36%) at about the upper limit for an unaltered I-type granite.

Isotopic composition: Gray (1990) reports an initial $^{87}Sr/^{86}Sr$ ratio of 0.7060 for this unit.

Continue on this minor road (Reids Way) through outcrops of Beechworth granite and some coarse gravels that are thought by some to be Permian glacial deposits, to join the main Beechworth-Wadonga road (3.7 km). Turn left and just before the junction with the Yackandandah road the Saw Pit Gully Fault is crossed and the road enters the Wagga Basement Terrane. From here the Wadonga road passes through Ordovician schists and gneisses, with the latter commonly grading into parautochthonus granites. At Boyds Road, 12.6 km from the Yackandandah intersection, turn right to take a short-cut to the Kiewa Valley Highway (6.2 km) and there turn left to the Murray Valley Highway (2.6 km). Turn right to Bonegilla (7.9 km) and then left taking the road through the Red Gum forest below the Hume Weir. Turn on to the Albury road and then right after 200 m and travel 1 km to the Hume Weir quarry.

Stop 2-2: Bethanga granite (Tallangatta 040057; map 5) sample VB213
Hawksview granite (Tallangatta 040057; map 5) sample VB90

The Bethanga granite, or gneiss as it has previously been called, is a coarse-grained heterogeneous rock that is in part gneissic with the foliation being near horizontal in places. There are fairly well-shaped crystals of K-feldspar (commonly 5 mm) and plagioclase, common red-brown biotite and cordierite and scattered garnets up to 35 mm. Some of the Bethanga unit is homogeneous and has a fabric like that of a typical granite. It has inclusions of calc-silicate rock and it is thought

TABLE 7. CHEMICAL ANALYSES: WAGGA AND MARAGLE BATHOLITHS

	CV224	VB90	VB213	VB220	VB140	VB230	CB134	CB126	CB138
Stop	2-1	2-2	2-2	2-3	2-4	2-5	2-6	2-7	2-8
SiO_2	73.93	70.31	68.06	67.34	72.48	76.73	76.74	69.55	75.50
TiO_2	0.21	0.45	0.76	0.95	0.25	0.08	0.04	0.53	0.08
Al_2O_3	13.47	14.91	14.50	15.14	14.50	12.44	12.65	14.49	12.96
Fe_2O_3	0.19	0.29	0.57	0.38	0.29	0.37	0.18	0.55	0.67
FeO	1.31	2.12	3.72	5.49	1.33	0.47	0.64	3.01	0.63
MnO	0.04	0.04	0.04	0.06	0.03	0.04	0.03	0.05	0.07
MgO	0.30	0.86	1.75	2.49	0.47	0.22	0.03	1.56	0.09
CaO	0.98	2.09	1.80	0.79	0.66	0.45	0.40	1.47	0.69
Na_2O	3.22	3.08	1.79	1.15	2.80	3.46	3.86	2.07	4.13
K_2O	4.87	4.38	4.20	3.53	5.20	4.78	4.65	4.30	4.13
P_2O_5	0.10	0.22	0.30	0.12	0.33	0.02	<0.01	0.17	0.01
H_2O+	0.70	0.90	1.11	1.68	1.03	0.52	0.73	1.65	0.43
H_2O-	0.17	0.13	0.20	0.27	0.16	0.17	0.14	0.24	0.14
CO_2	0.23	0.16	0.34	0.02	0.16	0.05	0.20	0.12	0.14
total	99.72	99.94	99.14	99.41	99.69	99.80	100.29	99.76	99.67
Trace elements (ppm)									
Rb	267	215	185	202	419	367	364	215	191
Sr	93	284	155	126	65	24.0	5.0	143	62
Ba	405	560	645	620	220	56	6	530	545
Zr	127	175	239	264	99	79	72	178	163
Nb	11.5	19.0	16.5	20.0	20.0	27.0	25.5	13.0	20.5
Y	40	17	18	30	14	72	79	24	47
Ce	61	72	92	92	45	38	44	70	88
Sc	6	6	8	19	4	<1	12	12	8
V	12	36	61	107	15	3	<1	59	1
Cr	3	5	41	81	10	<1	<1	40	<1
Ni	<1	4	20	38	4	<1	<1	17	<1
Zn	39	56	104	117	77	14	32	67	38
Ga	18.4	19.0	20.2	21.6	20.0	14.8	18.4	18.0	16.2
Pb	28	29	34	24	36	42	104	32	21
Th	19	19	26	28	14	32	30	21	19
U	9.8	6.0	2.2	4.2	10.8	15.2	13.4	4.2	3.2
Norm. C	1.36	1.83	4.45	8.28	3.85	0.80	0.54	4.16	0.47

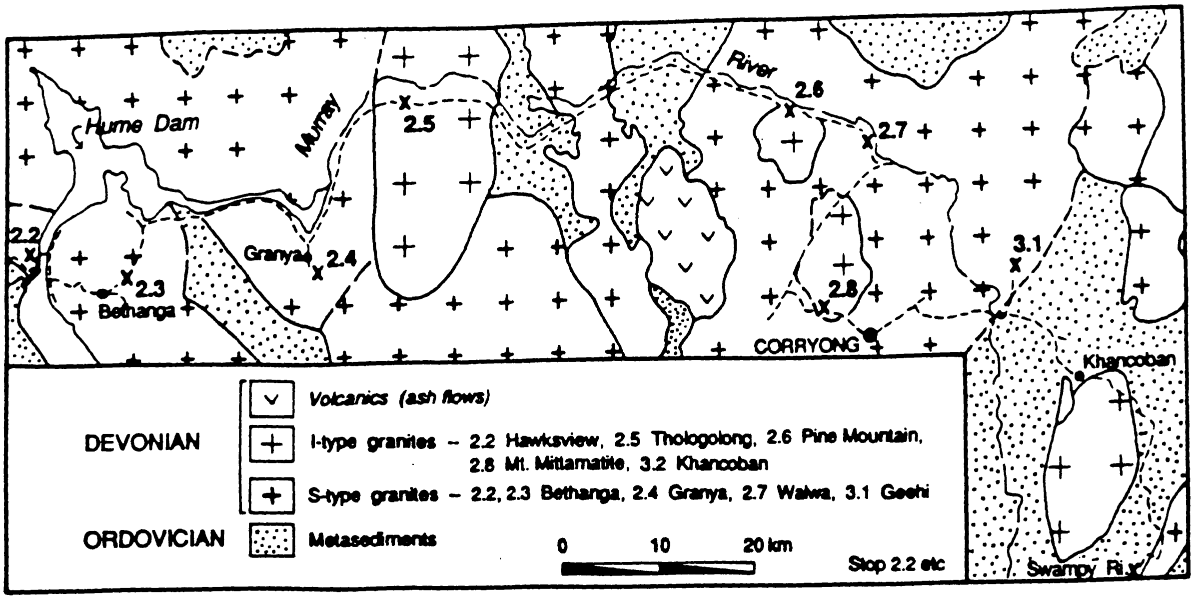


Figure 5. Geological sketch map of the Murray Valley from the Hume Weir to the Swampy River

to be parautochthonous.

In the upper level of the quarry the fine-grained grey Hawksview granite is seen to intrude the Bethanga granite, there being dykes of Hawksview in the Bethanga granite and inclusions of the latter within the Hawksview granite. Pegmatite dykes 0.5 m wide with muscovite and biotite intrude the Hawksview granite.

Petrographic description of the Bethanga granite: This is a medium-grained rock with a distinct foliation in parts. In thin-section this foliation is seen to result from bands only a few mm wide that are richer in biotite. Cordierite is abundant mostly as crystals 1-2 mm across commonly with good rectangular cross sections in both the biotite-rich areas and in the areas rich in quartz and feldspar. The cordierite is unaltered in places but much of it is pinitized and more rarely the outer parts are an aggregate of muscovite and chlorite. There are also a few somewhat skeletal muscovites scattered through the rock outside these cordierite alteration areas. Some relatively large sillimanite prisms (0.6 mm in cross-section) occur in some of the cordierite crystals. Quartz occurs as crystals up to about 5 mm across with undulose extinction, but some are aggregates of several crystals with triple junctions, particularly when they are that large. K-feldspar, with some well-shaped crystals up to 5 mm across, has no microcline twinning and appears free of perthitic intergrowths. It contains rounded inclusions of quartz and lesser plagioclase and small biotite crystals, some of which have good crystal shapes. Plagioclase occurs as crystals with irregular boundaries with remarkably little zoning. The composition is near An_{35}. Biotite (α = pale yellow-brown, $\beta = \gamma$ = foxy red-brown) is abundant, but patchy in distribution, and does not show any well-defined crystal shapes. Zircons with a rounded shape are common and easily seen when enclosed in the biotites because of the prominent dark pleochroic halos. Stumpy apatites 0.5 mm across, and opaque minerals, some of which are rod-shaped indicative of ilmenite, are accessory minerals.

Chemistry of the Bethanga granite: This is a fairly mafic S-type granite with the typical chemical features both of S-type granites of the LFB and specifically of the Cooma Supersuite. Thus, it has a low Fe^{3+}:Fe^{2+} ratio, but not as low as found in the Melbourne Basement Terrane, and low Na_2O and CaO. The latter two data are consistent with an origin from clay-rich sediments, and this rock is thought to have been derived by partial-melting of Ordovician sediments. It is extremely corundum-normative for a granite (4.45%).

Petrographic description of the Hawksview granite: This is grey and fine-grained with most grains ranging from 0.1 to 1 mm across. The largest areas of quartz are commonly aggregates of several crystals with triple junctions. Plagioclase typically appears as elongate rectangular cross-sections distinctly zoned from about An_{30} to An_{20} but with many oscillatory zones. K-feldspar is inconspicuous with only a trace of perthitic exsolution and feeble or no micocline twinning. Biotite (α = straw yellow, $\beta = \gamma$ = red-brown) is very ragged and rarely exceeds 1 mm in maximum dimension. There are clots of biotite about 3 mm across, and these are the normal red-brown variety. Biotite is altered in part to a fairly bright green chlorite with accompanying epidote lumps and strips, and occasional rutile needles arranged in a hexagonal pattern. Muscovite appears as flakes about the size of the biotites and could have crystallized at or above the solidus. Apatite occurs as slender prisms up to about 0.3 mm long and there are small opaque rods, lumps, and hexagonal-shaped plates, in the biotite. Small zircons are prominent as elongate prisms and there appear to be a few small monazites. In the thin-section examined, there is one aggregate of bright green chlorite and muscovite but this does not look like a cordierite pseudomorph.

Isotopic compositions: Gray (1990) reports an initial $^{87}Sr/^{86}Sr$ ratio of 0.7188 for the Bethanga granite and 0.7097 for the Hawksview granite.

Continue on the road across the Bethanga Bridge and then turn right through Bellbridge. At 4 km from the quarry there is a road junction near which there is a boulder of Bethanga granite, in which gradations can be seen from massive to foliated texture (VB221 at Tallangatta 048037). This rock has the same mineral assemblage and appearance as VB213 (Stop 2-2) but most of the cordierite is altered. Continue on the Bethanga Road to the Bethanga Hotel (6.2 km) and turn left on the Tallangatta Road and then left again after 200 m on the road to Talgarno. At 2.8 km from Bethanga, stop at the large boulder on the right hand side of the road just before the cutting.

Stop 2-3: Gneissic Bethanga granite (Tallangatta 108029; map 5) sample VB220

This is a more mafic rock with a prominent gneissic fabric and abundant large cordierite aggregates (50 mm across). There are some large K-feldspar crystals up to 20 mm in diameter and no garnet has been seen at this outcrop. The more mafic character of this rock meant that it was less "fertile" in terms of producing a granitic melt. In one place, the surmicaceous aggregates of biotite (commonly 20 mm long) are disoriented showing that magmatic mobilization occurred locally. This rock formed from a migma rather than a magma (White & Chappell, 1990).

Petrographic description: In the field this is seen to be a heterogenous cordierite-rich rock in which cordierite aggregates are up to 50 mm across. There are also large K-feldspars 20 mm across. Within the more even-grained parts, there are schistose aggregates of biotite similar to surmicaceous inclusions (enclaves) commonly 20 mm long and with a random orientation. Sillimanite can be seen in these biotite aggregates with a hand lens. A thin-section was cut to include two elongate wispy biotite aggregates varying from 1 mm to 10 mm across. In thin-section the aggregates are seen to consist of thin bands of oriented biotite alternating with strips of aligned sillimanite needles, the alignment being parallel to the long axis of the aggregates. The bands of biotite and sillimanite have kink folds across them but the biotites within the apices of the folds have recrystallized. Between the biotite-sillimanite bands of this thin-section, the dominant mineral is K-feldspar that is partly sericitized around the edges. K-feldspar grains are up to 5 mm across and have no microcline twinning nor visible perthite. There is lesser quartz that is smaller and sometimes seen to be rounded when included in the K-feldspar and a few scatterred irregularly-shaped biotites. Accessory minerals in this interband area are equidimensional chunks of apatite 1 mm across displaying no crystal faces, and a few opaque minerals. The even-grained material making up the bulk of the thin-section consists of quartz with small (1 mm) flakes of biotite and interstitial cordierite in optical continuity over distances of 10 mm. The cordierite has altered around the rims and along veinlets to tiny aggregates of mica with grains oriented at right-angles to the alteration surface. There are only a few more-or-less equidimensional plagioclase crystals in this even-grained area. The plagioclases have a composition near An_{25}. Zircons and small monazites (to judge from the shapes of some of the tiny crystals) are scattered throughout the rock but show up particularly in the biotites because of the very dark pleochroic haloes. The whole of this thin-section was apparently cut across an area that did not contain much, if any, melt phase.

Chemistry: This is more "extreme" in composition than sample VB213 at the previous stop. The high FeO and low CaO and Na_2O contents show that the protolith was rich in clay minerals and poor in feldspars. The "infertile" nature of the rock is confirmed by the very low Na_2O content (1.15%), so that even if all of that component were present in a melt, its Na_2O content of about 3 to 3.5% Na_2O would limit the amount of melt to about 40% of the total rock. This is consistent with the appearance of the rock in the field and its petrography. The normative C content of this rock is high at 8.28%, consistent with its mineralogy.

Continue to the Walwa Road (7.2 km) and turn right. At 19.4 km from the Walwa Road junction turn right on to the Murray Valley Highway; Granya township is 2.6 km along this road. 2.8 km beyond Granya, stop at the road cutting on the east side of the road (large vehicles continue a further 4.2 km to Granya Gap to turn around).

Stop 2-4: Granya granite (Tallangatta 288021; map 5) sample VB140

The Granya granite is closely related to the large Koetong granite body. It is a coarse and even-grained muscovite (two-mica) granite.

Petrographic description: The quartz in this rock is an aggregate of tiny polygonal grains, indicating deformation and recrystallization. K-feldspar occurs as grains up to about 5 mm across and has microcline twinning as well as the occasional Carlsbad twin. It commonly includes perfect little rectangular-shaped crystals of plagioclase. Most of the plagioclase has a composition near An_{20}, although there are a few completely sericitized cores that must have been more calcic. Biotite (α = pale yellow; $\beta = \gamma$ = red-brown) includes radioactive accessory phases around which there are very prominent pleochroic haloes. All of these inclusions are too small to be positively identified - a few may be monazite but most could be uraninite. No zircons were found. Muscovite generally occurs as large separate crystals 2 mm or more across but some are intergrown or butt against biotite; there are even a few symplectic intergrowths of biotite and muscovite. If muscovite is ever a primary mineral in granites then the texture of that mineral in this rock would support such an origin. Apatite occurs as large crystals up to 0.5 mm across. Large irregular crystals of tourmaline are relatively abundant and pleochroic in shades of brown. Sillimanite needles occur within quartz and K-feldspar and may appear as aggregates or trains of needles elsewhere in the rock.

Chemistry: This rock is remarkably similar in composition to the average Cornubian granite. It is a moderately fractionated S-type granite with the major element composition dominated by quartz and alkali feldspar components. The high Rb and low Ba and Sr show that feldspar fractionation has occurred and this is probably also the cause of the high Ga content. The P_2O_5 content is higher than in any other S-type analyses in Tables 6 and 7, a result of the high solubility of P in peraluminous melts leading to a concentration of that component during fractionation. Likewise, normative C is high (3.85%) as a result of the fractionation of quartz and feldspars from an originally less strongly peraluminous melt. The fractionation of feldspar results in increased water activity in the melt phase, resulting in the stability of muscovite above the solidus.

Isotopic composition: The Granya granite is closely related to the Koetong granite in the field and in composition, and Gray (1990) reports an initial $^{87}Sr/^{86}Sr$ ratio of 0.7158 for the latter unit.

Return on the Murray Valley Highway and continue towards Walwa. At Koetong Creek 8.5 km from Granya, the tree covered hills seen to the south-east are the felsic Thologolong granite. At Stockyard Creek, 5 km beyond this point, the contact of that granite is crossed. Ahead is Mt Porcupine, a steep hill strewn with boulders of that granite. Stop at the Thologolong Quarry 200 m south of the road, 19 km from Koetong Creek.

Stop 2-5: Thologolong granite (Holbrook 410196; map 5) sample VB230

A very felsic medium- to coarse- and even-grained granite with pink K-feldspar and greenish--white plagioclase. The only mafic mineral is dark-brown biotite. Miarolitic cavities are common, containing crystals of quartz, K feldspar, fluorite, chlorite and stilbite (Price *et al.*, 1983), and there are sub-horizontal schliera outlined by concentrations of biotite.

Petrographic description: This is a felsic granite consisting of quartz up to 5 mm across, either as single crystals or aggregates (about the same size) consisting of several crystals with triple junctions, coarsely perthitic K-feldspar (5 mm) and smaller plagioclases having a prominent core around An_{15} and fairly rapid normal zoning to An_{10}. The few grains of biotite (α = pale yellow, $\beta = \gamma$ = green-brown) are badly altered to a dark greenish vermiculite with some cloudy rutile patches. Within one of the least altered biotites there are patches of cloudy rutile and grains of fluorite. Accessory zircon is seen within the biotites and altered biotites, but apatite is very scarce or absent.

Chemistry: This is a more felsic rock than is VB140 from the previous stop, and slightly more fractionated. A notable difference is the relatively very low P_2O_5 content in this rock (0.02% compared with 0.33%), which is ascribed to fractionation of a metaluminous to mildly peraluminous liquid in which the solubility of P was much lower than the more peraluminous S-type melt, so that P was removed by crystallization of phosphates. For that reason, this is regarded as a fractionated I-type granite, and this rock and VB140 illustrate the differences in composition between moderately fractionated I-type and S-type granite melts. The normative C content of 0.80% is also consistent with an I-type origin.

Continue east along the Murray Valley Highway. Outcrops seen a few km from the quarry are Ordovician Walwa Schists, which are the screen between the Koetong Suite of the Wagga Batholith, and the Maragle Batholith to the east. Walwa township is 36 km from the quarry. Beyond this are outcrops of Walwa granite of the Tom Groggin Suite and 6 km beyond Walwa the boulder-strewn hill seen to the east is the felsic Pine Mountain granite. Stop at the quarry on the south side of the road, 10.1 km from Walwa (the quarry is overgrown and hard to see and is 450 m after the house with a green roof).

Stop 2-6: Pine Mountain granite (Rosewood 767163; map 5) sample CB134

This is a very felsic medium-grained granite with scattered and sometimes perfectly-shaped biotite crystals, commonly chloritized. Miarolitic cavities seen in the field are tiny but the rock may be porous enough to have allowed the passage of late fluids to cause extensive alteration.

Petrographic description: This granite is very felsic. Quartz, K-feldspar, and lesser plagioclase are seen as irregularly-shaped crystals up to 4-5 mm in diameter and there is an abundance of fairly coarse graphic intergrowths between quartz and K-feldspar. The K-feldspar is finely perthitic and is all cloudy (brownish in thin-section). Plagioclase is also cloudy (greyish in thin-section) and has a composition of An_5. Scattered biotites (α = pale yellow, $\beta = \gamma$ = dark chocolate-brown), sometimes perfectly shaped and up to 5 mm across, are almost all completely altered to greyish green chlorite as well as some bright green (?) vemiculite and with strips and patches of fluorite and rarely muscovite. Biotites are only unaltered when included in K-feldspar. Rare isolated muscovite flakes occur throughout the rock. There are a few zircons within the altered biotites. Some limonite pseudomorphs within a small (3 mm across) biotite clot seen in the thin-section examined has the shape and interal stucture of fayalite. No apatite was found. The rock has been hydrothermally altered to produce albite and secondary phyllosilicates after biotite.

Chemistry: This is an extremely felsic rock, with very low abundances of Mg, Fe and the trace transition metals. Although the Rb content is similar to VB230 at the previous stop, it has much lower Sr and Ba contents (5.0 and 6 ppm), and is therefore more strongly fractionated. Again, it has very low P_2O_5 (<0.01%) and it is therefore thought to be a fractionated I-type granite, in keeping with its low normative C content of 0.54%, although the latter may have been affected to some extent by alteration.

Continue along the Murray Valley Highway for 7 km and stop at the picnic tables (Jim Newman Wayside Stop). Examine the outcrop of Walwa granite (Tom Groggin Suite) in the cutting across the road. This is on a dangerous corner, so **care should be taken**. Specimens may be collected from the boulders blasted from this outcrop and pushed down the embankment at the north side of the picnic tables.

Stop 2-7: Walwa granite (Corryong 817143; map 5) sample CB126

This is a moderately mafic fine- and even-grained S-type granite with only a few inclusions, including surmicaeous types, and including lumps of quartz.

Petrographic description: Quartz is abundant as large aggregates of crystals commonly 5 mm across, with undulose extinction. Rectangular cross-sections of plagioclase are mostly in the range 0.5 to 2 mm and are mainly around An_{35}-An_{40} with outer zones near An_{20} and smaller outermost zones of An_{15}. Extensively sericitized inner parts of some plagioclase crystals may represent more calcic cores. Optically continuous microcline-microperthite crystals are up to 5 mm across and include all other minerals. Biotite (α = pale yellow, $\beta = \gamma$ = foxy red-brown), is mostly ragged and 1 to 2 mm across and in some parts of the rock biotite is completely altered to a pale green chlorite. A few biotite crystals are crossed by kink bands. Cordierite, almost invariably altered to pinite or mica aggregates, is very conspicuous as irregularly-shaped crystals 3 mm across as well as many rectangular and hexagonal cross-sections 1 to 2 mm across. Muscovite appears as large flakes within some of the altered cordierites as well as irregularly-shaped crystals clearly seen in hand-sample. Unlike the muscovite seen in the Granya granite (Stop 2-4), this is clearly a reaction product of cordierite and is considered to be a subsolidus mineral. Accessory minerals include opaques, well-shaped apatites up to about 0.3 mm in length, and zircon and monazite crystals, both with very prominent haloes when included in biotite.

Chemistry: This rock has a composition typical of most of the moderately mafic S-type granites of the Kosciusko and Wagga Basement Terranes. The Na_2O content of around 2% (2.07% in this case) is a direct consequence of the derivation of these rocks from sedimentary rocks that were clay-rich, but not as extremely so as the source of the rocks of the Cooma Supersuite, referred to in discussing the Bethanga granite. Such a Na content is very typical of the more mafic members of the Koetong and Bullenbalong Supersuites of the Wagga and Kosciusko Basement Terranes. The high normative C content of 4.16% is a consequence of the low Na and Ca contents of this rock.

Continue along the Murray Valley Highway. Approaching Tintaldra there is a good view of Mt Mittamatite to the south, another rather felsic granite body. Near Tintaldra, 6.4 km from the previous stop, turn south on the Cudgewa road for 17.5 km to the Corryong turnoff on the left side. Follow this road for 5.4 km to boulders of granite on the south side of the road.

Stop 2-8: Mittamatite granite (Corryong 767968; map 5) sample CB138

This is a rather felsic, attractive, even and medium-grained granite that is pinkish to buff in colour. Small biotite crystals are ragged and black. There are no inclusions. It is the most felsic of four samples of Mittamatite granite that have been analyzed (range 74.65% to 75.50% SiO_2). There are no miarolitic cavities and quartz and epidote occur in joints. This is a felsic member of the I-type Boggy Plain Supersuite (Wyborn *et al.*, 1987).

Petrographic description: This is another felsic granite in the Upper Murray Valley consisting essentially of quartz, finely perthitic K-feldspar and plagioclase crystals mostly 1-3 mm across. Some of the quartz grains have embayments as if they have been resorbed but there are no graphic intergrowths. The plagioclases are more or less rectangular in cross-sections and have a composition near An_{10}, and there are some relict cores. The biotites (α = pale yellow, $\beta = \gamma$ = very dark chocolate-brown) are about 1 mm across and show no crystal faces. Most biotites are unaltered, but those that are have been replaced by bright green chlorite and rare strips of (?) sphene and fluorite. Opaque minerals appear to be mainly magnetite. Small zircons are fairly common accessories seen throughout the rock as well as in the biotites. There are a few stumpy prisms of apatite and there may be some yellow monazite crystals.

Chemistry: This rock has a composition typical of the felsic members of the Boggy Plain Supersuite of Wyborn *et al.* (1987). Note in particular that the high Ba that is characteristic of that supersuite is still evident in this very felsic composition. Its felsic I-type character is consistent with its low normative C content of 0.47%.

Isotopic composition: Gray (1990) reports an initial $^{87}Sr/^{86}Sr$ ratio of 0.7043 for this unit, which is consistent with it being an I-type granite that can be assigned to the Boggy Plain Supersuite.

Continue on the road to Corryong at 6.2 km for an overnight stay.

DAY 3: GRANITES OF THE MARAGLE AND KOSCIUSKO BATHOLITHS

On the third day, the excursion crosses the Main Divide between the Murray and the Snowy rivers. After stopping at a location in the Geehi Granodiorite of the Cooma Supersuite, it follows the Alpine Way through Dead Horse Gap across the faulted boundary between the Maragle and Kosciusko Batholiths. This boundary is also a major tectonic boundary between the Wagga and Kosciusko Basement Terranes. A variety of S-type and I-type granites of the Kosciusko Batholith are then examined in the Jindabyne region. Analyses of rocks in this area are shown in Table 8.

Take the Murray Valley Highway to Towong (10.9 km). Here, leave the highway and travel straight on across the Murray River into the Shire of Tumbarumba after 11.8 km. For a distance of 1.7 km the road crosses the flood plain of the Murray River which is famous for its billabongs, one of which is seen on the left immediately after crossing the river. At the junction of the Jingellic-Khancoban road (15.0 km), turn left and stop at the large boulders on the left hand side of the road 1.5 km from this intersection. (Large vehicles should continue on for another 550 metres to turn around on the grassy area covering an old gravel pit 50 m after the power line crosses the road).

Stop 3-1: Geehi Granodiorite (Kosciusko 920045; map 5) sample CB144

This is a mafic, medium-grained rock containing many small clots of biotite, with or without sillimanite and cordierite, with abundant inclusions. The latter include sillimanite-biotite-cordierite gneisses, surmicaceous types, and large (up to 200 mm) lumps of quartz. Some large feldspars ranging from 10 to 100 mm are also inclusions, and large feldspars are seen in some of the gneiss inclusions. Red-brown biotite is abundant and there are altered cordierites. Rarely, large crystals of garnet and blue unaltered cordierite may be found in hand-samples.

Petrographic description: In thin-section this rock is dominated by quartz, both as aggregates up to 5 mm across consisting of several crystals with triple junctions, and as individuals commonly with rounded outlines. Microperthitic K-feldspar, some crystals of which are optically continuous for more than 10 mm, are more conspicuous than plagioclase, the latter appearing as smaller crystals mostly 0.5 to 2 mm and rarely more than 3 mm in diameter. The plagioclase has a composition around An_{40} with outer zones around An_{20} and a few albitic rims when in contact with K-feldspar. Biotite (α = pale yellow, $\beta = \gamma$ = foxy red-brown), is mostly irregular in shape and about 0.5 to 1 mm across. Cordierite, most of which is only slightly altered, is almost as abundant as biotite and occurs as crystals 1 to 2 mm across. A few cordierite crystals have tufts of sillimanite in their inner parts. There is very little alteration of cordierite to pinite, but sometimes the crystals are replaced, or surrounded, by large (1-2 mm) flakes of muscovite and biotite in which the rare tufts of sillimanite appear to be preserved. More skeletal crystals of muscovite occur elsewhere in the rock. Accessory minerals include zircons that are conspicuous in the biotites as a result of the prominent pleochroic haloes (as they always are in S-type granites), chunky apatites and lumps of opaque mineral.

Chemistry: This is a fairly mafic S-type granite with the very low abundances of CaO and Na_2O that characterize the Cooma Supersuite. It contains comparable amounts of Mg and Fe to sample VB213 from the Hume Weir Quarry, but is more SiO_2-rich, and lower in CaO and Na_2O. As a consequence of the low contents of the last two elements, it is even more strongly corundum-normative than VB213 (6.29%).

Return towards the south-east along the Jingellic to Khancoban road past Bringenbrong, where a left turn is taken to Khancoban (10.4 km). As the town of Khancoban is entered (23.3 km), the road crosses the boundary of the Khancoban granite, a poorly exposed felsic I-type granite that occupies the the broad valley to the south of the town. It is surrounded by a hornfels ridge breached only at the town. Beyond Khancoban the road, now known as the Alpine Way, enters the Kosciusko National Park. Before reaching the Murray 1 Power Station, 8.7 km from Khancoban, the road enters and then leaves the Khancoban granite. At Scammels Lookout, 22.8 km from Khancoban, there is a pull-off area for photographs if required. Steep cuttings in this area are rotten granite thought to belong to the Tom Groggin Suite. The Swampy Plains River is crossed 32 km from Khancoban. Mt Townsend (2210 m) is seen to the east, 1760 m above Swampy Plain; this is the greatest relief anywhere in Australia. From Tom Groggin, 53 km from Khancoban, the road wanders up the range to Dead Horse Gap, through strips of granite across a series of faults which are the reactivated boundary between the Wagga and Kosciusko

TABLE 8. CHEMICAL ANALYSES: MARAGLE AND KOSCIUSKO BATHOLITHS

	CB144	KB32	KB22	KB12	KB2	KB4	KB65
Stop	3-1	3-3	3-4	3-6	3-7	3-8	3-8
SiO_2	70.76	67.68	62.29	68.94	66.71	60.56	55.37
TiO_2	0.60	0.64	0.54	0.59	0.41	0.56	0.64
Al_2O_3	14.08	14.70	16.46	14.11	15.76	17.25	15.80
Fe_2O_3	1.10	0.68	1.85	0.87	1.34	1.99	2.23
FeO	3.25	4.03	3.41	3.27	2.42	3.48	5.17
MnO	0.07	0.07	0.10	0.06	0.08	0.11	0.23
MgO	1.91	2.22	2.85	1.91	1.87	3.40	6.32
CaO	0.95	2.26	6.05	2.46	4.44	6.71	8.43
Na_2O	1.41	1.92	2.60	2.22	3.08	2.66	2.48
K_2O	3.72	3.60	2.01	3.53	2.09	1.55	1.31
P_2O_5	0.12	0.15	0.11	0.13	0.10	0.11	0.09
H_2O+		1.51	1.20	1.20	1.29	1.24	1.75
H_2O-		0.22	0.20	0.31	0.17	0.10	0.13
CO_2		0.12	0.10	0.14	0.06	0.06	0.09
total	97.97	99.80	99.77	99.74	99.82	99.78	100.04
Trace elements (ppm)							
Rb	181	183	89	170	90	62	48
Sr	117	139	254	128	190	254	215
Ba	505	475	355	460	325	275	170
Zr	220	187	112	194	107	85	52
Nb	13.5	13.0	6.5	10.5	6.5	5.0	5.5
Y	32	27	21	31	22	20	55
Ce	92	69	47	68	44	38	57
Sc	10.5	15	23	15	14	25	62
V	69	87	131	81	74	154	203
Cr	57	61	25	47	9	28	219
Ni	27	20	7	15	4	9	55
Zn	79	82	62	64	51	61	91
Ga	17.8	18.2	16.4	16.8	15.2	15.2	16.0
Pb	32	27	9	26	13	7	7
Th	20	19	9	19	11	7	6
U	5.2	4.0	1.4	3.8	2.0	1.4	1.6
Norm. C	6.29	3.89	-	2.48	0.60	-	-
Modes							
Quartz		34.5	25.2	35.1	28.7	22.3	
K-feldspar		7.7	3.0	9.7	4.6	0.4	
Plagioclase		27.7	49.9	33.8	51.3	52.3	
Biotite		26.7	14.7	19.0	14.6	16.0	
Hornblende			6.7		0.5	8.2	
Cord + Musc		3.4		1.9			
Opaques			0.4	0.4	0.3	0.7	
Sphene							
Apatite			0.1	0.1		0.1	

Basement Terranes. From Dead Horse Gap to Thredbo Village and beyond, the road follows the Crackenback Fault; the granite on each side of the fault is the mafic Mowambah granite of the Bullenbalong Suite in the Kosciusko Batholith. 13 km past Thredbo the road leaves the Crackenback Valley and 20 km from Thredbo it enters a broader valley occupied by the Pendergast Granodiorite of the I-type Jindabyne Suite. The high hills to north and south are Mowambah Granodiorite. At the junction of the Summit Road and the Alpine Way turn right to Jindabyne (136 km from Khancoban). The park on the edge of Lake Jindabyne opposite the town centre is a convenient place for lunch.

Stop 3-2: Lake Jindabyne (map 6)

Lake Jindabyne is a man-made feature forming part of the diversion of eastward-flowing rivers through the Snowy Mountains into the westerly flowing Murrumbidgee and Murray Rivers. There was also a pre-historic natural lake in this position, apparently resulting from movements on the Jindabyne Thrust, which dips at a shallow angle to the east on the eastern side of the valley (White *et al.*, 1976a). The Jindabyne Valley lies between the Beloka and Kosciusko plateaux. The latter, to the west, has formed by recent warping on a north-south axis (White *et al.*, 1977).

The large statue on the edge of the lake is of Paul Edmund Strzelecki (1797-1873), erected as an Australian Bicentennial (1988) project. Strzelecki arrived in Australia from Poland in 1839 and during the period 1839-1843 he explored and surveyed a vast area of south-eastern Australia. He is best known for his discovery of Australia's highest peak, Mt Kosciusko (2228 m), 33 km to the west, which he named in honour of the Polish leader and patriot, Tadeusz Kosciuszko. Strzelecki was one of the first of Australia's natural scientists, with interests in many fields including geology and mineralogy.

If time permits, travel west from Jindabyne on the Alpine Way and take the Summit Road after 3.3 km. The road enters the Kosciusko National Park 6.1 km from that junction (and a park entrance fee is payable at that point). The felsic Kalkite Adamellite (KB31 at Berridale 414767) can be seen near the surge tank of the Jindabyne Pumping Station 3.5 km from the park entrance. The Kosciusko Park Headquarters and Visitors Centre are located 1.6 km further west. At Rennix Gap, another 8 km along the Summit Road, the more mafic Mowambah Granodiorite is exposed in large boulders (KB46 at Berridale 347748). Both of those units are part of the Bullenbalong Suite. During the summer, or when snow conditions permit, the road can be followed for a further 18 km within the Mowambah unit to Charlotte Pass (1940 m), where Pleistocene glacial features can be seen. From that point there is a footpath over 10 km to the summit of Mt Kosciusko which is made up of mylonitized Rawson Pass Granite. Return to Jindabyne.

The Barry Way leaves the Alpine Way 1.3 km west of Jindabyne. Follow this road south towards Ingebyrah. Turn left after 8.9 km, along Gullies Road. The flat-topped hill to the south is capped by a Cainozoic flow of nephelinite. Boulders of Jillamatong Granodiorite occur on the north side of the road 5.1 km from the Barry Way.

Stop 3-3: Jillamatong Granodiorite (Numbla 429569; map 6) sample KB32

The Jillamatong Granodiorite (101 km^2) is a mafic S-type granite occurring just south of Jindabyne in the Kosciusko Batholith (Hine *et al.*, 1978). It is part of the Bullenbalong Suite. It is one of the most mafic S-type granites of the LFB, with a mode transitional from mafic granodiorite to tonalite; the low K-feldspar content results from the abundance of biotite (27%) which also partly accounts for the high quartz content (35%) of such a mafic rock. Some fresh cordierite is present but it is more frequently altered; muscovite can be seen in some places. Metasedimentary inclusions are abundant and these have been described by Chen *et al.* (1989).

Petrographic description: This is a bluish-grey, mafic cordierite-bearing granodiorite in which the total mafic mineral content, including cordierite and muscovite, is just over 30%. Quartz is seen in thin-section as large crystals 2.5 mm across, either with prominent undulose extinction or as polygonal recrystallized aggregates. An unusual feature of the quartz grains from the Jillamatong Granodiorite intrusion is that they contain an abundance of tiny, randomly-oriented rutile needles. As in virtually all cordierite-bearing S-type granites, the quartz content is high relative to the two feldspars. Plagioclase occurs as tabular crystals

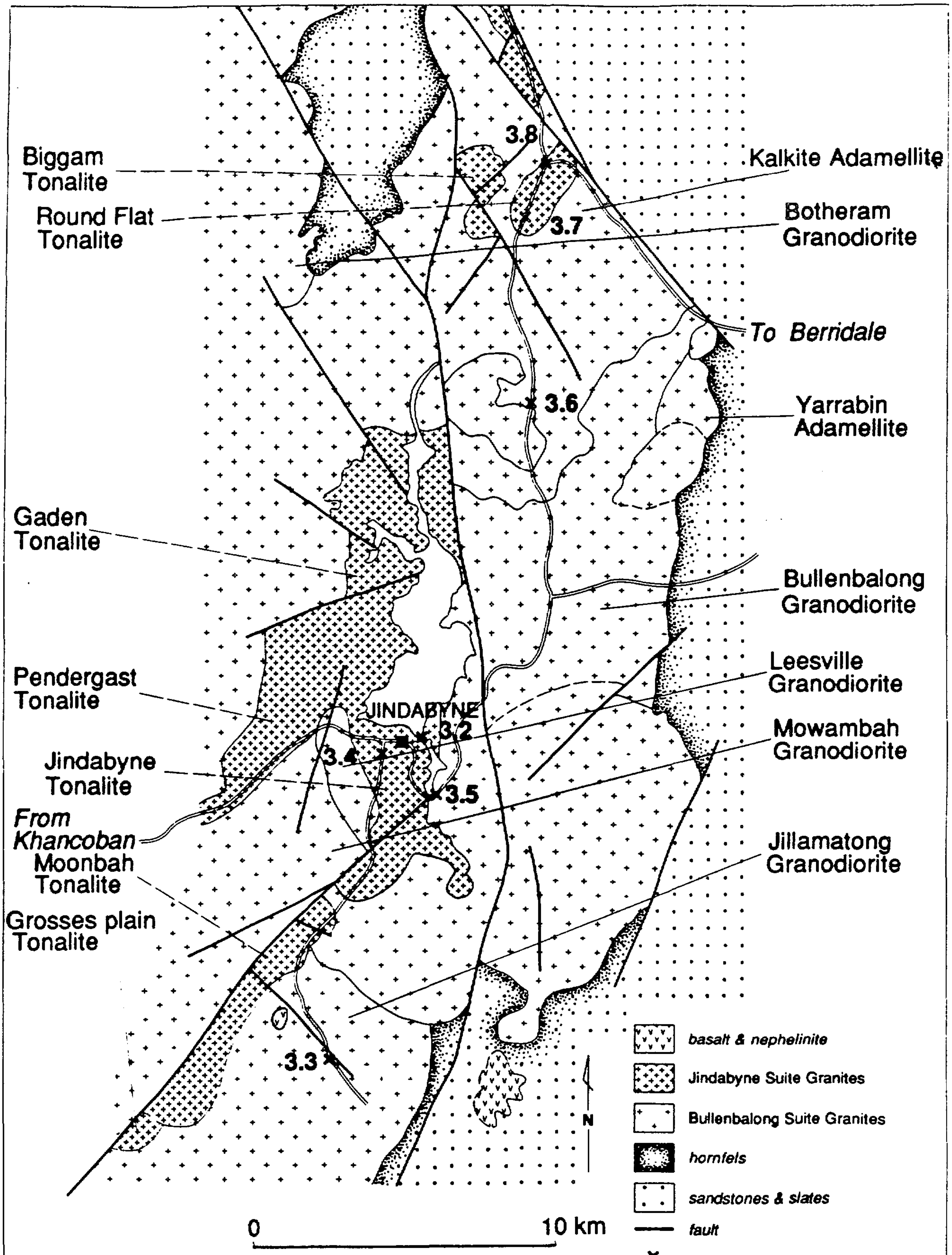


Figure 6. Granite plutons of the Kosciusko Batholith near Jindabyne

averaging about 2 mm across with prominent cores near An_{55} surrounded by less calcic oscillatory zones and outer rims near An_{25}. K-feldspar is low in abundance and may be difficult to find in some thin-sections except for those grains that have prominent but irregular microcline twinning or myrmekite on boundaries with plagioclase. Most K-feldspars are interstitial grains about 2 mm across. Biotite (α = straw yellow, β = γ = foxy red-brown) appears as irregularly-shaped grains commonly in aggregates. Within the biotites there are inclusions of zircon and lesser monazite that has even more prominent pleochroic haloes than the zircon crystals. Apatite inclusions within the biotite are also surrounded by weak pleochroic haloes. Muscovite may be interleaved with biotite, suggestive of a primary origin but more commonly it is seen as irregularly--shaped grains mostly in association with green biotite. Both these latter minerals may surround yellow pinite, the whole representing altered cordierite; some fresh cordierite is preserved within these aggregates. Apart from apatite, zircon and monazite, other accessory phases include small patches of yellow-brown tourmaline and rare ilmenite and pyrrhotite. There are also a few tufts of sillimanite needles.

Chemistry: This rock has a composition typical of the most mafic representatives of the Bullenbalong Suite. CaO is low for such a mafic rock and Na_2O is just below 2%. The Fe_2O_3:FeO ratio is low as is typical of S-type granites, but not as extremely low as we have observed in the Melbourne Basement Terrane. The rock is strongly corundum-normative (3.89%), a characteristic feature of the more mafic rocks of the Bullenbalong Supersuite.

Isotopic ages: The Jillamatong Granodiorite has yet to be dated by Rb-Sr or K-Ar. Ion-probe analyses of zircons from KB32 show that every zircon crystal consists predominantly of inherited zircon (incontrovertibly restite). The inherited crystals are overgrown by a thin mantle of zircon precipitated from the melt. The ages of the inherited cores range from late Archaean to early Palaeozoic. The age of magmatism is difficult to measure because of the scarcity of mantles thick enough to analyse, but it appears to be about 430 Ma.

Isotopic composition: The isotopic data reported by McCulloch & Chappell (1982) are ε_{Nd} = -8.8, $^{87}Sr/^{86}Sr(I)$ = 0.71504, T^{Nd} = 1710 Ma and $\delta^{18}O$ = 11.6‰.

[Note that the T^{Nd} ages quoted in this guide from McCulloch & Chappell (1982) have been recalculated using different constants. The values given in this report are those calculated by McCulloch for the ICOG-7 excursion guide (Chappell *et al.*, 1990).]

Return to the Barry Way and back towards Jindabyne. Stop at the deep cutting 850 m south of the junction with the Alpine Way.

Stop 3-4: Jindabyne Tonalite (Berridale 442677; map 6) sample KB22

The Jindabyne Tonalite (17 km^2) is part of the Jindabyne Suite (Hine *et al.*, 1978) which consists of nine separate plutons on the eastern side of the Kosciusko Batholith. There is an excellent exposure of Jindabyne Tonalite in the cutting at this locality. Note the numerous joints in both the deeply weathered and the fresh granites of this cutting. Joints are coated with chalcopyrite altering to malachite and limonite. Molydenum occurs in a similar fashion elsewhere within the Jindabyne Tonalite. This is a weak porphyry copper-style mineralization. The fresh rock is dominated by plagioclase crystals but perfectly-shaped hornblendes up to 20 mm in length are the most distinctive mineral. There are some small mafic inclusions.

Petrographic description: Plagioclase amounts to almost 50% of the rock. Under a microscope, it is seen as rectangular crystals (commonly 1 mm or more long) complexly twinned and strongly zoned with the outer zones outlining perfect crystal shapes. The very outermost zone is An_{25} but there is an outer zone rim about 0.1 to 0.2 mm wide with a composition close to An_{35}. The irregularly corroded (sometimes rounded), inner core is near An_{80} in composition and normally untwinned. Quartz is interstitial to plagioclase and commonly has undulose extinction or appears as aggregates of smaller grains with triple junctions; these features are indicative of weak deformation. Biotite (α = straw-yellow; β = γ = dark sepia-brown with a greenish tint) contains a few tiny prismatic inclusions of apatite and a few small zircon inclusions. Rarely it shows some alteration to green chlorite or is replaced along cleavages by strips of epidote and prehnite. Hornblende (α = brownish yellow, β = dark olive-green, γ = blue-green) has well-defined prism faces but ragged terminations. Potassium feldspar is orthoclase. Magnetite is conspicuous as grains up to 0.5 mm across sometimes displaying octahedral shapes and commonly occurring as inclusions in hornblende or biotite. Ilmenite is also present but can only be identified under a microscope using reflected light. Apatite is an accessory mineral, but sphene, seen in many tonalites, is not present in this or any other rock of the Jindabyne Suite, because of the relatively low Ti content. Zircon is seen in biotite but pleochroic haloes are weakly developed, in marked contrast to the nearby S-type granites. Allanite is also an accessory mineral commonly recognizable in hand-sample as black specks surrounded by tiny radiating cracks resulting from expansion during metamictization.

Calcic cores in the plagioclase crystals of this rock are more-or-less uniform in composition at around An_{80}. Cores of that composition occur in the plagioclase of all rocks of the Jindabyne Suite, from the most felsic (68% SiO_2) to the most mafic (56% SiO_2). The amount of core material decreases as the rocks become more felsic, but the compositions remain constant. Similarly, other granite suites also have constant composition cores in their plagioclase crystals, and the compositions vary from suite to suite (see discussion of the Glenbog Suite, Stop 5-7).

Because of the flattening of the plagioclase loop in granitic systems (e.g. Johannes, 1989), very calcic plagioclase is expected as the first liquidus phase of granitic melts, and at the P and T of partial melting, the restite plagioclase must also have this composition. Furthermore, if equilibrium batch melting occurred to produce the magma, the restite calcic plagioclases would be expected to have a more-or-less uniform composition. The calcic cores of the plagioclase are therefore considered to be restite and the surrounding normal and oscillatory zoned plagioclase with lower Ca content to have crystallized from the melt phase of the magma. The cores were sealed from low P and low T reaction by overgrowths seen as zoning. This implies that the melt phase of all of the Jindabyne Suite magmas, irrespective of their SiO_2 content, had the same composition. The variation of the Jindabyne Suite magmas was the result of varying amounts of restite being present, including pyroxenes and other minerals as well as plagioclase.

Chemistry: Griffin *et al.* (1978) compared the compositions of the tonalites of the Jindabyne Suite and the Moruya Suite (Day 7) some 150 km to the east. K_2O contents are similar, unlike the differences seen across younger fold belts. The most significant chemical differences are distinctively lower Ti, Na, P, Zr, and Nb and higher Ca and Al in the Jindabyne Suite.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 415 Ma has been measured on this sample. Preliminary results indicate moderate inheritance ranging in age from early Proterozoic to early Palaeozoic.

Isotopic compositions: McCulloch & Chappell (1982) report values $\varepsilon_{Nd} = -5.0$, $^{87}Sr/^{86}Sr(I) = 0.70769$ and $T^{Nd} = 1480$ Ma for this rock. Unpublished Pb data for feldspars are $^{206}Pb/^{204}Pb = 18.226$, $^{207}Pb/^{204}Pb = 15.633$ and $^{208}Pb/^{204}Pb = 38.253$.

Source-rocks of the Jindabyne Suite: McCulloch & Chappell (1982) noted that the Sr and Nd isotopic compositions of the Jindabyne Tonalite are consistent with derivation from a source-rock containing about 60% of a crustal component (CC) with the isotopic composition of the Ordovician sediments, and 40% of a depleted mantle-like component (DMC). However, they pointed out that this would not be consistent with the chemical composition of this suite. For example, Rb has an average abundance of 168 ppm in analyzed Ordovician sediments (Wyborn & Chappell, 1983). Even assuming a zero Rb content in DMC, this leads to a mixed-source Rb content of 100 ppm. That value is higher than the observed Rb content in KB22 of 89 ppm (Table 8) and this conflicts with the expectation that the fractionation of KB22 from its source-rocks would have lead to an *increase* in Rb content. Using methods that are admittedly model-dependent, McCulloch & Chappell (1982) calculated a source-rock Rb content of 33 ppm for the Jindabyne Suite, implying a DMC Rb content of -84 ppm! Such considerations would invalidate the conventional isotope mixing model and would also greatly limit the amount of a Rb-rich component, such as shale, that can have been in the source-rocks. Although a simple mixing model for the source-rock compositions satisfies the isotopic constraints, it does not accord with the geochemical data. On that basis, McCulloch & Chappell (1982) concluded that a simple binary mixing model is not adequate to explain both the geochemical and isotopic data. A variety of source-rocks of different ages could account for both types of data. There is, however, a general correlation between the Sr and Nd and the O isotopic data, and we have noted above that old zircons have been identified in this rock. At the present time, details of the source-rocks remain unresolved. We also note that by ignoring the geochemical arguments of McCulloch & Chappell (1982), Gray (1984) was able to postulate a simple mixed source for the Jindabyne Tonalite.

Return via the Alpine Way to Jindabyne and continue beyond that town for 2.7 km to the parking area just before the Jindabyne Dam spillway.

Stop 3-5: Contact between Jindabyne and Bullenbalong units (Berridale 463666; map 6)

An irregular intrusive contact between a finer grained phase of the Jindabyne Tonalite and the Bullenbalong Granodiorite can be seen in the spillway excavation at Jindabyne Dam. The contact is sharp and there are xenoliths of foliated Bullenbalong Granodiorite within the younger Jindabyne Tonalite. The fine-grained phase at the southwest side of the dam wall is a dyke or minor intrusion which has a sharp contact with the normal Jindabyne Tonalite. Both rocks have large perfectly formed hornblendes but those in the fine-grained phase are replaced by an aggregate of biotite (K-alteration). The fine-grained phase is considered to be the result of pressure-quenching. There is a Cainozoic basalt dyke in the south wall of the spillway.

Follow the Alpine Way towards Berridale. At the Snowy Valley Motel 9 km from Jindabyne the trace of the Jindabyne Thrust trending north is seen a little to the east of the edge of the lake. Turn north on the Eucumbene road 13 km from Jindabyne. Follow this road north through S-type granites for 7.3 km to the place where broken boulders occur on eastern side of the road near a small lake.

Stop 3-6: Bullenbalong Granodiorite (Berridale 498808; map 6) sample KB12

The Bullenbalong Granodiorite at this point is part of a remnant within large intrusions of the more felsic Kalkite Adamellite. It is a coarse-grained, biotite-rich, S-type granite occurring over an area of 184 km^2. This unit is the type example of both the Bullenbalong Suite and Supersuite, the latter being the dominant granite of the Kosciusko Basement Terrane. The array of inclusions (enclaves) in this rock is typical of mafic S-type granites and includes cordierite gneisses, surmicaceous clots and lenticular inclusions, quartz lumps and microgranular inclusions. The lumps of quartz up to 50 mm across are considered to be fragments of vein quartz from the source region of partial melting. Large dull grey patches up to 10 mm across are altered cordierite crystals. Foliation is not prominent at this locality but the quartz crystals have a bluish tint indicative of deformation.

Petrographic description: In thin-section all quartz crystals more than about 1 mm across have complex undulose extinction and smaller crystals occur in aggregates of tiny grains with triple junctions. Some large quartz crystals are traversed by randomly oriented veins of tiny quartz aggregates and others may be surrounded by aggregates of tiny grains. There are no rutile needles of the kind found in the Jillamatong Granodiorite of the Bullenbalong Suite, nor are there any platelets of ilmenite, and hence the blue colour of the quartz is considered to result from deformation and not titanium. Plagioclase crystals are up to about 6 mm across and not deformed. They have prominent cores around An_{50}-An_{55}, prominent zones around An_{40}-An_{45}, and outer zones around An_{20}. Small irregularly-shaped grains of K-feldspar 1 mm or less across, are difficult to find. Biotite (α = straw yellow, $\beta = \gamma$ = foxy red-brown) is abundant as grains up to 5 mm across, but most large biotites are ragged and are commonly surrounded by an aggregate of smaller grains indicating recrystallization. There is very little chloritization of biotite. Former cordierites consist of recrystallized aggregates of tiny micas. Stumpy apatites are common, zircons and monazites are commonly seen as small crystals in the biotite and in some biotites there are opaque rods of ilmenite. There are a few sheaves of tiny blue tourmaline crystals.

Chemistry: The slightly less mafic nature of this rock relative to KB32 (Stop 3-3) is reflected in the chemical composition, which is characteristically that of a rather mafic S-type granite of the Bullenbalong Supersuite.

Isotopic ages: Biotite from KB12 has not been dated, but a Rb-Sr age of 412 ± 4 Ma has been measured on biotite from sample KB9, 5 km to the south. Too few whole-rocks from the Bullenbalong Granodiorite have been analyzed for Rb-Sr to construct an isochron. However, the 20 analyses from granites of the Bullenbalong Suite (Bullenbalong, Mowambah, Kalkite and Jillamatong) plot very similarly in scatter and dispersion to the samples of Cootralantra Granodiorite. The age is poorly defined, but if it is assumed to be 420 Ma, the initial $^{87}Sr/^{86}Sr$ of the whole rocks covers the range 0.712 to 0.716, very similar to the Cootralantra Granodiorite and significantly higher than for the I-type granites. Conventional analyses of zircons from KB12 show strong inheritance with a 'mean' age of 1900 Ma. The lower intersection of the discordance line is 410 Ma, significantly less than the age of concordant monazite, 431 ± 3 Ma. Ion-probe analyses of the zircons show the ages of inheritance to range from early Palaeozoic to late Archaean. The age of zircon precipitated from the melt is difficult to measure, but appears to be consistent with the conventionally-measured monazite age.

Continue north along the Eucumbene road which passes into the Kalkite Adamellite. Just beyond Wandilla, 13 km north of the Alpine Way, a north-west trending left-lateral wrench fault is crossed as the road steps to the left as it crosses a small stream. Stop at the outcrops 500 m beyond this fault.

Stop 3-7: Hornblende-poor Round Flat Tonalite (Berridale 495872; map 6) sample KB2

The exposed rock is here a felsic member of the Bullenbalong Suite (Kalkite Adamellite). It is a coarse-grained felsic granite dominated by quartz with lesser plagioclase and K-feldspar. Red-brown biotite is the main mafic mineral but there are some cordierite pseudomorphs and small amounts of (?) secondary muscovite can be seen in hand-sample. There is a pronounced foliation trending about 30°. The foliation results from the orientation both of biotites and of the elliptically--shaped metasedimentary inclusions. Walk northwards through this unit in the field on the east side of the road, parallel to the road as it descends into the broad valley to the north. The contact with the Round Flat Tonalite is crossed and the foliation persists, but is weaker in the tonalite. The weaker foliation in the Round Flat granite is considered to result from the great abundance of mechanically strong plagioclase whereas the Kalkite Adamellite is relatively poor in plagioclase but rich in quartz which is easily deformed.

Cross the fence again at the exposure of KB2. The Round Flat Tonalite is a small I-type granite (6.6 km^2) completely enclosed by the older S-type Kalkite Adamellite. It lies in a valley and this is typical of the tonalites of the Jindabyne Suite that intrude the S-type granites of the eastern part of the Kosciusko Batholith.

Petrographic description: The Round Flat Tonalite is a member of the Jindabyne Suite. This sample is from the hornblende-poor southern (outer) part of the unit. Plagioclase accounts for more than 50% of the rock and consists mostly of rectangular shaped grains ranging from about 0.5 mm to more than 3 mm in longest dimension. The larger grains have calcic cores that are almost completely sericitized so that their composition cannot be determined. The boundary between the sericitized cores and the oscillatory zoned outer parts of the crystals, are sharp. The composition of the outer parts range down to at least An_{20} and the unaltered zones nearest the cores are up to An_{60}. The oscillatory zones outline good crystal shapes but the outer margins of the crystals are ragged. Quartz and K-feldspar appear to be inclusions in the core or near the core boundary of one crystal. Quartz appears as polygonal aggregates up to 6 mm across. Individual crystals of the aggregates have sutured interlocking boundaries and crude triple junctions with their neighbours. Biotite (α = straw coloured, $\beta = \gamma$ = greenish brown) occurs as ragged crystals commonly altered on the margins to chorite and containing strips of secondary green epidote. Blue-green hornblende is rare and may appear as isolated crystals mostly ragged, or as crystals surrounded by biotite. K-feldspar is rare and interstitial to other minerals. Magnetite, commonly perfect crystals, is conspicuous mostly as crystals up to 0.5 mm across. Apatite appears as stout prisms also up to 0.5 mm long as well as tiny prisms included in other minerals, especially biotite. Metamict allanite grains, up to about 1 mm are surrounded by radiating cracks in quartz and feldspar. Prismatic zircons are not common; they are up to 0.5 mm long and may display oscillatory zoning. Broken and recrystallized quartz is indicative of deformation followed by some recrystallization. A weak foliation is seen in the field to trend northeast parallel to that in the surrounding Kalkite Adamellite.

Chemistry: This composition is characteristic of the least mafic rocks of the Jindabyne Suite and is probably approaching that of the primary melt of that suite, thought to have been a "non-minimum temperature" melt.

Continue north across the Round Flat Tonalite for 1.3 km to boulders beside the road just south of Rocky Plains Homestead.

Stop 3-8: Hornblende-rich Round Flat Tonalite (Berridale 499887; map 6) sample KB4

This is one of the most mafic samples of tonalite in the Kosciusko Batholith. Although it contains approximately 60% SiO_2, the modal quartz content is 22%, as a consequence of its low K content. There is less than 0.5% K-feldspar. Biotite and hornblende occur in equal proportion. Magnetite is abundant and small allanite crystals are present, and there is no sphene, a feature of all Jindabyne Suite rocks. The rock contains mafic inclusions but their abundance is low compared with other tonalites of the LFB to be seen later in the excursion; an analysis of one inclusion (KB65) is given in Table 8.

Petrographic description: The northern part of the Round Flat unit contains abundant hornblende. Plagioclase comprises more than 50% of the rock and consists mostly of rectangular-shaped grains ranging up to more than 3 mm in longest dimension and having good crystal shapes. Calcic cores, easily distinguished in thin-section by having higher birefringence than the rest of the plagioclase, are mostly unaltered and commonly untwinned. Those that are twinned have extinction angles corresponding to a composition of An_{80}. Quartz appears as large crystals 3-4 mm across including other grains and rarely with undulose extinction, so that the deformation has been weak. Biotite (α = straw coloured, $\beta = \gamma$ = sepia-brown with a greenish tint) appears as large grains (up to 3 mm) with poor crystal shapes. It is partly altered in places to chlorite and it contains irregular patches of secondary epidote and sphene. Hornblende (α = pale yellow-green, β = pale olive-green and γ = dark blue-green) is abundant and may appear as well-shaped crystals when not associated with aggregates or surrounded by biotite in apparent reaction relationship. K-feldspar occurs as tiny interstitial grains amounting to less than one per cent. of the total minerals. Magnetite is relatively abundant and sometimes appears as good crystals 0.5 mm across. Apatite is seen as small stout prisms. Like all rocks of the Jindabyne Suite, there is no primary sphene but scattered brown metamict allanite grains, up to about 1 mm are surrounded by radiating cracks in other minerals; one was found in hornblende in this rock. Stumpy zircons are not common.

Chemistry: This composition is approaching that of the most mafic samples of the Jindabyne Suite, so that this rock and KB2 from the previous locality encompass most of the chemical variation observed in that suite. This mafic composition is interpreted as resulting from the combination of a higher temperature more mafic melt and the presence of substantial amounts of restite as evidenced by the calcic plagioclase cores.

Isotopic age: The Rb-Sr biotite age of the Round Flat Tonalite at this locality is 413 ± 4 Ma.

Continue north to the Cooma-Eucumbene road and turn to the right. 4 km from this junction is a historic church that lies close to the line of the Berridale Wrench Fault. 9 km from the junction is The Gap and a crush zone of the Berridale Fault can be seen in the cutting on the right. The wooded hill in the foreground is Gygederick Hill which is part of a screen separating several intrusions within the Berridale Batholith. The hills on the skyline are Cainozoic basalts. At 18 km from the junction north of Round Flat, take the road to the south and follow it to Berridale. 3.7 km from this point, Wullwye Creek is crossed at the Berridale Wrench Fault; 1.7 km beyond that creek, turn right on the Snowy Mountains Highway into Berridale town.

TABLE 10. MINERAL AGES FOR THE BERRIDALE AND KOSCIUSKO BATHOLITHS

Sample	Mineral	Method	Age ($\pm 1\sigma$)	Reference	Comment
Buckleys Lake Adamellite					
BB7	Biotite	Rb-Sr	419.6 ± 1.3	W75	
	Biotite	K-Ar	418.5 ± 4.2	W82	
BB10	Biotite	Rb-Sr	416.9 ± 0.9	W75	
	Biotite	K-Ar	412.9 ± 2.4	W82	
	Biotite	Ar-Ar	421.3 ± 0.9	T79	
BB22	Biotite	Rb-Sr	417.0 ± 1.3	W75	
	Biotite	K-Ar	420.4 ± 3.9	W82	
BB30	Biotite	Rb-Sr	416.5 ± 1.9	W75	
BB33	Biotite	Rb-Sr	419.0 ± 1.9	W75	
	Biotite	K-Ar	415.8 ± 3.7	W82	
BB109	Biotite	Rb-Sr	414.8 ± 1.9	W75	
	Biotite	K-Ar	417.9 ± 3.8	W82	
BB110	Biotite	Rb-Sr	417.2 ± 1.3	W75	
	Biotite	K-Ar	417.5 ± 3.4	W82	
Bullenbalong Granodiorite					
KB9	Biotite	Rb-Sr	411.9 ± 1.9	W73	
Cootralantra Granodiorite					
BB3	Biotite	Rb-Sr	411.1 ± 1.3	W75	Reset by Tara
	Biotite	K-Ar	413.2 ± 3.4	W82	Reset by Tara
BB19	Biotite	Rb-Sr	421.1 ± 1.3	W75	
	Biotite	K-Ar	417.2 ± 2.0	W82	
	Biotite	Ar-Ar	422.1 ± 1.1	T79	
BB36	Biotite	Rb-Sr	412.0 ± 1.3	W75	Reset by Wullwye
	Biotite	K-Ar	411.3 ± 3.4	W82	Reset by Wullwye
BB83	Biotite	Rb-Sr	418.0 ± 1.9	W75	
	Biotite	K-Ar	416.4 ± 2.4	W82	
Dalgety Granodiorite					
BB9	Biotite	Rb-Sr	415.4 ± 1.9	W82	
	Biotite	K-Ar	410.3 ± 2.3	W82	
	Biotite	Ar-Ar	421.6 ± 1.1	T79	
BB26	Biotite	Rb-Sr	417.8 ± 1.3	W82	
	Biotite	K-Ar	418.0 ± 3.4	W82	
BB68	Biotite	Rb-Sr	416.4 ± 1.9	W75	
	Biotite	K-Ar	418.0 ± 3.4	W82	
BB90	Biotite	Rb-Sr	419.0 ± 1.3	W75	
BB94	Biotite	Rb-Sr	413.1 ± 1.9	W75	
BB96	Biotite	Rb-Sr	415.2 ± 1.9	W82	
	Biotite	K-Ar	414.6 ± 3.9	W82	
Finister Granodiorite					
BB16	Biotite	Rb-Sr	418.4 ± 1.9	W75	
BB100	Biotite	Rb-Sr	416.9 ± 1.9	W75	
	Biotite	K-Ar	414.6 ± 3.4	W82	
BB160	Biotite	Rb-Sr	411.7 ± 1.9	W82	
	Biotite	K-Ar	419.9 ± 3.5	W82	
BB161	Biotite	Rb-Sr	421.5 ± 1.9	W82	
	Biotite	K-Ar	415.5 ± 3.4	W82	
BB163	Biotite	Rb-Sr	415.9 ± 1.3	W82	
	Biotite	K-Ar	420.1 ± 2.9	W82	
	Biotite	Ar-Ar	427.5 ± 1.7	T79	
	Hornblende	K-Ar	410.9 ± 3.7	T79	
	Hornblende	Ar-Ar	414.6 ± 1.5	T79	
BB165	Biotite	Rb-Sr	417.6 ± 1.9	W82	
	Biotite	K-Ar	416.1 ± 3.4	W82	

TABLE 10. MINERAL AGES FOR THE BERRIDALE AND KOSCIUSKO BATHOLITHS

Sample	Mineral	Method	Age ($\pm 1\sigma$)	Reference	Comment
Kalkite Adamellite					
KB13	Biotite	Rb-Sr	410.4 ± 1.9	W73	
Maffra Adamellite					
BB21	Biotite	Rb-Sr	409.9 ± 1.1	W75	
	Biotite	K-Ar	412.9 ± 2.4	W82	
	Biotite	Ar-Ar	414.2 ± 1.1	T79	
	Muscovite	Rb-Sr	413.6 ± 1.9	W75	
BB31	Biotite	Rb-Sr	413.8 ± 1.3	W75	
	Biotite	K-Ar	411.9 ± 2.4	W82	
Numbla Vale Adamellite					
BB2	Biotite	Rb-Sr	417.5 ± 1.1	W75	
	Biotite	K-Ar	422.2 ± 2.4	W82	
	Biotite	Ar-Ar	429.9 ± 1.1	T79	
BB29	Biotite	Rb-Sr	418.5 ± 1.9	W82	
	Biotite	K-Ar	414.9 ± 3.3	W82	
Round Flat Tonalite					
KB4	Biotite	Rb-Sr	412.7 ± 1.9	W73	
Tara Granodiorite					
BB15	Biotite	Rb-Sr	414.3 ± 1.9	W82	
	Biotite	K-Ar	415.5 ± 3.4	W82	
	Biotite	Ar-Ar	420.5 ± 1.2	T79	
BB71	Biotite	Rb-Sr	413.1 ± 1.3	W75	
BB75	Biotite	Rb-Sr	410.9 ± 1.9	W82	
	Biotite	K-Ar	415.4 ± 3.4	W82	
BB86	Biotite	Rb-Sr	411.1 ± 1.3	W75	
	Biotite	K-Ar	413.7 ± 2.6	W82	
	Biotite	Ar-Ar	423.6 ± 1.1	T79	
	Hornblende	K-Ar	410.8 ± 3.6	T79	
	Hornblende	Ar-Ar	409.1 ± 1.6	T79	
BB87	Biotite	Rb-Sr	410.2 ± 1.9	W75	
	Biotite	K-Ar	411.1 ± 3.4	W82	
Wullwye Granodiorite					
BB34	Biotite	Rb-Sr	416.3 ± 1.9	W75	
	Biotite	K-Ar	410.7 ± 2.4	W82	
	Biotite	Ar-Ar	419.5 ± 1.2	T79	
BB62	Biotite	Rb-Sr	414.6 ± 1.9	W75	
	Biotite	K-Ar	411.2 ± 2.4	W82	
	Biotite	Ar-Ar	412.2 ± 1.2	T79	
BB93	Biotite	Rb-Sr	412.8 ± 1.9	W75	

W73 - Williams (BSc thesis, 1973)
W75 - Williams, Compston, Chappell & Shirahase (1975)
T79 - Tetley (1979)
W82 - Williams, Tetley, Compston & McDougall (1982)

DAY 4: THE COOMA COMPLEX AND THE BERRIDALE BATHOLITH

The fourth day of the excursion inspects components of the Cooma Complex, in which an S-type granodiorite is located at the centre of a small regional metamorphic complex. Later, the contrasting occurrences of both S-type and I-type granites in the contact-aureole environment of the Berridale Batholith are examined. Chemical and modal analyses of rocks from some of these localities are given in Table 9.

Take the Alpine Way towards Cooma. The road crosses various intrusions of the northern part of the Berridale Batholith. Berridale itself is located on the Dalgety Granodiorite. After 2.1 km the road crosses the Berridale Wrench Fault and the granite exposed to the north of the road is the Buckleys Lake Adamellite. At 4.3 km the more rubbly outcrops are of the S-type Cootralantra Granodiorite and after 5.3 km the road enters the Wullwye Granodiorite, a felsic I-type granite completely enclosed within the Cootralantra Granodiorite, with large buff-coloured tors. After a further 3 km the road passses back into the Cootralantra Granodiorite. To the south, the grass-covered hills without tors are Cainozoic basalts of the Monaro Province. The tree-covered hills in the distance are contact rocks forming a ridge on the eastern side of the Berridale Batholith. At 19.7 km the road passes through a cutting of these contact rocks at the eastern edge of the Berridale Batholith and then into Ordovician phyllites and sandstones of low greenschist facies grade. After 24 km a road cutting exposes these low-grade rocks.

Stop 4-1: Retrogressed spotted schists (Cooma 824856; map 7)

This is a relatively low-grade zone of the Cooma Complex in which quartzofeldspathic schists are interlayered with knotted mica schists. The knots were formerly andalusite or cordierite or both but they have been retrogressed to aggregates of mica.

Continue towards Cooma. 250 m before the junction of the Snowy Mountains Highway there are exposures of gneiss south of the road and there are fresh boulders on the north side.

Stop 4-2: Mottled gneiss of the sillimanite zone (Cooma 840863; map 7)

This gneiss is just above the sillimanite isograd and the mineral assemblage is quartz + orthoclase ± plagioclase + biotite + muscovite + cordierite + andalusite + sillimanite. Bedding can be seen in a large fresh boulder on the north side of the road.

Isotopic composition: McCulloch & Chappell (1982) reported $\varepsilon_{Nd} = -8.3$, $^{87}Sr/^{86}Sr(I) = 0.71837$ and $T^{Nd} = 1620$ Ma for this locality.

Continue on the road towards Cooma to the Gladstone Lookout turn-off on the right 2.6 km after joining the Snowy Mountains Highway. Walk 30 m further down the road to an outcrop on the north side, while admiring the basalt flows in the distance beyond Cooma.

Stop 4-3: Migmatites (Cooma 867872; map 7)

These are migmatites and biotite-cordierite gneisses, the more pelitic bands having pods, patches and veins of granitic material (leucosomes) surrounded by coarse-grained melanosomes. Fresh purplish-blue crystals of cordierite 5 mm or more across are seen in some of the granitic patches. This shows the birth of a Cooma Suite cordierite granite! The amount of partial melting in this particular outcrop is fairly small.

Continue on the road through the migmatite zone to the town of Cooma. Cross Cooma Back Creek and take Creek Street to the left then first right (Massie Street) and drive to top of hill and turn left to Nanny Goat Hill Lookout.

TABLE 9. CHEMICAL ANALYSES: COOMA GRANITE AND BERRIDALE BATHOLITH

	CC1	BB83	BB137	BB130	BB139	BB131	BB86	BB3	BB9	BB93
Stop	4-4	4-8	4-8	4-8	4-8	4-8	4-9	4-10	4-11	4-12
SiO_2	72.00	67.82	41.46	51.50	60.25	66.40	67.32	67.71	68.21	74.77
TiO_2	0.54	0.61	1.37	1.05	1.10	0.77	0.47	0.58	0.53	0.26
Al_2O_3	13.72	14.47	30.51	24.32	15.07	15.45	15.24	14.29	14.25	13.24
Fe_2O_3	0.59	0.54	2.34	1.03	1.07	1.09	1.17	0.84	0.93	0.61
FeO	3.48	4.09	8.12	6.31	7.93	2.96	2.68	3.75	3.10	0.92
MnO	0.06	0.07	0.15	0.13	0.15	0.07	0.08	0.07	0.07	0.05
MgO	1.76	2.33	5.00	3.81	3.11	1.77	1.67	2.23	1.68	0.44
CaO	0.95	3.05	2.03	4.54	6.66	3.77	4.33	2.95	3.11	1.45
Na_2O	1.49	2.06	1.32	2.23	1.03	2.56	3.23	2.00	2.23	3.89
K_2O	3.73	3.40	2.43	2.35	0.95	3.15	2.24	3.41	3.77	3.16
P_2O_5	0.13	0.14	0.21	0.13	0.15	0.22	0.13	0.14	0.13	0.06
H_2O+	1.28	1.13	4.06	1.83	1.92	1.10	1.03	1.48	1.28	0.60
H_2O-	0.14	0.19	0.52	0.25	0.17	0.23	0.13	0.21	0.12	0.21
CO_2	0.13	0.18	0.21	0.30	0.24	0.13	0.14	0.12	0.29	0.04
total	100.00	100.08	99.73	99.78	99.80	99.67	99.86	99.78	99.70	99.70
Trace elements (ppm)										
Rb	153	169	107	134	46.5	151	86	166	179	130
Sr	127	139	112	192	161	176	252	134	167	186
Ba	765	445	140	475	140	410	440	470	530	580
Zr	201	174	209	190	145	229	126	169	158	152
Nb	9.0	11.5	26.5	17.5	7.0	13.0	9.0	11.0	11.5	15.5
Y	39	28	47	32	36	32	22	29	30	25
Ce	68	64	141	107	55	50	65	69	63	101
Sc	12	17	32	22	34	16	14	18	18	6
V	64	88	208	175	259	102	65	89	95	11
Cr	56	65	179	121	9	4	12	71	32	5
Ni	24	20	68	28	5	10	3	21	10	<1
Zn	71	70	290	178	114	60	48	72	57	25
Ga	15.0	16.8	46.2	35.2	19.2	17.6	15.4	16.8	16.2	14.0
Pb	35	26	16	24	14	30	13	25	24	16
Th	21	17	36	24	11	11	11	17	15	16
U	3.8	3.8	18.6	3.8	2.2	1.8	2.2	2.4	2.6	5.4
Norm. C	5.82	2.19	22.52	10.16	0.60	1.50	-	2.28	1.16	0.93
Modes										
Quartz	48.3	34.8					32.1	36.1	35.6	34.0
K-feldspar	8.8	9.5					8.6	4.9	13.8	21.0
Plagioclase	18.9	33.7					46.6	38.0	34.7	40.2
Biotite	17.4	21.6					9.7	20.8	15.6	4.1
Hornblende							2.4			
Muscovite	4.0									0.3
Opaques	0.1	0.1					0.4	0.1	0.2	0.3
Apatite	0.1	0.3					0.2	0.1	0.1	0.1
Andalusite	2.4									

Stop 4-4: Cooma Granodiorite, Nanny Goat Hill (Cooma 902876; map 7) sample CC1

Nanny Goat Hill is an outcrop of Cooma Granodiorite (14 km^2). The low country immediately west and south and the low hills to the east and south are also part of that unit. The higher hills to the west are migmatite and the bare flat-topped hills to the east are Monaro basalt. The rock is deeply weathered at the lookout but fresh blocks were once available in a road cutting 50 m south-east of the lookout. At this locality, the granodiorite is massive, medium- to coarse-grained and rich in biotite and biotite-rich inclusions. Large quartz crystals are common, as once were pale blue cordierite crystals up to 10 mm across. The inclusions are all of sedimentary derivation; most are biotite-rich, some are rich in sillimanite, and many show compositional banding. They are considered to be residual material from partial melting (restite) that has moved up from the source during intrusion of the granite. The lumps of milky and clear quartz are considered to be relicts of vein quartz from the partly melted metamorphic protolith. The muscovite seen in thin-section is considered to be a near-solidus alteration product which is characteristic of many S-type granites in the LFB.

The most distinctive chemical features of this rock are the very low CaO and Na_2O contents which resulted from the rock being derived from a clay-rich sedimentary source rock from which those two elements had earlier been lost during chemical weathering. Consequently the rock has a high quartz content and is extremely peraluminous (5.82% normative C) and therefore contains abundant Al-rich minerals. The Fe^{3+}:Fe^{2+} ratio is very low.

Petrographic description: The Cooma Granodiorite at Nanny Goat Hill is a massive medium-grained rock with a complex mineral assemblage. Quartz is by far the most abundant mineral with the two feldspars relatively low in amount, in keeping with the relatively low CaO and Na_2O contents. The quartz is seen as sutured interlocking aggregates indicative of post magmatic deformation and recrystallization. Plagioclase crystals are more-or-less tabular with well defined inner cores (An_{40}-An_{30}) and outer zones mostly around An_{15}. Irregularly-shaped K-feldspars, up to about 3 mm across, show a little patch perthite, no signs of microcline twinning and have myrmekite around their edges. Biotite (α = pale straw-yellow, $\beta = \gamma$ = reddish brown) appears as ragged flakes up to 1.5 mm and as aggregates in which muscovite may also appear. There are very wide pleochroic haloes around inclusions of zircon and monazite. Although blue cordierite crystals up to 10 mm in diameter are sometimes seen in hand specimens of this rock, fresh cordierite is rare in thin-section where most is seen as aggregates of muscovite and a greenish biotite rarely with cores of brownish pinite. Sillimanite (fibrolite) needles are rare within cordierite pseudomorphs or in ragged biotites. Andalusite is conspicuous as large (up to 1.5 mm) irregularly-shaped sieved crystals that appear to be late in that they apparently replace cordierite pseudomorphs and may surround mattes of fibrolite. Stout crystals of apatite, zircon, monazite and some tourmaline are accessory minerals.

Chemical composition: This rock has a high SiO_2 content (72%) for such a high total FeO content (4.01%), which is probably a reflection of abundant of restite quartz in this rock. CaO and Na_2O are very low in amount (0.95% and 1.49%), the distinctive feature of the Cooma Supersuite, and a reflection of derivation from clay-rich metasediments. As a consequence of these chemical features, this rock contains abundant modal quartz (48.3%) and normative C (5.82%). Normative Q is 42.43%, a lower figure than the modal quartz because of the high biotite content of the rock.

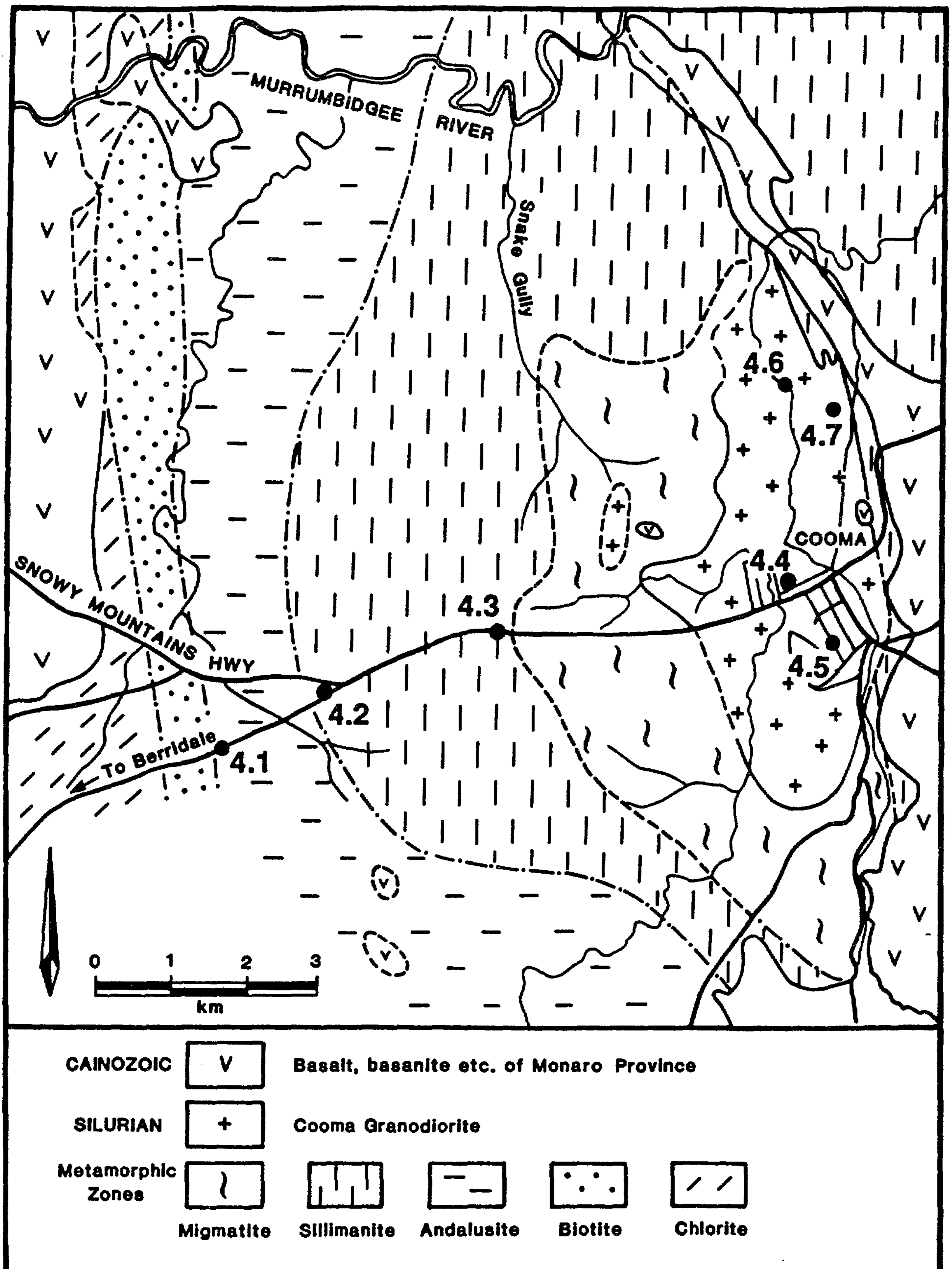
Isotopic ages: see detailed discussion on pp 19-24.

Isotopic composition: McCulloch & Chappell (1982) have given values of $\varepsilon_{Nd} = -9.2$, $^{87}Sr/^{86}Sr(I) = 0.71802$, T^{Nd} = 1560 Ma and $\delta^{18}O$ = 12.0‰ for this locality.

Return to Massie Street and then north and turn east on Soho Street. Cross the highway and two more cross-streets past the church constructed of Cooma Granodiorite. Stop just after Egan Street.

Stop 4-5: Soho Street Amphibolite (Cooma 909869; map 7)

A block of pyroxene-bearing amphibolite which occurs within the Cooma Granodiorite is found on the south side of the crest of Soho Street. Joplin (1939) considered this to be an original noritic intrusion. The amphibolite is intruded by a pegmatite on its western side. On the north side of Soho Street 50 m north-west of the amphibolite is a cutting in strongly foliated Cooma Granodiorite.



Map 7. Geological sketch map of the Cooma Complex

Isotopic ages: Tetley (1979) measured hornblende K-Ar and Ar-Ar ages from this locality, the latter being more precise at 407 ± 2 Ma. Harrison (1981) studied diffusion of Ar in hornblende from this locality.

Isotopic composition: The present-day $^{87}Sr/^{86}Sr$ composition of the amphibolite is 0.7038 (Pidgeon & Compston, 1965).

Return to the highway and turn north through Cooma and left on Bombala Street after the "Cooma Flags". Follow the street past the gaol and take the crossing on the right over Cooma Back Street and then right again to the sewerage works on Cooma Creek. Examine the large exposure in the creek a little more than 1 km downstream.

Stop 4-6: Foliated heterogeneous granite in Cooma Creek (Cooma 904904; map 7)

Large pavements of granite occur in Cooma Creek that include large areas of migmatite of the venite type elongated parallel to the north-south foliation and up to a few metres long. These occur in gneissic granite containing disrupted fragments of migmatite as well as almost continuous streaks of biotite-rich material resembling surmicaceous inclusions. The matrix is a mafic biotite-cordierite gneissic granite with conspicuous well-shaped feldspars commonly up to 10 mm across. Patches containing feldspars 2 to 5 mm across resemble the granite at Nanny Goat Hill. There is about 20% of melt in the outcrop area.

Return to near the centre of Cooma and take the road towards the Murrumbidgee River. On the left-hand side of the road, level with the northern edge of the cemetary on the right, there is a hill on which is located a water tank. Stop and climb towards that tank.

Stop 4-7: Cooma migmatite and granite (Cooma 913900; map 7)

Migmatite is exposed at the base of the hill and massive granite near the water tank. Between the two the is a transition zone some 100 m in width. Fresh exposures of granite have been excavated near the tank.

Return to the Snowy Mountains Highway and follow it south and west towards the Berridale Batholith. At 4.1 km from Soho St, at the top of the hill, there is a good view of the Snowy Mountains in the distance. Continue on the Snowy Mountains Highway to the right at the junction at 6.3 km and then after a further 2.1 km turn left on the Middlingbank Road. Follow that road west towards the wooded Coolringdon Hill, across the poorly exposed low-grade part of the Cooma Complex, partly covered on both sides of the road by alkali basalt. Watch for kangaroos when passing through the more thickly wooded Ordovician sediments on the eastern contact of the Berridale Batholith. Beyond the hornfels ridge, north of Coolringdon Hill, the edge of the Berridale Batholith (Cootralantra Granodiorite) is reached, 6.4 km from the Snowy Mountains Highway. Exposures of these granites continue for 2.1 km, beyond which a broad valley partly filled with basalt and basanite is crossed for 5.2 km. About 100 m beyond the reappearance of the granite, and 13.7 km from the Snowy Mountains Highway, there are fresh exposures of Cootralantra Granodiorite on both sides of the road.

Stop 4-8: Cootralantra Granodiorite (Berridale 693872; map 8) sample BB83

This is a relatively inclusion-rich example of the Cootralantra Granodiorite, an S-type granite and the second most abundant rock type in the Berridale Batholith after the I-type Buckleys Lake Adamellite. This unit has an exposed area of 360 km^2 with an additional area of approximately 50 km^2 being covered by Cainozoic basalt. It probably comprises several separate plutons (White *et al.*, 1977) and it is part of the Bullenbalong Supersuite. At this locality the granodiorite is medium- to coarse-grained and crowded with metasedimentary inclusions ranging from tiny pieces a few mm in diameter to large blocks of gneiss in which cordierite, sometimes accompanied by sillimanite and garnet, is recognizable. Green spinel is also found within the cordierites of some of the inclusions. Small dark grey clots 5 mm or less in diameter are pinite aggregates after cordierite. There are some relict garnets surrounded by altered cordierites. Cordierite pseudomorphs, some of which are well-shaped stumpy prisms about 10 mm long, are abundant. Analyses of the granodiorite (BB83) and of four inclusions (BB137, BB130, BB139 and BB131) are given in Table 9. Samples BB130 and BB131 are from this locality, BB137 is from 700 m further west on the Middlingbank Road (Berridale 686874), and BB139 is from still further along the road, 3.2 km west of this stop (Berridale 668891). These four have been chosen to illustrate the three types of inclusion found in the Cootralantra Granodiorite. BB137 and BB130 are representative of the cordierite-rich gneisses, and are relatively low in SiO_2 and contain abundant Al_2O_3. BB139 is an example of a Ca-rich inclusion containing abundant aggregates of actinolite, thought to be after orthopyroxene. BB131 represents a fine- and even-grained type without banding that is mineralogically similar to the host granite and this type may represent crystallized pieces of the granodiorite that have been reincorporated in the melt.

Petrographic description: Quartz dominates the mineral assemblage, occurring as irregularly-shaped crystals up to 3-4 mm across and sometimes as aggregates. It includes other minerals of the rock, particularly stumpy rectangular-shaped crystals of plagioclase. Plagioclase included in quartz may be quite small grains but elsewhere there are large crystals 3-4 mm long. Most plagioclase sections are dominated by calcic cores (An_{80} from optical determinations and fairly uniform in composition) surrounded mostly by normal zones but with some oscillatory zoning. Cores mostly outline the rectangular shapes but in detail are corroded. Some have a mottled core distribution, presumably because the section is cut along the boundary of the core. Biotite (α = pale yellow, $\beta = \gamma$ = foxy red-brown) is abundant (more than 20%) and appears as large crystals up to 3 mm across. K-feldspar is conspicuous as irregularly-shaped perthitic crystals with microcline twinning. Cordierite is scattered as large (up to 6 mm across) well-shaped crystals, always with some micaceous alteration along cracks and around the edges. There are also pseudomorphs consisting of an aggregate of colourless orthorhombic amphibole (anthophyllite) presumably after primary orthopyroxene. Apatite mostly appears as large (up to 0.5 mm) stumpy prisms. Zircon is seen as both long prisms and as very stumpy crystals, and monazite is easily recognized as smaller equidimensional crystals with lower relief than the zircons. There are a few tiny plates of ilmenite included in the biotites.

Chemical composition: This composition is very characteristic of the more mafic members of the Bullenbalong Supersuite, with Na_2O close to 2% (2.06%). Note also the analyses of four inclusions from this locality listed in Table 9, and the comments that have been made above on these four rocks.

Isotopic ages: Biotite from this locality gives ages of 418 ± 4 Ma and 416 ± 5 Ma by Rb-Sr and K-Ar respectively. The Cootralantra Granodiorite is a composite body consisting of several plutons of very similar ages and biotite from a second pluton at the western end of the Cootralantra type (BB19) gives 421 ± 3 Ma, 417 ± 4 Ma and 422 ± 2 Ma by Rb-Sr, K-Ar and Ar-Ar respectively. It is highly likely that none of these ages record emplacement.

The more than 30 Rb-Sr whole rock granodiorite and inclusion analyses from the Cootralantra scatter widely (MSWD 116) in a broad band that gives a model age of about 465 Ma. The scatter reflects isotopic differences in the protolith of the granodiorite which were not homogenized during magmatism. It is very likely that the whole-rock age also is affected by source isotopic heterogeneity, similar to that discovered in the S-type granites of the Murrumbidgee Batholith (Roddick & Compston, 1976). If that is the case, the emplacement age of the Cootralantra Granodiorite is almost certainly less than the whole-rock age. The initial $^{87}Sr/^{86}Sr$ for Cootralantra samples covers the range 0.711 to 0.716.

Cootralantra is rich in inherited zircon, with virtually every zircon grain containing an inherited core. Conventional zircon analyses show the 'mean' age of the inherited component to be about 1400 Ma. The strong inheritance prevents conventional zircon analyses being used to date emplacement. In contrast, a conventional monazite age from the Cootralantra Granodiorite of 428 ± 3 Ma is probably very close to the emplacement age. This is confirmed by the ion-probe analyses of inherited zircons and their younger precipitated rims. The ages of the inherited components are from Archaean to early Palaeozoic. If the emplacement age is close to 430 Ma, then the biotite Rb-Sr, K-Ar and Ar-Ar ages in all measured samples of the Cootralantra Granodiorite must have been partly reset, presumably during the emplacement of the younger I-type granites.

Conventional analyses of zircons from one metasedimentary enclave from the Cootralantra Granodiorite show zircon inheritance to be if anything slightly stronger than in the host granodiorite. However, the pattern of inheritance is almost identical, with the 'mean' age of inheritance being about 1800 Ma. This coincidence strongly supports the thesis that the Cootralantra Granodiorite is derived from metasediments and remnants of the source survive in the magma as lithic inclusions.

Isotopic composition of the Cootralantra Granodiorite: McCulloch & Chappell (1982) studied a sample (BB19) of the Cootralantra Granodiorite from another locality. They found ε_{Nd} = -8.4, $^{87}Sr/^{86}Sr(I)$ = 0.71206 and T^{Nd} = 1730 Ma. Unpublished data for Pb in feldspar are $^{206}Pb/^{204}Pb$ = 18.107, $^{207}Pb/^{204}Pb$ =15.641 and $^{208}Pb/^{204}Pb$ = 38.229. O'Neil & Chappell (1977) found a range of $\delta^{18}O$ of 9.96 to 10.55‰

for four samples of this unit; corresponding values for δD were -74 and -74 to -50‰.

Continue to the west where the Cootralantra Granodiorite on either side of the road is partly covered by basalt flows. Those flows persist until the eastern boundary of the younger Tara Granodiorite is crossed, 18 km from the Snowy Mountains Highway. Tors of the Tara Granodiorite are larger, more abundant, and more rounded. The western boundary of the Tara pluton is crossed 630 m before the road junction at Middlingbank Church; this contact runs north, just east of the road north from Middlingbank. On following that road, the Tara pluton is entered again 1.6 km north of the Middlingbank Church. A typical example of the Tara Granodiorite can be examined at a road cutting 3.0 km from the church.

Stop 4-9: Tara Granodiorite (Berridale 634924; map 8) sample BB86

The Tara Granodiorite is an elliptical pluton, 24 km^2 in area, intruded into the Cootralantra Granodiorite. The rock is an even-textured medium-grained hornblende-biotite granodiorite to transitional tonalite, typical of the late granodiorite-tonalite I-type intrusions of the Berridale--Kosciusko area. Mafic inclusions are fairly common at this locality, as they are throughout most of the body. Large crystals of allanite are common and easily recognized in the field since they have caused small expansion cracks to form in the surrounding minerals which may also be stained a rusty colour.

The physical conditions of formation of the this pluton were discussed by Miller *et al.* (1988). They concluded that the Tara magma separated from its source at a temperature of 766° C (with an uncertainty in the calibration of the model of about ± 30° C) and that it was emplaced to a depth of 9 ± 2 km.

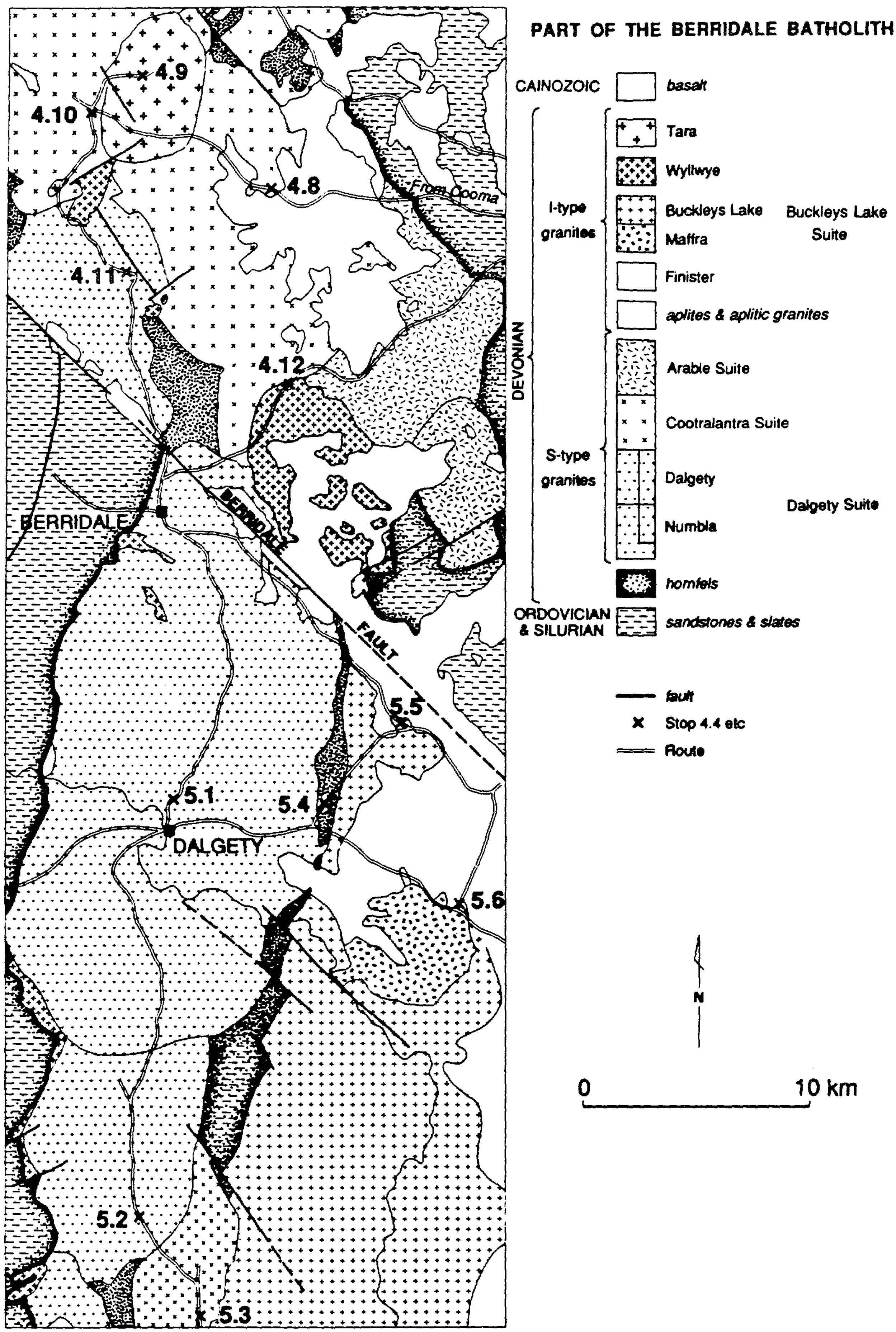
Petrographic description: Plagioclase is the dominant mineral, occurring as stubby well-shaped crystals mostly 1-2 mm in length with a composition zoned from cores near An_{60} (not a good determination) to outermost rims near An_{20}. Quartz appears as irregular crystals between and including other minerals. K-feldspar is present as small untwinned crystals interstitial to plagioclase and quartz. Most biotite (α = pale brownish yellow, $\beta = \gamma$ = dark sepia-brown to chocolate-brown) is unaltered but some grains are replaced by a bright green chlorite containing strips and lumps of epidote. Epidote is also present in some of the altered plagioclase cores. Fairly well-shaped prisms of hornblende (α = light yellow-green, β = olive-green, γ = dark grass-green) occur up to about 5 mm in length. Accessory apatite is seen as stout prisms commonly about 0.5 mm long ranging down to tiny prisms mainly in biotite and hornblende. Zircons are small and stout. Magnetite (up to 0.3 mm) with some ilmenite lamellae seen in polished sections, is scattered throughout and many of the small crystals have perfectly square cross-sections. Small sphenes with poor crystal shapes appear to be primary. Allanite is common and easily seen in hand-sample as well as in thin-section.

Chemical composition: This is a very typical composition of a more mafic I-type granite of the Berridale Batholith. Compare with the S-type BB83 from the previous stop (Table 9) and see the comparable SiO_2 contents, the lower Mg, Fe, Cr, K and Rb, and the higher Ca, Na and Sr. The Fe_2O_3:FeO ratio is also much higher in this I-type granite.

Isotopic ages: The Tara Granodiorite is geologically one of the later plutons in the Berridale Batholith, a fact supported by its measured age. Samples throughout the pluton yield ages by Rb-Sr and K-Ar that consistently are about 412 Ma. The ages measured on BB86 are biotite Rb-Sr 411 ± 3 Ma, biotite K-Ar 414 ± 5 Ma, biotite Ar-Ar 424 ± 2 Ma, hornblende K-Ar 411 ± 7 Ma and hornblende Ar-Ar 409 ± 3 Ma. The anomalously high biotite Ar-Ar age is highly reproducible and is associated with an 'anomalous' age spectrum characteristic of the biotites from several of the Berridale plutons (Tetley, 1979). It is thought that the anomalous spectra, characterized by high $^{40}Ar/^{39}Ar$ in the gas released between 750 and 950°C, are due to nuclear or structural effects. A consistent feature of the biotites yielding 'anomalous' spectra is their lower than average K and octahedral Al (Tetley, 1979).

The Rb-Sr whole rock analyses from the Tara Granodiorite show very little scatter, but also little dispersion and generally low Rb-Sr. They give a model age of about 418 Ma, consistent with the mineral ages. The inclusion of enclave analyses increases both the dispersion and scatter. The initial $^{87}Sr/^{86}Sr$ is closely clustered about 0.706.

Conventionally analyzed zircons from the Tara Granodiorite show significant inheritance of a pre-emplacement zircon component, but in much lesser amounts than in any of the S-type granites. The inheritance is sufficient, however, to prevent the determination of the granodiorite's emplacement age by conventional methods. The zircon has not yet been analyzed by ion-probe. Conventional analyses of zircons from one dioritic enclave show little or no inheritance. The only evidence for inheritance is that three of the analyzed fractions have $^{206}Pb/^{238}U$ ages significantly greater than the Rb-Sr and K-Ar mineral ages



Map 8. Map of granite units in the central part of the Berridale Batholith

Isotopic composition: McCulloch & Chappell (1982) determined values of ε_{Nd} = -3.2, $^{87}Sr/^{86}Sr(I)$ = 0.70628 and T^{Nd} = 1230 Ma for this locality. O'Neil & Chappell (1977) found $\delta^{18}O$ values in the range 7.86 to 8.33‰ and δD from -77 to -71‰ for three granites from other localities in this pluton.

Return to Middlingbank Church and examine the granite 100 m south of the cross-roads.

Stop 4-10: Cootralantra Granodiorite (Berridale 613910; map 8) sample BB3

This is another locality in the Cootralantra Granodiorite, in this case within the aureole of the Tara Granodiorite. The Skylab photograph of this area, used as a frontispiece by White *et al.* (1977), clearly shows the Tara pluton and its aureole, rather than the pluton itself, c.f. the interpretation of Miller *et al.* (1988).

Petrographic description: Quartz occurs as aggregates up to 5 mm across, each consisting of small sutured interlocking crystals with triple junctions. Plagioclase crystals are more-or-less rectangular in section with prominent sericitized cores. Normal zoning around the cores is still preserved with zones ranging from An_{30} to An_{20}. Most of the K-feldspar in this rock occurs as tiny crystals in recrystallized quartz aggregates, possibly accounting for the low K-feldspar content recorded in the counted slab, which is lower than KB83 even though the K and biotite contents of the two rocks are similar. Biotites (α = pale yellow, $\beta = \gamma$ = foxy red-brown) are ragged, most having recrystallized around the edges. Some biotites are aggregates of smaller crystals that have clearly replaced the original biotite. The biotite of these recrystallized patches may be more greenish-brown, suggesting more oxidizing conditions during alteration. Patches of secondary epidote may occur in biotites. Large cordierites with secondary micas along cracks are still preserved but unaltered crystals with ragged outlines appear within recrystallized aggregates. Small more-or-less equidimensional zircons and stumpy apatites are accessory minerals. Small monazite crystals within biotites were tentatively identified.

Chemical composition: This is very similar to that of BB83 from Stop 4-8.

Isotopic ages: Both the Rb-Sr and K-Ar isotopic systems in the biotite at this locality have been reset to the age of the Tara, giving 411 ± 2 and 413 ± 7 Ma respectively. It is this local metamorphic resetting of the isotopic age of its host rocks that gives us confidence that the Rb-Sr and K-Ar ages of the Tara Granodiorite are very close to its emplacement age. Similar isotopic resetting of the Cootralantra Granodiorite has been documented within the aureole of the 412 Ma Wullwye Granodiorite (Stop 4-12).

Isotopic composition: O'Neil & Chappell (1977) determined values of $\delta^{18}O$ = 9.96‰ and δD = -50‰ for this locality. Miller *et al.* (1988) have pointed out that the significant difference in δD between this locality and the Tara pluton (Stop 4-9) precludes a process of significant exchange of water between the Tara intrusion and its host, so that heat exchange must have occurred principally by conduction.

Continue south on the road towards Berridale through the Cootralantra Granodiorite and an aplitic phase, into the Dalgety Granodiorite. Boulders of that rock occur on the left side of the road at 10.0 km.

Stop 4-11: Dalgety Granodiorite (Berridale 631837; map 8) sample BB9

The Dalgety Granodiorite (310 km^2) is one of the major components of the Berridale Batholith. It is a coarse-grained S-type biotite granodiorite in which inclusions are present but not abundant. The biotites are reduced, as shown by their red-brown colour. Irregular-shaped clots of dull-grey material could be altered orthopyroxene. In both chemical composition and mineralogy this rock is not typical of the S-type granites of the region. It is not part of the Bullenbalong Supersuite, as it contains more CaO and Na_2O and it is also therefore less peraluminous (1.16% normative C), which is the reason for the absence of cordierite and aluminosilicate minerals. It is thought to have been derived from a slightly more feldspar-rich (less mature) sedimentary source.

Petrographic description: In this rock quartz and plagioclase are in about equal proportions. Quartz consists of aggregates or crystals with strong undulose extinction resulting from deformation but the plagioclases are well-shaped rectangular crystals with rounded inner cores near An_{50} that are sometimes sericitized and outer zones near An_{20}. There are lesser amounts of biotite (α = yellow-brown, $\beta = \gamma$ = dark brown with a reddish tint) some of which have almost perfect pseudohexagonal shapes, but most crystals show ragged teminations as a result of deformation and alteration. The alteration assemblage includes epidote and sphene as well as chlorite. Some biotite crystals are traversed by kink bands. The biotite contains inclusions of zircons with pleochroic haloes and a few apatites and rare rods of ilmenite. Elsewhere accessory apatites occur as large prisms. Cordierite is not present in this rock.

Chemical composition: This is an S-type composition (compare with the I-type BB86 of Stop 4-8) but is less "extreme" than the analyses of the Cootralantra Granodiorite in Table 9. Thus while it is more felsic, it is also higher in Ca, Na and K, and is consequently only mildly peraluminous (1.16% normative C).

Isotopic ages: The biotite in this sample of Dalgety Granodiorite has been dated by Rb-Sr, K-Ar and Ar-Ar, giving 415 ± 4, 410 ± 5 and 422 ± 2 Ma respectively. As in the the Tara Granodiorite, the Ar-Ar age is significantly older than the other two. However, in this case the release pattern is in no way anomalous and we consider the Ar-Ar age may be closer to the emplacement age of the granodiorite than the Rb-Sr and K-Ar results. As in the Cootralantra Granodiorite, it appears that the Rb-Sr and K-Ar systems in biotite have been partly reset.

The Rb-Sr whole rock analyses from the Dalgety Granodiorite show minor scatter about, and wide dispersion along, an isochron (MSWD 31). The model age is about 420 Ma, consistent with the mica results, but not sufficiently precise to test whether resetting of the mica ages might have occurred. The initial $^{87}Sr/^{86}Sr$ for the Dalgety Granodiorite samples is 0.709 to 0.711.

Conventional U-Pb analyses of zircons from the Dalgety Granodiorite show marked inheritance, but not as strongly as in the Cootralantra Granodiorite. The interpreted 'mean' age of the inheritance is similar however, at about 1700 Ma. The discordance pattern is strongly curved downwards at its lower end, showing very clearly that the zircon population consists of more than two principal components. Extrapolation of the upper part of the discordance line gives a concordia intersection of about 380 Ma, significantly less than the age of 430 ± 3 Ma recorded by concordant monazites. The monazite age is thought to be the most accurate estimate of the Dalgety Granodiorite's emplacement age, a conclusion supported by recent ion-probe work. This is a clear validation of our general conclusion that concordia intersections of discordance arrays in cases where inheritance is significant, are very poor estimators of the age of magmatism.

Isotopic composition: For this locality, O'Neil & Chappell (1977) reported $\delta^{18}O$ = 9.6‰.

Continue towards Berridale on the Dalgety Granodiorite. The town of Berridale comes into view; the wooded hills to the west are Ordovician sedimentary rocks that separate the Berridale and Kosciusko Batholiths. The hills to the east are the northern end of a screen that runs for 70 km to the southern end of the Berridale Batholith, the Gygederick Screen, which will be seen further south at Stop 5-4. After 4.5 km turn left on the Rocky Plains Road towards Cooma. The road passes onto the Gygederick Screen after 1.1 km; the screen is only 700 m wide at this point. At this northern end of the batholith, the screen separates the Dalgety and Cootralantra Granodiorites, and the characteristic small tors of the latter are seen again on crossing to the eastern side. After 8.2 km turn right on the Alpine Way towards Berridale. Stop after 1.0 km at large granite blocks on the south side of the road at the boundary of the Cootralantra and Wullwye Granodiorites.

Stop 4-12: Wullwye Granodiorite (Berridale 695783; map 8) sample BB93

The Wullwye Granodiorite (39 km^2) is a very felsic I-type granite with evenly scattered biotite crystals. Hornblende is not present and inclusions are virtually absent. The pink-coloured K-feldspar is the only field indication of the I-type character of this pluton (Chappell & White, 1984). However, chemical data with high Na:K, are diagnostic of its being I-type. In thin-section, the rock is seen to be strongly deformed. The contact between the Wullwye and Cootralantra intrusions at this locality can be located to within a few metres. No inclusions of Cootralantra have been seen within the younger Wullwye, nor any sign of contamination. Note the difference in the size and colour of the tors between these two units.

Petrographic description of the Wullwye Granodiorite: Plagioclase is the dominant mineral amounting to 40% of the rock. Crystals are irregular in detail but crudely rectangular in section. Normal zoning is common but rarely strong enough to outline internal crystal shapes, and almost all sections show cores outlined by the distribution of sericite. The composition is near An_{20}-An_{25}. The albite twinning on all crystals is exceptionally fine. Quartz is abundant as aggregates of sutured interlocking crystals. K-feldspar is microcline microperthite. Biotite (α = pale yellow with a greenish tint, $\beta = \gamma$ = dark brown with a slight reddish tint) is the sole mafic mineral. Chlorite with patches of green epidote and a few flakes of white mica are secondary. Zircons are seen as mostly tiny equidimensional crystals; one stumpy prism had several oscillations in its outer zones. Monazite also occurs as crystals smaller than the zircons. There is also a rusty brown radioactive mineral of similar dimensions in the biotite. It looks like partly metamict uranothorite but the U and Th of this rock are normal if not low for a rock with almost 75% SiO_2. There are a few grains of magnetite. Bent biotites, bent plagioclase crystals, undulose extinction in the quartz and some quartz aggregates with sutured boundaries, indicate that this sample has been deformed.

Chemical composition: This is a felsic granite with a very distinctive composition, unique in the LFB, characterized by an unusually high Na:K ratio and high Sr.

Isotopic ages: The biotite Rb-Sr age measured on BB93, 413 ± 4 Ma, is the same as that measured on all other samples from the pluton by Rb-Sr and K-Ar. As the pluton is geologically one of the youngest in the Berridale Batholith, it is likely that the mica ages are very close to the age of emplacement. The only Ar-Ar age measured on the pluton, biotite dated at 420 ± 3 Ma, is significantly greater. The biotite does not show an obviously anomalous release spectrum, but we nevertheless have reservations about the geological significance of the older age. The Wullwye Granodiorite is very uniform in Rb/Sr, making it impossible even to guess its whole rock age. If the emplacement age of the pluton is assumed to be the same as the mica age, then the whole rock initial $^{87}Sr/^{86}Sr$ is 0.706.

Isotopic composition of the Cootralantra Granodiorite: McCulloch & Chappell (1982) studied a sample (BB19) of the Cootralantra Granodiorite from another locality. They found ε_{Nd} = -8.4, $^{87}Sr/^{86}Sr(I)$ = 0.71206 and T^{Nd} = 1730 Ma. Unpublished data for Pb in feldspar are $^{206}Pb/^{204}Pb$ = 18.107, $^{207}Pb/^{204}Pb$ =15.641 and $^{208}Pb/^{204}Pb$ = 38.229. O'Neil & Chappell (1977) determined a value of $\delta^{18}O$ of 10.55‰ for this locality and a range of 9.96 to 10.55‰ for four samples of this unit; corresponding values for δD were -74 and -74 to -50‰.

Isotopic composition of the Wullwye Granodiorite: For another sample of this unit (BB62), very similar in composition to BB93, McCulloch & Chappell (1982) reported ε_{Nd} = +0.4, $^{87}Sr/^{86}Sr(I)$ = 0.70555 and T^{Nd} = 920 Ma. Unpublished Pb data on feldspars are $^{206}Pb/^{204}Pb$ = 18.261, $^{207}Pb/^{204}Pb$ = 15.623 and $^{208}Pb/^{204}Pb$ = 38.263. On yet another sample (BB34), O'Neil & Chappell (1977) measured a $\delta^{18}O$ value of 8.33‰ and a δD of -89‰.

Continue on the Alpine Way to Berridale. This road crosses the northern part of the Wullwye Granodiorite, which is easily recognized in the distance by its large buff-coloured and more isolated tors. The bare hills without tors south of the road are covered by a veneer of basalt. The road re-enters the Cootralantra Granodiorite 3.1 km from the eastern contact at Stop 4-12. To the north of the road, the large wooded Gygederick Hill again marks the screen at western edge of the Cootralantra Granodiorite. East of the summit of that hill, black graptolitic shales of Ordovician age are interbedded with quartzites and contain small chiastolite crystals. The southern extension of this screen has been faulted 11 km to the south-east by the left-lateral movement of the Berridale Wrench Fault (Lambert & White, 1965). At Gygederick Creek, the trace of that fault may be seen by the line of springs south of the road. The granite outcrops north of the road are of Buckleys Lake Adamellite, which will be seen further south at Stop 5-5. The Berridale Fault is crossed just before entering Berridale.

DAY 5. GRANITES OF THE KOSCIUSKO AND BEGA BASEMENT TERRANES (BERRIDALE AND BEGA BATHOLITHS)

On the fifth day of the excursion, granites in the Berridale Batholith, on both sides of the IS-line, are examined. Leaving the Berridale Batholith and travelling towards the south-east, and after crossing an extensive area covered by basalts of the Monaro Province, the excursion visits I-type granites from the the Bega Batholith. The latter are representative of the five more westerly supersuites (out of seven) from that batholith, in which progressive compositional changes are observed in the direction of the continental margin. Inspection of those I-type granites is followed by a visit to an A-type granite locality. Finally, an examination is made of a cutting in Ordovician sediments, from which samples have been obtained for isotopic studies. Chemical and modal analyses of rocks from these localities are given in Tables 11 and 12.

Leave Berridale by the Dalgety road. This traverses much of that part of the Dalgety Granodiorite that occurs south of the Berridale Fault. After 8 km notice the tree-covered Wullwye Hill to the south-east, which is part of the southern extension of the Gygederick Screen. At 13 km there is a good view of the snow-covered Kosciusko Plateau on the right and the broad valley occupied by the Dalgety Granodiorite ahead to the south. Wooded hills in the far distance to the south-east are contact rocks around the Dalgety Granodiorite. At 15 km the road crosses Wullwye Creek and 1.4 km beyond the bridge boulders on the right side of the road are examined.

Stop 5-1: Dalgety Granodiorite (Berridale 645600; map 8) sample BB11

This rock is similar to BB9 at Stop 4-11 except that the K-feldspars are larger and up to 40 mm long and a small amount of cordierite occurs in the rock. As in BB9, there are dark fine-grained pseudomorphs, presumably after orthopyroxene. Inclusions at this locality include large (400 mm) more mafic Dalgety Granodiorite which themselves contain relatively coarsely crystalline inclusions (double enclaves); these are presumably re-incorporated early Dalgety Granodiorite. There are also inclusions of quartz 50 mm across and some fine-grained microgranular inclusions.

Petrographic description: Plagioclase occurs as fairly good crystals particularly when enclosed in K-feldspar. Some rectangular sections are up to 5 mm long. Cores, commonly sericitized are near An_{60} and these are surrounded by normally zoned rims with a prominent outer zone near An_{20} and an outermost zone near An_{15}. Quartz is abundant as irregular lumps up to 10 mm across with undulose extinction. K-feldspar includes other minerals that sometimes appear as optically continuous patches up to 10 mm across. Biotite (α= yellow-brown, $\beta = \gamma$ = brown with a slightly reddish tint) is commonly bent and extensively altered to chlorite with patches of epidote and sphene commonly along swollen cleavages. Cordierite, altered to pinite and commonly to aggregates of mica, occurs as small crystals. Zircon, stout prisms of apatite and ilmenite rods in biotite are rare. Monazite was not positively identified. Patches consisting of fine-grained quartz and biotite may be made over orthopyroxene. A small amount of magnetite was identified in the field with a hand-magnet.

Chemical composition: This is a more felsic example of the Dalgety Granodiorite than BB9 of Stop 4-11. As is the case with that other rock, it is less peraluminous than rocks of the Bullenbalong Supersuite, containing 1.44% normative C.

Continue on the road to Dalgety. If time permits, continue through Dalgety to see the felsic Numbla Vale Adamellite and mafic Finister Tonalite (Stops 5-2 and 5-3). Alternatively, turn left at 1.9 km south of Stop 5.1 on to the Nimmitabel road and continue from "Nimmitabel Road" below.

The crest of the ridge on the Jimenbuen road 11.5 km south of the Jindabyne-Dalgety road is close to the contact between the Dalgety and Numbla Vale granites. Continue across the latter pluton for a further 8 km, to boulders on the eastern side of the road 2.4 km south of the Matong Road near Numbla Vale.

TABLE 11. CHEMICAL ANALYSES: BERRIDALE BATHOLITH (CENTRAL PART)

	BB11	BB2	BB100	BB10	BB21
Stop	5-1	5-2	5-3	5-5	5-6
SiO_2	70.89	73.48	64.54	71.15	76.56
TiO_2	0.35	0.22	0.45	0.37	0.19
Al_2O_3	13.92	13.41	14.71	13.90	12.60
Fe_2O_3	0.72	0.44	0.98	1.18	0.43
FeO	2.26	1.47	4.34	1.40	0.43
MnO	0.06	0.04	0.10	0.05	0.02
MgO	1.00	0.71	2.77	0.86	0.21
CaO	2.31	1.70	5.30	2.61	0.97
Na_2O	2.56	2.63	1.86	3.04	3.52
K_2O	3.96	4.63	2.55	3.98	4.16
P_2O_5	0.09	0.08	0.09	0.08	0.03
H_2O+	1.39	0.74	1.81	0.67	0.47
H_2O-	0.15	0.14	0.15	0.19	0.15
CO_2	0.29	0.11	0.07	0.24	0.11
total	99.95	99.80	99.72	99.72	99.85
Trace elements (ppm)					
Rb	178	236	132	190	214
Sr	198	97	135	191	99
Ba	625	350	385	590	545
Zr	136	100	109	152	115
Nb	10.5	10.0	7.5	12.0	16.5
Y	40	33	21	32	26
Ce	70	49	46	88	66
Sc	12	7	28	11	5
V	42	25	129	45	7
Cr	13	10	60	4	<1
Ni	6	4	12	2	<1
Zn	47	28	66	32	17
Ga	15.2	13.8	15.8	14.8	12.0
Pb	33	37	13	19	17
Th	18	19	14	21	19
U	4.2	6.4	1.8	4.8	3.6
Norm. C	1.44	1.17	-	0.04	0.61
Modes					
Quartz	37.5	34.4	33.1	36.1	34.3
K-feldspar	24.5	29.5	4.1	19.6	35.0
Plagioclase	27.1	27.1	41.7	38.3	28.3
Biotite	10.7	8.7	14.8	5.5	1.9
Hornblende			6.3		
Muscovite		0.2			0.2
Opaques	0.1	0.1		0.5	0.3
Sphene					
Apatite	0.1			0.1	
Allanite					

Stop 5-2: Numbla Vale Adamellite (Numbla 627414; map 8) sample BB2

The Numbla Vale Adamellite (49 km^2) occurs immediately south of, and is intruded by, the Dalgety Granodiorite. It is is the most felsic S-type granite of the Berridale Batholith and is very poorly exposed. It is thought to be very close to an unfractionated minimum-temperature S-type melt composition and its composition has been used in modelling S-type partial melting in the LFB. In spite of its felsic character, this rock contains accessory cordierite which appears as large well-formed crystals that show various stages of alteration to micas and pinite.

Petrographic description: This is a felsic cordierite-bearing granite, with only 9% of ferromagnesian minerals. Like the more mafic cordierite-bearing granites of the Bullenbalong Suite, this rock also contains more quartz than either of the two feldspars. Individual grains are up to 4 mm across. Plagioclase is only slightly more abundant than K-feldspar. It is seen as tabular crystals up to 4 mm long, containing sharply defined corroded cores near An_{60} surrounded by many oscillatory zones and outermost zones near An_{20}. There are some thin rims of almost pure albite and myrmekite intergrowths are common at the boundaries between plagioclase and K-feldspar crystals. Weakly perthitic K-feldspar commonly includes other minerals. Biotite (α = straw yellow, $\beta = \gamma$ = dark sepia-brown to foxy-brown) is seen either as poorly shaped isolated crystals up to 2 mm across or as ragged aggregates of crystals commonly with clusters of small equigranular quartz, scattered zircons and relatively large apatites (0.5 mm across). Biotites contain tiny inclusions of zircon and monazite both of which are surrounded by prominent pleochroic haloes. The monazites are distinguished from zircons by their lower relief and tabular habit. Cordierite appears as tabular crystals up to 2 mm across. It is always partly altered around the edges and along cracks to aggregates of sericite and greenish mica. An accessory phase in this rock is magnetite which is rare in cordierite-bearing granites. Some blue-coloured tourmaline is present.

Chemical composition: This rock has a felsic composition thought to be close to that of a primary minimum-temperature composition S-type granite melt. In that context, note that the normative C content is 1.17%. It is the most felsic S-type granite analyzed from the Berridale Batholith and it does not show signs of feldspar fractionation (elevated Rb, low Sr and Ba). Na_2O is still low in amount for a felsic rock (2.63%), consistent with its derivation from Na-poor sediments.

Isotopic ages: Mica ages measured from this locality, one of the few fresh samples in this body, are 418 ± 2 Ma (Rb-Sr), 422 ± 5 Ma (K-Ar) and 430 ± 2 Ma (Ar-Ar). The Numbla Vale biotite is one of those that Tetley (1979) found to have an anomalous release pattern so the Ar-Ar age is suspected to be too high. The other two mica ages, and those measured on a second sample (BB29) are nevertheless significantly higher than the ages measured on the small I-type plutons.

Only three whole-rock samples of the Numbla Vale Adamellite have been measured for Rb-Sr dating. Fortunately the analyses are well dispersed so that while they are not adequate to define a good whole-rock isochron, it is possible to see that they are consistent with the mica age of about 418 Ma. The initial $^{87}Sr/^{86}Sr$ for the Numbla Vale is high, as in the other S-type granites, at 0.711.

Conventionally analyzed zircons from the Numbla Vale show moderate inheritance with an apparent 'mean' age of 1600 Ma. The lower concordia intersection is 390 Ma, significantly less than the age of two concordant monazite fractions, 440 ± 3 Ma. The monazite is probably recording the age of emplacement, making the Numbla Vale Adamellite perhaps the oldest S-type granite in the Berridale Batholith. The reservation in this claim is that with alteration monazite tends to increase its Pb/U, so if the Numbla Vale monazite has been affected by weathering it is possible the monazite age is too high.

The Numbla Vale zircons have not yet been analyzed by ion-probe.

Isotopic composition: McCulloch & Chappell (1982) reported values of ε_{Nd} = -8.0, $^{87}Sr/^{86}Sr(I)$ = 0.71076 and T^{Nd} = 1740 Ma for this rock. Unpublished Pb data on feldspars are $^{206}Pb/^{204}Pb$ = 18.135, $^{207}Pb/^{204}Pb$ = 15.644 and $^{208}Pb/^{204}Pb$ = 38.240. O'Neil & Chappell (1977) gave a $\delta^{18}O$ value of 10.23‰.

Continue south towards Jimenbuen. The distant hills to the east are made of Buckleys Lake Adamellite which occurs on the eastern side of the central screen of the Berridale Batholith, which at this latitude is represented by the older Finister Granodiorite. Continue to boulders of that body next to the road 5.7 km south of Stop 5-2.

Stop 5-3: Finister Tonalite (Numbla 653368; map 8) sample BB100

This I-type pluton (33 km^2) is a light-grey even-grained hornblende-biotite granodiorite transitional to tonalite. It is intruded by the Numbla Vale Adamellite, and hence it is one of the oldest rocks in the Berridale Batholith. It makes up part of the screen between the I- and S-type granites in that batholith.

Petrographic description: Plagioclase is dominant as small fairly well-formed crystals that rarely exceed 2 mm in longest dimension. They have more calcic cores that are sharply defined and easily seen by their higher birefringence (yellow as opposed to the surrounding grey) when they are not altered to sericite which is most common. The cores have a composition of at least An_{70}-An_{75} and the surrounding normally and sometimes oscillatory zones, are mostly An_{35}-An_{40}. In contrast to the plagioclase, quartz appears as large crystals with undulose extinction or aggregates averaging 10 mm across. Biotite (α = straw yellow, $\beta = \gamma$ = dark sepia-brown with a slight reddish tint occurs as large crystals but surroundng these there are commonly aggregates of smaller biotites and these may have a more green-brown colour indicating that the biotites have recrystallized under more oxidizing conditions. Biotite is extensively altered to chlorite and commonly contains strips and lenses of epidote and possibly secondary sphene along the cleavage planes. Hornblende crystals are ragged. Large grains have brown cores (α = pale greenish yellow, β = brown with greenish tint, γ = brown-green) and blue-green outside rims (α = yellowish, β = olive-green, γ = blue-green). The blue-green hornblende appears as separate crystals within the recrystallized biotite aggregates and this second generation may be the result of later recrystallization in a metamorphic aureole. There is no primary sphene. K-feldspar is minor and occurs as small interstitial, shapeless crystals along with some small grains of quartz. Apatite prisms and zircons are accessory. No magnetite or ilmenite was found in this thin-section.

Chemical composition: This is a mafic I-type granite of unusual composition. Ca and Cr are particularly high in amount, while Na and Sr have low abundances.

Isotopic ages: The Finister Tonalite is somewhat of an enigma isotopically and even more work needs to be done to understand it. Geologically the pluton is one of the earliest in the Berridale Batholith, predating as it does the Numbla Vale and Buckleys Lake Adamellites. The mica ages measured on BB100 are 417 ± 4 Ma (Rb-Sr) and 415 ± 7 Ma (K-Ar). Mica ages measured on five other samples from the pluton are similar to these, with the exception of the Ar-Ar result of 428 ± 3 Ma measured on BB163. Once again, however, this result is suspected to be an overestimate of age because the Ar release pattern shows an anomalous peak for the steps between 750 and 950° C. The K-Ar and Ar-Ar ages measured on hornblende from BB163 are 411 ± 7 Ma and 415 ± 3 Ma, respectively.

The enigmatic feature of the Finister isotopic systems is the steepness of the Rb-Sr whole rock isochron. Uncharacteristically for an I-type granite, the Finister whole rock age, 497 ± 37 Ma, is much greater both than the pluton's mica age and the inferred age of the pluton's host rocks (late Ordovician to Silurian). The initial ratio for the tonalite is high relative to the other I-type granites, 0.708, but nevertheless on the low side relative to the S-type granites.

Conventional analyses of zircons from the Finister unit show that inheritance is present, but in lesser amounts than in the Tara Granodiorite, which shows no inheritance in its whole rock Rb-Sr and a much lower initial $^{87}Sr/^{86}Sr$ of 0.706. The zircon analyses define a discordance array with an apparent 'mean' upper intersection age of a little over 1000 Ma. It remains for ion-probe analyses of the zircons to be made to see whether there is anything unusual about the age makeup of the Finister source rocks that might indicate the reason the inheritance in the whole rock Rb-Sr is so pronounced.

Isotopic composition: McCulloch & Chappell (1982) studied a different sample from this unit (BB163) and obtained ε_{Nd} = -8.1, $^{87}Sr/^{86}Sr(I)$ = 0.71189 and T^{Nd} = 1620 Ma. O'Neil & Chappell (1977) measured $\delta^{18}O$ (7.94 and 8.01‰) and δD (-52 and -65‰) on another two samples.

The road south from Stop 5-3 crosses the eastern edge of the Finister Granodiorite 600 m west of Jimenbuen homestead and a very felsic phase of the I-type Buckleys Lake Adamellite can be examined 100 m north of that building. The I-S line has been crossed between Stop 5-3 and this point. Return north to Dalgety and then to the junction of the Nimmitabel Road 500 m north of the Snowy River Bridge. Note that Dalgety was on the short list for selection as Australia's Capital!

Nimmitabel Road: Travel towards the east along this road across the Dalgety Granodiorite to the Bobundra Road at 6.6 km. This is the eastern edge of the Dalgety pluton. Take the road up the hill along the screen between the Dalgety and Buckleys Lake intrusions for 1.4 km.

Stop 5-4: Wullwye screen on the I-S line (Berridale 709597; map 8)

From the Wullwye Screen on the I-S line, the Dalgety Granodiorite is seen to the west and the Buckleys Lake Adamellite to the east. The screen between these two units can be seen trending to the south by the absence of any outcrop, although some of the outcrop-free area is covered by a thin cover of basalt. A few kilometres further south the screen narrows to a few metres and is finally breached and the Dalgety unit intrudes the Buckleys Lake pluton. This screen can be traced to the south for a distance of 50 km and marks the eastern limit within the LFB of S-type granites derived from deeper pre-Ordovician sedimentary source rocks. This limit and its extension to both north and south was called the IS-line by White *et al.* (1976a) and as those authors pointed out it marks the eastern limit of thick crystalline crust in the belt. It is now regarded as the boundary between the Kosciusko and Bega Basement Terranes (Chappell *et al.*, 1988). From now on, the excusion will remain east of the IS-line until immediately before the return to Canberra and no more S-type granites will be seen. From this point there is a good panorama of the central parts of the Berridale Batholith. In the distance to the west the Kosciusko Plateau is on the horizon and in front of that is the lower Beloka Plateau the edge of which is seen at the Barneys Range scarp with a prominent gap through which flows the Snowy River.

Continue on the road past Wullwye Hill. The contact with the Buckleys Lake Adamellite is covered by scree but 2 km from Bobundara turnoff there is a large boulder of Buckleys Lake Adamellite on the south side of the road. After 5 km from the turnoff turn left towards Berridale to outcrops of Buckleys Lake Adamellite at the southern end of Buckleys Lake, 600 m from this junction.

Stop 5-5: Buckleys Lake Adamellite (Berridale 746634; map 8) sample BB10

This is the most extensive rock type in the Berridale Batholith, with 470 km^2 of exposure and approximately an additional 150 km^2 covered by Cainozoic basalt. It is one of seven I-type plutons in the LFB with areas between 560 and 620 km^2, a prominent mode in the frequency distribution of areas, with two larger bodies (Bemboka and Tynong) near 1000 km^2 in area. The Buckleys Lake unit is a coarse-grained porphyritic biotite adamellite containing scattered hornblende-bearing mafic inclusions. The large crystals of K-feldspar are commonly 40 mm across, and are pink and as they are in most I-type granites, the main exception being the ilmenite-series I-type granites. The plagioclase has a greenish tint and both sphene and magnetite are accessories. The only hornblende in this rock is in the inclusions.

Petrographic description: Quartz grains are 10-15 mm across are seen in thin-section to have strong undulose extinction but are not broken into smaller crystals and recrystallized as in many granites. Plagioclase, mostly zoned from An_{40} to An_{20} and commonly as crystals 2-3 mm long, may show bent twin planes. Biotite crystals (α = pale yellow-brown, $\beta = \gamma$ = dark chocolate-brown) are mostly beween 1-2 mm. Some biotites are traversed by kink bands but few are partly altered to green chlorite and accompanying strips of epidote. Beautifully zoned allanites and perfectly-shaped crystals of sphene are both commonly around 1mm across. Magnetite is also an abundant accessory mineral commonly displaying square cross--sections. In contrast to the size of other accessory minerals, apatite occurs as inconspicuous tiny prisms, mostly in biotites.

The deformation of minerals in this rock is unlike those recorded in many other localities, for instance in the Bullenbalong suite rocks such as KB12. Deformation here is presumably the result of movement on the adjacent Berridale Fault.

Chemical composition: This is a moderately felsic I-type granite composition, that is very weakly peraluminous (0.04 % normative C).

Isotopic ages: Biotite ages have been measured on seven samples from the large Buckleys Lake Adamellite. All give ages very close to 417 Ma. The results obtained from BB10 are Rb-Sr 417 ± 2 Ma, K-Ar 413 ± 5 Ma and Ar-Ar 421 ± 2 Ma. The Ar-Ar age is greater than any Rb-Sr or K-Ar age measured on the other samples, and the Ar release spectrum is anomalous, so the Ar-Ar age is at present not considered to be geologically significant.

Rb/Sr in the Buckleys Lake whole-rocks, including inclusions, shows a wide dispersion ($^{87}Rb/^{86}Sr$ 3 to 13) so the pluton's whole rock isochron is well defined. There is significant scatter (MSWD 37) but it is contributed principally by the enclave analyses. The whole rock isochron age is indistinguishable from the biotite age of 417 Ma and the initial $^{87}Sr/^{86}Sr$ is moderate, 0.706 to 0.708 for the adamellite samples. No zircons have been analyzed from the Buckleys Lake Adamellite.

Isotopic composition: McCulloch & Chappell (1982) report values of ε_{Nd} = -2.6, $^{87}Sr/^{86}Sr(I)$ = 0.70673 and T^{Nd} = 1210 Ma for this rock. Unpublished data on Pb in feldspar are $^{206}Pb/^{204}Pb$ = 18.179, $^{207}Pb/^{204}Pb$ = 15.632 and $^{208}Pb/^{204}Pb$ = 38.246. O'Neil & Chappell (1977) measured a $\delta^{18}O$ value of 8.78‰ for this rock and a δD of -77‰, with values of 8.53‰ and -83‰ for another locality.

Return towards the south from the BB10 locality and after 1 km what is probably the eastern margin of the Berridale Batholith is seen in the wooded hills to the east beyond the area covered by basalt. Most of the area under basalt to the east and south is probably Buckleys Lake Adamellite. Outcrops on the immediate right are of an aplitic granite. At 5.4 km from BB10 turn right on the Bungarby Road to Maffra. 4.5 km from this turn and 150 m before the Dalgety-Bombala road, examine outcrops of Maffra Adamellite.

Stop 5-6: Maffra Adamellite (Numbla 769549; map 8) sample BB21

This is a fine-grained pink I-type granite with green-brown biotite (1.9%) as the only mafic mineral and an area of 24 km^2. Small amounts of muscovite, probably secondary, are seen in thin--section. There are few inclusions, as expected in such a felsic rock. This rock must be very close to a primary minimum-temperature melt in composition.

Petrographic description: This is a fine-grained pink adamellite rarely seen unaltered. Quartz is 3-4 mm across and sometimes occurs as irregular grains and sometimes as aggregates. In hand-samples, plagioclase is green when the rock is not weathered. In thin-section plagioclase is seen to have good crystal outlines. It has cores near An_{35} surrounded by normal zones mostly near An_{20}. Finely perthitic K-feldspar occurs as large crystals (10 mm) including other minerals as well as small interstitial grains and small inclusions in quartz. Biotite (α = straw coloured, $\beta = \gamma$ = chocolate-brown) can look slightly reddish in some sections but it is not like the biotite in the cordierite granites. There are a few large interstitial muscovites but these are all considered to be secondary. Fairly abundant magnetite, zircon, apatite and very rare large primary sphenes are accessory.

Chemical composition: This rock has close to the "ideal" I-type minimum-temperature composition. Like the postulated S-type minimum-temperature melt (BB2 of Stop 5-2), it is mildly corundum normative, 0.61% in this case compared to 1.17% for BB2.

Isotopic ages: The Maffra Adamellite is one of the few I-type granites in the Berridale Batholith that is felsic enough to contain muscovite. The mica ages measured on BB21 are biotite Rb-Sr 410 ± 2 Ma, K-Ar 413 ± 5 Ma, Ar-Ar 414 ± 2 Ma, and muscovite Rb-Sr 414 ± 4 Ma. The great similarity among these results gives confidence that the emplacement age of the Maffra Adamellite is about 413 Ma.

Only two samples have been analyzed for whole rock Rb-Sr. They differ in Rb/Sr by about 30% and define an isochron consistent with the mica age. The indicated initial $^{87}Sr/^{86}Sr$ is 0.705, as low as any measured on the Berridale Batholith.

Several zircon fractions from the Maffra have been analyzed conventionally for U-Pb. Two notable features of the zircons are that they are particularly uranium-rich (800-1200 ppm) and they are the only zircons so far analyzed from the Berridale and Kosciusko batholiths that show no evidence of inheritance. Interpretation of the zircon age is not completely straightforward however, because there is a wide range in discordance and a clear tendency for the more discordant fractions to be the highest in radiogenic $^{207}Pb/^{206}Pb$. This cannot be explained by simple recent loss of radiogenic Pb from zircons of uniform age. Either this is an unlikely case of more discordant fractions containing a small inherited zircon component or, more probably, the more discordant fractions have suffered some preferential loss of intermediate daughter products from the ^{238}U decay chain, the most likely being gaseous ^{222}Rn, which has a half-life of 4 days, 5 orders of magnitude longer than the ^{219}Rn in the ^{235}U chain.

The Maffra Adamellite also contains monazite. The mean age of three concordant monazite fractions is 412 ± 2 Ma, indistinguishable from the mean mica age. This increases the confidence that the emplacement age of the Maffra is 412 Ma, and reinforces the conclusion that the higher $^{207}Pb/^{206}Pb$ ages measured on some of the zircon fractions (up to 505 Ma) are not geologically significant.

Isotopic composition: McCulloch & Chappell (1982) analyzed another, very similar, rock from this unit (BB31) and obtained ε_{Nd} = 0.0, $^{87}Sr/^{86}Sr(I)$ = 0.70504, T^{Nd} = 1010 Ma. O'Neil & Chappell (1977) report a value for $\delta^{18}O$ of 9.32‰ for this locality and δD of -78‰. For the whole Buckleys Lake unit, those authors found ranges of 9.32 to 9.56‰ for $\delta^{18}O$ and -87 to -71‰ for δD.

Follow the Bombala road south for 3.7 km and then turn left along the Nimmitabel road. At 2.1 km from this junction there is an inlier of Buckleys Lake Adamellite but apart from this the only rocks exposed on the road to Nimmitabel are basalts of the Monaro Province. At 28 km from the Bombala road turn south along the Snowy Mountains Highway. Ordovician sediments on the western side of the Bega Batholith are reached 3 km from that junction. After 4.4 km the highway enters the deeply weathered Nimmitabel Adamellite. The first tors are of Glenbog Granodiorite. Both the Nimmitabel and Glenbog units are parts of the Glenbog Suite which extends down much of the western side of the batholith. Tors of Glenbog Granodiorite are seen on the roadside 1.2 km beyond the McLaughlin River. Continue on the highway past the Bombala turnoff at 3.9 km after the river and continue 5.2 km to outcrops of the Glenbog Granodiorite on the south side of the road (400 m past the bridge over the headwaters of the Bombala River).

Stop 5-7: Glenbog Granodiorite (Bombala 105460; map 9) sample AB6

The Glenbog Suite consists of twelve plutons with a total area of 1510 km^2 occurring over a distance of 265 km along the western edge of the Bega Batholith (Chappell, 1984). The Glenbog Granodiorite (335 km^2) is one of the more mafic members of this suite, which is part of the Glenbog Supersuite (1752 km^2).

The most conspicuous textural feature of this suite is the occurrence of quartz as large equidimensional grains (10-20 mm), commonly surrounded by a rim of small hornblende grains and generally with embayed margins. Larger lumps of quartz, 40 mm across, are occasionally present. Hornblende is present as prismatic crystals more than 10 mm in length. This rock is typical of those occurring near the western edge of the Bega Batholith. The most distinctive features are the low Na_2O and Sr contents. The Glenbog Granodiorite is one of the more mafic members of the Glenbog Suite. Many clots of hornblende and biotite seen in hand-sample are interpreted as restite or modified restite. Inclusions are fairly abundant at this locality. They have been discussed in detail by Chen *et al.* (1990).

Petrographic description: The most conspicuous textural feature is the occurrence of quartz as large equidimensional grains (10-20 mm), commonly surrounded by a rim of small hornblende grains and generally with embayed margins. Larger lumps of quartz, 40 mm across, are occasionally present. Plagioclase occurs as complexly zoned, rectangular crystals having prominent oscillatory zoning around mottled calcic cores near An_{50}, which often contain grains of quartz and fine apatite needles. The cores are extensively altered to epidote and sericite in many samples. The mafic minerals occur both as discrete grains and as clots. Hornblende (α = pale green, β = olive-green, γ = dark brownish green with patches having a bluish tint) occurs both as well-shaped prisms up to 10 mm across and as irregular grains in clots intergrown with biotite and magnetite. The biotite (α = straw yellow, $\beta = \gamma$ = dark sepia-brown) occurs mostly as ragged grains containing an abundance of tiny apatite crystals and some small zircons as well large crystals of magnetite. K-feldspar is interstitial, enveloping all other minerals, including quartz crystals. Hornblende and biotite occur as discrete well-formed crystals when enclosed within K-feldspar or quartz. Zircon, magnetite, apatite,and allanite are accessory minerals but there is no sphene. This rock shows signs of deformation with some bent biotite cleavages and undulose extinction in quartz grains.

All granites of the Glenbog Suite contain plagioclase crystals with cores near An_{50}. This is analogous to the situation for the Jindabyne Suite which has been discussed earlier (Stop 3-4). The Kadoona Dacite, a volcanic unit that is very close to the Glenbog Suite in composition, comprises large crystals of orthopyroxene, clinopyroxene, quartz and plagioclase, in a fine matrix of quartz + feldspars. Plagioclase crystals in that dacite again have compositions near An_{50}, they are uniform in composition, and have virtually no outer zones of less calcic plagioclase. It is thought that all of the large crystals (phenocrysts) in the Kadoona Dacite are restite, and that all of the plagioclase component of the melt is now in the groundmass. The large crystals in the Kadoona Dacite make up about 60% of the rock, which means that the amount of melt was only a little greater than the critical melt fraction (van der Molen & Paterson, 1979), needed to produce a magmatic fluid.

Chemical composition: This is a moderately mafic I-type composition, with the distinctive features being the high Ca and low Na and Sr that are characteristic of the western side of the Bega Batholith.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 425 Ma has been measured on this sample. Most of the zircon analyzed, as in all the I-type granites, is new zircon precipitated from the melt during magmatism. A small number of the zircons contain cores that have ages that range from early to late Proterozoic.

Zircons from two dioritic enclaves from the AB6 locality also have been analyzed using the ion-probe. Like their host granite they are dominated by zircon about 400 Ma old precipitated from the melt, and also contain rare inherited cores. A feature of the cores, however, is that the great majority (one exception) give ages less than 600 Ma. This is in direct contrast to the inheritance in the granite, where most of the cores (one exception) give ages substantially in excess of 600 Ma. The same pattern is seen in enclaves from two other western Bega Batholith localities; irrespective of the age and amount of inherited zircon in their host granite, the enclaves contain virtually only inheritance 600 Ma old or younger (Chen & Williams, 1990). This is strong evidence that the enclaves are not simply early crystallized portions of the granite magma, but must represent a subset of the material forming the source of that magma.

The most likely materials to survive as enclaves are the more mafic parts of the source. This implies that the rocks from which the older inherited zircons were derived are those in the source that are most easily melted. This is in direct contrast to the result obtained from the one studied enclave from an S-type granite (BB83, Cootralantra Granodiorite, Stop 4-8). In that case the enclave showed the same pattern of

TABLE 12. CHEMICAL ANALYSES: BEGA BATHOLITH AND SEDIMENTS

	AB6	AB5	AB149	AB195	AB206	GI1	IWS2	IWS6
Stop	5-7	5-8	5-10	5-11	5-12	5-14	5-15	5-15
SiO_2	67.39	71.26	65.36	65.27	76.53	73.60	74.19	53.97
TiO_2	0.53	0.40	0.51	0.58	0.06	0.34	0.64	0.87
Al_2O_3	14.48	13.75	14.73	15.22	12.39	12.44	12.07	23.35
Fe_2O_3	1.58	0.94	1.56	1.76	0.19	1.42	0.74	
FeO	3.02	1.97	3.44	2.83	0.65	1.49	2.88	5.73
MnO	0.09	0.06	0.10	0.09	0.04	0.08	0.03	0.03
MgO	1.72	0.97	2.49	2.01	0.25	0.27	1.92	3.04
CaO	4.32	2.93	5.21	4.40	0.35	1.24	0.22	0.02
Na_2O	2.63	2.82	2.48	2.74	3.57	3.53	1.70	0.18
K_2O	2.99	3.37	2.15	3.43	4.67	4.23	2.52	7.13
P_2O_5	0.11	0.09	0.12	0.19	0.01	0.07	0.17	0.11
H_2O+	0.95	0.90	1.53	1.26	0.60	0.56	2.46	5.21
H_2O-	0.13	0.14	0.15	0.09	0.13	0.34	0.11	0.22
CO_2	0.08	0.23	0.28	0.20	0.14	0.14	0.20	0.40
total	100.02	99.83	100.11	100.07	99.58	99.75	99.85	100.26
Trace elements (ppm)								
Rb	135	151	108	133	304	201	129	347
Sr	148	153	258	410	17.5	142	54	17.5
Ba	415	635	400	805	65	710	360	
Zr	145	173	121	184	64	472	299	137
Nb	9.0	8.0	8.0	9.0	13.0	28.0	13.0	18.0
Y	32	29	19	21	60	83	33	27
Ce	64	78	60	70	46	147	91	106
Sc	17	11	19	14	5	17	9	21
V	101	47	116	97	1	5	61	
Cr	11	7	33	17	1	2	59	128
Ni	4	3	7	7	<1	2	26	53
Zn	55	37	50	61	15	121	64	112
Ga	15.8	15.0	15.6	15.8	15.0	21.2	16.6	32.8
Pb	15	15	7	15	30	31	19	32
Th	16	17	12	13	23	23	16	21
U	3.3	3.2	1.4	4.2	8.9	6.4	3.6	4.9
Norm. C					0.85			
Modes								
Quartz	30.1	36.4	27.4	27.1	36.0	31.3		
K-feldspar	13.8	22.6	8.5	15.3	37.5	44.7		
Plagioclase	36.1	31.6	41.2	40.2	26.1	21.3		
Biotite	13.4	9.2	12.3	11.0	2.5	1.5		
Hornblende	6.6		10.2	4.4		0.7		
Muscovite					0.7			
Opaques		0.2	0.2	0.7	0.1	0.2		
Sphene			<0.1	1.2				
Apatite			0.1	0.1				
Allanite			0.1					

inheritance as its host, and if anything the amount of inheritance in the enclave was the greater.

Isotopic composition: ε_{Nd} = -6.4, $^{87}Sr/^{86}Sr(I)$ = 0.70869, $^{206}Pb/^{204}Pb$ = 18.149, $^{207}Pb/^{204}Pb$ = 15.629, $^{208}Pb/^{204}Pb$ = 38.203, T^{Nd} = 1520 Ma. The $\delta^{18}O$ composition is 8.8‰.

[The Pb isotope data for the Bega Batholith that are quoted in this guide were determined by McCulloch and Woodhead and are taken from the ICOG-7 excursion guide (Chappell *et al.*, 1990).]

Continue east and enter basalt 1 km beyond Stop 5-7 and the cutting of the Brown Mountain Screen after 2 km. Beyond the screen the road enters the Bemboka Granodiorite. Stop 4.6 km from the Glenbog outcrop in a cutting on the south side of the road.

Stop 5-8: Bemboka Granodiorite (Bombala 154442; map 9) sample AB5

The Bemboka Granodiorite has the largest area of exposure of any I-type granite in the LFB (970 km^2) with additional areas covered by Upper Devonian red-beds. It is probably the largest pluton in the belt, since the "larger" S-type bodies of the Kosciusko, Maragle and Wagga Batholiths are probably composite. This unit and the Wadbilliga Adamellite (75 km^2), a separate pluton further to the north, comprise the Bemboka Suite, the major component of the Bemboka Supersuite (1850 km^2), one of the three extensive supersuites in the central parts of the Bega Batholith. It is a medium- to coarse-grained rock with large prominent quartz crystals 20 mm across in places but mostly 10 mm. Some large quartz crystals are surrounded by hornblende grains. This is a felsic rock and some of the K-feldspars are distinctly pinkish in colour, consistent with its more felsic composition. Inclusions are not common.

Petrographic description: This is a felsic example of the Bemboka Granodiorite. No hornblende was found in the thin-section studied although this mineral is present in the more mafic samples of this unit Quartz grains are large and commonly up to 10 mm but more rarely they may be 20mm across. The largest quartz crystals in the more mafic Bemboka rocks may be surrounded by a rim of tiny hornblende crystals just as in rocks of the Glenbog Suite. Some of the larger quartz grains appear to have embayed margins. Plagioclase crystals are commonly 1-2 mm across and are rectangular or boat-shaped in section with good crystal shapes particularly when included in K-feldspar. K-feldspar is more abundant than in most Bemboka samples and is interstitial to or includes other minerals. It has a delicate pink colour in hand-sample and in thin-section it is seen to be finely perthitic. Biotite (α = straw coloured, $\beta = \gamma$ = sepia to chocolate-brown) appears as crystals mostly 1-2 mm across, occasionally with good crystal shapes. There are some small clots rich in biotite. Biotites may be altered to green chlorite with patches of secondary sphene and epidote. Prominent allanites are large (0.5 mm), zoned and always metamict, there being tiny radiating cracks in the surrounding minerals. Some allanites have partial rims of epidote. Accessory opaque minerals appear to be both magnetite and ilmenite to judge from their shapes in thin-section. Accessory apatites are mostly tiny stubby crystals and accessory zircons are prominent.

Chemical composition: This is a moderately felsic I-type composition, with low Na and Sr contents characteristic of the western parts of the Bega Batholith.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 400 Ma has been measured on this sample. It contains Archaean to Proterozoic zircon inheritance.

Isotopic composition: For another nearby sample from this unit (AB105), values of ε_{Nd} = -6.4, $^{87}Sr/^{86}Sr(I)$ = 0.70897, $^{206}Pb/^{204}Pb$ = 18.160, $^{207}Pb/^{204}Pb$ = 15.630, $^{208}Pb/^{204}Pb$ = 38.207, T^{Nd} = 1390 Ma have been obtained.

Return 1.6 km to the Brown Mountain Screen.

Stop 5-9: Brown Mountain Screen (Bombala 132448; map 9)

This is a long screen that separates the Bemboka Granodiorite to the east from the Glenbog Granodiorite further west. The western part of the screen and its contact with the Glenbog Granodiorite are obscured at this point by a Cainozoic basalt flow. The slates and phyllites of the screen are deeply weathered. This locality is close to the edge of the Monaro Plateau, the dissected edge of which is clearly visible to the south.

Return to the Bombala turnoff and follow the Monaro Highway to the south. After 1.8 km the road leaves granites and enters outcrops of basalt. Just beyond the Dalgety road junction at 24 km the tree-covered hills seen ahead are Upper Devonian red bed sediments. Outcrops of that unit on both sides of the road occur 1.3 km from the Dalgety road junction. At 35 km (6.4 km before Bombala) there is a basalt quarry on the left of the road (a locality of Kesson, 1973). Continue through Bombala past the junction of the Cann River Highway 2.0 km beyond the town to the the entrance of the "Bombala" property 8.3 km from Bombala. Outcrops of granite occur east of the homestead which is 300 m from the road, although the analyzed sample came from about 100 m west of the house.

Stop 5-10: Bombala Granodiorite (Bombala 919118; map 9) sample AB149

The Bombala Granodiorite (37 km^2) is separated from the Bega Batholith and it comprises the Bombala Suite. It is placed in the Tonghi Supersuite (573 km^2), but its affinities with the other members of that supersuite further south in the batholith are not as good as for members within the other supersuites. That supersuite is the most westerly in the Bega Batholith. This rock contains abundant large hornblende crystals, reflecting its high Ca/Na ratio.

Petrographic description: This is a hornblende granodiorite dominated by plagioclase which occurs as well-shaped crystals with a large range in grain size but mostly between 0.5 and 3 mm across. All of the plagioclases contain large prominent cores that are near An_{80}. The cores are surrounded by many fine oscillatory zones superimposed on normal zoning passing rapidly out to outermost zones near An_{20}. Quartz grains are in the range 1 to 2 mm and mostly interstitial. K-feldspar is all interstial. Hornblende crystals commonly with well-defined prism faces may exceed 5 mm in length and include small crystals of magnetite apatite and zircon. Biotite (α = straw coloured, $\beta = \gamma$ = sepia to chocolate-brown) also has some good crystal shapes and includes accessory minerals. A few crystals of biotite are altered to bright green chlorite in which there are lumps of epidote. The magnetite is abundant as an accessory mineral and is commonly seen as square cross-sections. Apatite appears as stumpy prisms and allanite is conspicuous. No sphene was found in hand-sample or thin-section. There are many clots of ferromagnesian minerals and these to gether with the abundance of calcic plagioclase cores indicate that the magma was restite-rich.

Chemical composition: This is a rather mafic I-type granite rich in Ca and with low Na and K, and with a low Sr content for such a mafic rock, consistent with its location at the western side of the Bega Batholith.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 415 Ma has been measured on this sample. It contains inherited zircon cores that are Archaean to Proterozoic in age.

Isotopic composition: Values of ε_{Nd} = -4.9, $^{87}Sr/^{86}Sr(I)$ = 0.70776 and T^{Nd} = 1320 Ma have been obtained. The $\delta^{18}O$ composition is 7.0‰.

Return towards Bombala and take the Cann Valley Highway to the south. On the left is Wog Wog Mountain within the Bega Batholith. Further south (21 km) Nungatta Mountain, capped by gently dipping Upper Devonian red-beds, is seen in the distance. After 27 km turn left on the Imlay Road. Stop at the far end of a large cutting 15.4 km along that road.

Stop 5-11: Yurammie Granodiorite (Craigie 192867; map 9) sample AB195

The Yurammie Granodiorite (245 km^2) makes up the central part of a zoned pluton in the Bega Batholith. It is gradational outwards into the more mafic Candelo Tonalite (45 km^2) from which Yurammie is distinguished by pink K-feldspar being noticeable in the field. Together these two units comprise the Candelo Suite, part of the Candelo Supersuite (1199 km^2) which is the "central" of the seven supersuites of the Bega Batholith. Yurammie is a moderately felsic member of the Candelo Suite. It consists of large crystals (30 mm) of pink K-feldspar, white plagioclase crystals up to 10 mm and quartz 5 to 10 mm across. Large red-brown sphenes can be seen in hand specimen and chalcopyrite is also relatively abundant. There are quite a few mafic inclusions, some containing large feldspar and quartz crystals.

Petrographic description: The rock is coarse-grained with large pink K-feldspar crystals, which in thin-section are seen to have microcline twinning. There is other evidence of deformation, as the quartz has undulose extinction and some biotite cleavages are bent. Plagioclase crystals up to 6 mm across are mostly in the range An_{40}-An_{45} with outermost zones down to An_{25} and with rare cores near An_{70}. Ragged grains of biotite may be slightly chloritized. Hornblende (α = pale yellow-green, β = olive-green, γ = dark green with bluish tint) occurring as slender prisms up to 10mm, is not common. Sphene is fairly abundant and occurs as large crystals, sometimes 0.5 mm across. Accessory allanite, magnetite, needles of apatite and zircon are conspicuous. Some sulphides including chalcopyrite are seen in hand-samples.

Chemical composition: This has a similar SiO_2 content to AB149 at the previous stop, but it is significantly less mafic with lower amounts of Fe, Mg and Ca. The lower Ca and higher Na and Sr are characteristic of the central parts of the Bega Batholith (this locality has been displaced westward by the Burragate Wrench Fault relative to the more northerly parts of the batholith).

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 415 Ma has been measured on this sample. The rock contains a similar amount of inherited zircon to the Glenbog Tonalite, even though its ε_{Nd} is not quite so negative (-4.6). About half the inheritance is latest Proterozoic, and half early Proterozoic. There is a marked lack of inherited zircons with intermediate ages.

Isotopic composition: ε_{Nd} = -4.6, $^{87}Sr/^{86}Sr(I)$ = 0.70544, $^{206}Pb/^{204}Pb$ = 18.176, $^{207}Pb/^{204}Pb$ = 15.613, $^{208}Pb/^{204}Pb$ = 38.168, T^{Nd} = 1270 Ma. The $\delta^{18}O$ composition is 9.2‰.

The bridge over Nungatta Creek is crossed 1.6 km beyond Stop 5-11. Boulders near the bridge contain abundant mafic inclusions, some of which have been analyzed. 26 km from the bridge and 600 m before Imlay Creek, stop at a roadside cutting of felsic Wallagaraugh Adamellite.

Stop 5-12: Wallagaraugh Adamellite (Eden 379762; map 9) sample AB206

The Wallagaraugh Adamellite (210 km^2) is a felsic granite occurring on the eastern side of the Bega Batholith, south of Mt Imlay. It is the most dull rock that there is - a haplogranite with a few per cent. of biotite. This and the Croajingalong (315 km^2) and Yambulla (55 km^2) bodies, comprise the Wallagaraugh Suite, part of the Kameruka Supersuite (Stop 6-4).

Petrographic description: This is a felsic, coarse-grained to medium pink granite consisting almost entirely of strongly perthitic K-feldspar, quartz as aggregates of 3 or 4 crystals commonly about 5 mm across with triple junctions and finely sutured interlocking boundaries with undulose extinction, and cloudy plagioclase forming tabular normally-zoned crystals with outer zoned from about An_{20}-An_{10}. The small amounts of biotite (crystals to 3 mm) are chloritized commonly with strips of secondary fluorite, sphene and white mica along the relict cleavage traces. In other Wallagaraugh samples unaltered biotites have α = yellow-brown, $\beta = \gamma$ = very dark chocolate-brown. There are a few scattered flakes and skeletal grains of muscovite scattered throughout the rock. No apatite or zircon were detected. A few patches of fluorite occur elsewhere in the rock. Sulphides are seen in some of the hand-samples

Chemistry: Examples of extensive feldspar fractionation are uncommon in I-type granites of the LFB, but such a process is well shown by the Wallagaraugh unit. It shows progressive changes among which the prominent decrease in Ba and Sr and increase in Rb are evidence for feldspar fractionation. Other elements vary in a concomitant way. Note in particular the low P_2O_5 content, analogous to the Thologolong and Pine Mountain granites of Day 2, in contrast to the fractionated S-type granites.

Isotopic composition: ε_{Nd} = -2.5, $^{87}Sr/^{86}Sr(I)$ = (0.72612), T^{Nd} = 1150 Ma.

Exposures of the batholith do not extend beyond Imlay Creek and 600 m east of the creek there is a quarry on the north side of the road.

Stop 5-13: Devonian unconformity (Eden 398761; map 9)

In this quarry there is an unconformity between Upper Devonian red-beds and contact metamorphosed Ordovician shales. The younger sediments are the equivalents of the European Old Red Sandstone and rocks of this red-bed "Lambian Facies" are found throughout the eastern third of the LFB.

Continue to Highway 1 (which extends around Australia), 12 km east of Stop 5-13. Turn south on the highway and then follow the Ireland Timms Forest Road east of the road 2.8 km south of the Imlay Road. At a distance of 3.8 km from Highway 1, take the Cockatoo Road to left, stopping at a cutting in granite 1.4 km from that junction.

Stop 5-14: Watergums Granite (Eden 513684; map 9) sample GI1

This is sample 4466 of Collins *et al.* (1982) and is representative of the more mafic of the two A-type granite suites described by those authors. The Watergums Granite (28 km^2) is the largest and most northerly of the six bodies of granite that comprise the Gabo Island Suite (58 km^2) in the south-eastern corner of mainland Australia. It is very felsic and virtually free of inclusions. This locality is a little more than 100 m into the granite from its western contact. This is the rock studied experimentally by Clemens *et al.* (1986).

Petrographic description: The Watergums Granite is a medium- to fine-grained rock with K-feldspar ($Or_{60}Ab_{40}$) being the most abundant mineral, forming tabular microperthitic crystals or graphic intergrowths with quartz. It is accompanied by normally zoned plagioclase (An_{30}-An_5) with a composition mostly in the oligoclase range. Quartz also appears as clusters of small grains between K-feldspar or as large embayed crystals having the β-quartz form. Biotite (α = pale yellow, β = γ = dark brown) is mostly interstitial to K-feldspar but may display some well-formed crystal shape when it is within the graphic parts of the rock. Microprobe analysis shows that the mica is annite. Fluorite sometimes occurs as small lenses interleaved in biotite. Hastingsite (α = colourless, β = light brown, γ = khaki) is subordinate to biotite and forms long prisms - in places it is interstitial to K-feldspar. It typically has inclusions of zircon, apatite and opaque minerals. A distinctly blue amphibole (α = aqua-blue, β = pale to inky-blue) occurs as small irregular grains around the hastingsites; microprobe analysis shows that these are riebeckite-arfvedsonite solid solutions. Zircon (including some large zoned crystals), fluorite, and magnetite (with exsolved ilmenite) are constant accessory minerals whereas apatite and allanite are less common. Relicts of fayalite are rare.

Chemical composition: Collins *et al.* (1982) showed that the rocks of the Gabo Island Suite are a fairly uniform group which are not particularly felsic for A-type granites, containing from 71.5 to 73.6% SiO_2. These rocks show the distinctive high Zr, Nb, Y, REE, Sc and Zn and Ga of A-type granites, while Mg and V are less abundant than in I-type rocks of similar SiO_2 content. Rb, Sr, Pb and Th are comparable to I-types and Ba is high. The high content of highly charged cations and the high Ga:Al ratio in rocks of relatively high Sr and Ba contents, is diagnostic of an A-type granite.

Isotopic age: An ion-probe U-Pb zircon magmatic crystallization age of approximately 390 Ma has been measured on this sample. Only one inherited core (Archaean) was found in the thirty zircon crystals that were dated.

Isotopic composition: ε_{Nd} = +0.3, $^{87}Sr/^{86}Sr(I)$ = 0.70516, T^{Nd} = 1050 Ma.

Return to Highway 1 and travel north towards Eden. Stop at a large coad cutting in the sedimentary rocks 5 km north of the Towamba River.

Stop 5-15: Ordovician sediments (Eden 547882; map 9) samples IWS2 and IWS6

Ordovician sediments are exposed in this cutting. A "dirty sandstone", standing out as a competent layer in the western face of this cutting is one of four samples from the environs of the Bega Batholith that has been subjected to U-Pb zircon analysis. An analysis of that sample (IWS2), and of a shale (IWS6) from this locality, are given in Table 12.

Chemical composition: The extremely low Ca contents of these rocks is typical of the Ordovician sediments of the LFB, and reflects the low feldspar content of the those rocks. Wyborn & Chappell (1983) have pointed out that the Ordovician sedimentary rocks of the LFB are dominantly mixtures of two components, quartz and clay minerals, and this is illustrated by the two analyses in Table 12.

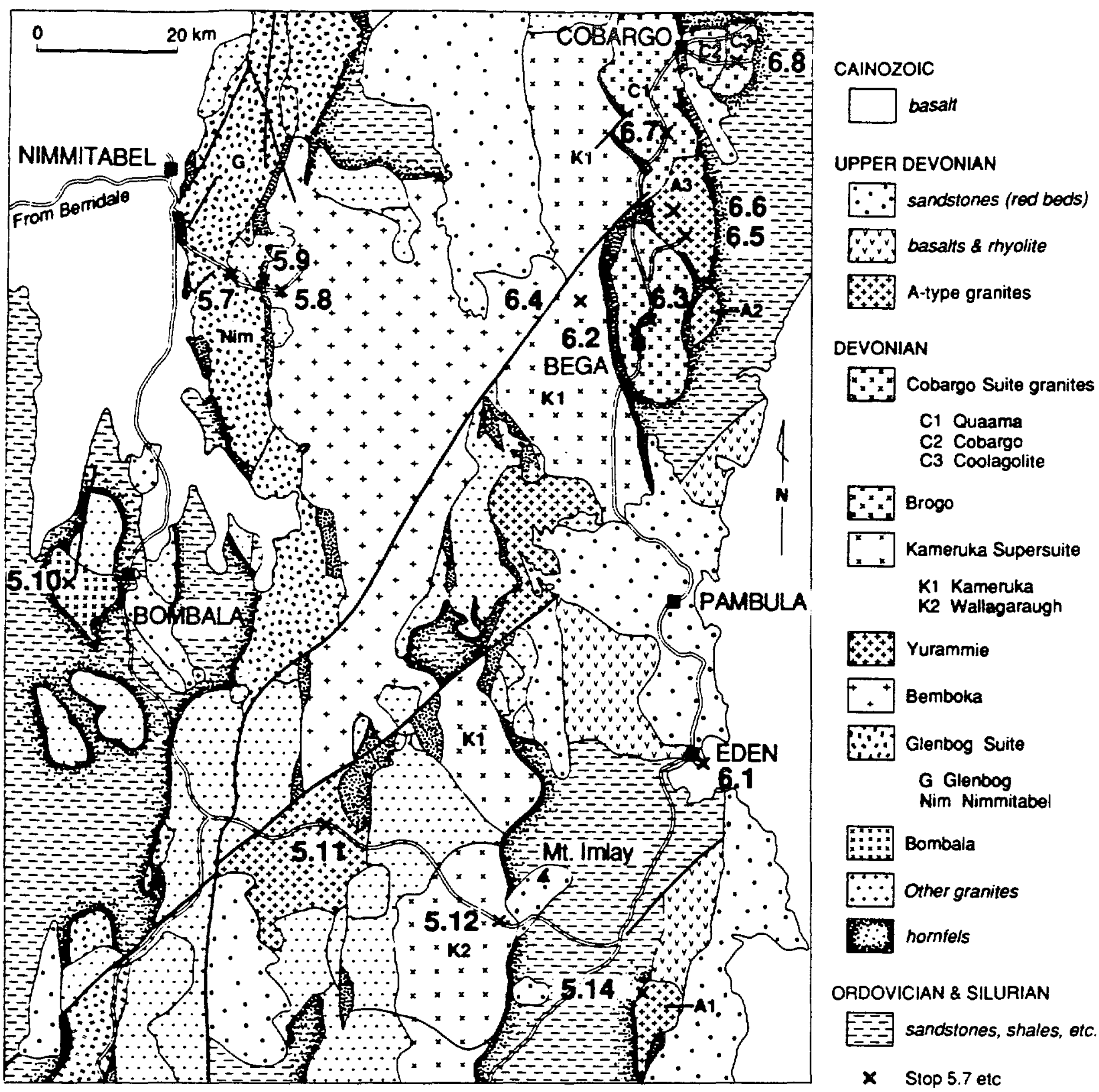
Isotopic ages: This is one of four localities from which zircons have been separated from the Ordovician sediments for ion-probe analysis. Analyses of 100 zircons from each of these samples of the host rocks to the Bega Batholith show great consistency in the age groups represented, over a distance of a few hundred kilometres. A feature of the sedimentary zircons is that they generally are remarkably concordant, even those that are early Proterozoic and Archaean. The age groups represented are therefore quite clearcut, even though each grain has only been analyzed once and its individual discordance pattern is therefore not known.

Every sediment contains a major zircon population slightly older than 500 Ma, which tails upwards to ages not exceeding 600 Ma. All samples contain major age groupings at about 1000 Ma, and a further minor groupings upwards to middle Archaean ages. The proportions of the different components differ from sample to sample but the ages represented are consistent from one to the next. For the first time we are getting hard information on the provenance of the massive flysch deposits of south-eastern Australia. Clearly the source is not so distant that the sediments have had a chance to become well mixed.

On the other hand, major igneous activity in Pan African (~600 Ma) and Grenville (~1000 Ma) times has yet to be recognized in southeastern Australia. One can always call on a lost source to the south, the predominant palaeocurrent direction, possibly in Antarctica or beyond, but a viable alternative, given the patterns of inheritance in the granites, is that we are reading a record of igneous activity in eastern and possibly central Australia now largely obscured by younger cover.

Isotopic composition: Unpublished data on the total-rock sample are $\varepsilon_{Nd} = -9.7$, $^{87}Sr/^{86}Sr(I) = 0.72240$, $^{206}Pb/^{204}Pb = 19.111$ (18.253), $^{207}Pb/^{204}Pb = 15.688$ (15.641), $^{208}Pb/^{204}Pb = 39.561$(38.061), $T^{Nd} = 1690$ Ma.

Continue north along Highway 1 to Eden.



Map 9. Map of granite units in the central part of the Bega Batholith

DAY 6. EDEN TO NAROOMA

PARTS OF THE BEGA BATHOLITH AND THE MT DROMEDARY COMPLEX

The sixth day of the excursion examines rocks from the eastern side of the Bega Batholith, and also the very felsic Mumbulla A-type granite. Those localities are followed by a brief visit to the Cretaceous Dromedary Complex. Chemical and modal analyses of rocks from these localities are listed in Table 13.

Follow the main street of Eden for 1.2 km south from the post office to the Rotary Lookout.

Stop 6-1: Eden Rhyolite at Rotary Park Lookout (Eden 590927; map 9)

Apart from the panoramic view of Twofold Bay, notice the steeply dipping Ordovician sandstones and shales in the bay on the west side of the lookout and ash-flow tuff sheets of the Eden Rhyolite on the east side. The latter are altered volcanic equivalents of the Gabo Island Granites, as shown by the high Ga/Al ratios of the volcanic rocks, and other features.

Return through Eden and travel north on Highway 1. Beyond Merimbula (26 km) there are roadside exposures of Upper Devonian red-beds as the road climbs out of the town. The Bega Batholith is re-entered 12 km beyond Merimbula at the Candelo-Wolumla turnoff. From the top of the hill after a further 800 m, Mumbulla Mountain may be seen in the distance. The Bega Batholith granites are deeply weathered in this region. Good exposures are present around Frogs Hollow Creek, 23 km from Merimbula. Near the radio mast after another 2 km, the road passes into the more mafic Brogo Granodiorite. The highway is followed through Bega to a cutting 2.8 km beyond the Bega Post Office.

Stop 6-2: Brogo Granodiorite (Bega 523387; map 9) sample AB82

The Brogo Granodiorite is an elliptical pluton centred a few kilometres NNE of Bega. It has a distinctive composition and comprises the Brogo Suite, part of the Cobargo Supersuite. The rock is medium-grained with biotite and lesser hornblende. The K-feldspar crystals, up to 15 mm across, have a slightly pinkish shade. This is an "oxidized" rock containing brown biotite plus sphene, allanite and magnetite. Inclusions are dominantly of the mafic hornblende-bearing variety but a large metasedimentary block, 3 m across, occurs in the western side of the cutting. Such inclusions are very rare in granites of the LFB and in general only occur near the contact.

Petrographic description: This rock is dominated by plagioclase, appearing in thin-section as rectangular-shaped crystals up to 4 mm long that may have prominent cores, many of which are epidotized and sericitized. There are complex zones with oscillatory zones surrounding the cores. Most of the plagioclase has a composition near An_{25}. Aggregates of quartz have crude triple-junctions between individual grains, all of which show some undulose extinction indicative of deformation. K-feldspar is weakly perthitic and mainly appears as interstitial grains or as large plates enclosing other grains. Biotite (α = straw yellow, $\beta = \gamma$ = dark sepia-brown) is seen either as well-shaped pseudo-hexagonal crystals or as irregularly--shaped aggregates. It is partly replaced by chlorite, epidote and secondary sphene. Hornblende may also form isolated, well-formed prismatic crystals or occur as aggregates along with magnetite and sphene. Magnetite is common in these crystal aggregates as well as in inclusions in hornblende. Apatite in this rock mainly appears as tiny stubby crystals included in biotite. Tiny zircons are scattered through the rock. Allanite is a rarely seen accessory phase and is mostly found as scattered grains in hand-samples.

Chemical composition: This is a moderately mafic rock showing the distinctive chemical features of the eastern side of the Bega Batholith, with relatively low Ca and high Na and Sr contents - compare this composition with sample AB6 from the Glenbog Suite at the western edge of the batholith (Table 12).

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 420 Ma has been measured on this sample. The inherited zircons are dominantly late Proterozoic and early Palaeozoic in age.

TABLE 13. CHEMICAL ANALYSES: BEGA BATHOLITH AND DROMEDARY COMPLEX

	AB82	AB40	AB116	AB118	AB190	AB128	MD1	MD8	MD10	MD12
Stop	6-2	6-4	6-5	6-6	6-7	6-8	6-9	6-10	6-10	6-10
SiO_2	67.18	68.77	77.51	77.00	67.59	64.47	52.06	59.60	64.82	67.16
TiO_2	0.47	0.53	0.14	0.15	0.54	0.66	0.96	0.54	0.37	0.31
Al_2O_3	15.05	14.75	11.76	11.83	15.22	15.54	15.67	17.98	16.26	16.13
Fe_2O_3	1.44	0.99	0.27	0.40	0.97	1.29	3.21	1.21	1.60	1.55
FeO	2.05	2.46	1.04	1.05	2.65	2.98	5.73	3.32	2.09	1.07
MnO	0.08	0.07	0.03	0.04	0.07	0.08	0.18	0.13	0.11	0.09
MgO	1.96	1.29	0.05	0.04	1.59	2.52	4.52	1.16	1.03	0.64
CaO	3.82	3.12	0.34	0.61	3.77	4.96	8.43	3.50	2.45	2.41
Na_2O	3.66	3.53	3.04	3.06	3.56	3.61	2.88	4.17	4.03	4.38
K_2O	2.66	2.94	4.94	4.98	2.49	2.30	4.45	6.46	5.69	4.98
P_2O_5	0.16	0.16	0.02	0.02	0.15	0.16	0.72	0.27	0.19	0.12
H_2O+	1.10	0.96	0.59	0.47	0.99	0.93	0.62	0.66	0.61	0.50
H_2O-	0.12	0.11	0.17	0.18	0.13	0.14	0.19	0.15	0.36	0.31
CO_2	0.19	0.20	0.18	0.07	0.20	0.18	0.18	0.66	0.46	0.23
total	99.94	99.88	100.08	99.90	99.92	99.82	99.80	99.81	100.07	99.88
Trace elements (ppm)										
Rb	92	123	232	230	103	87	133	272	321	224
Sr	406	256	43.5	50	339	390	1440	940	630	965
Ba	485	505	640	655	390	405	1225	715	490	895
Zr	117	191	173	187	146	159	86	161	284	189
Nb	9.0	9.5	20.0	18.0	8.5	9.0	6.0	17.0	26.0	19.5
Y	20	18	84	100	22	21	21	16	24	18
Ce	54	71	153	142	54	54	59	59	83	61
Sc	10	10	18	14	9	13	16	9	8	7
V	62	54	2	2	61	85	230	53	31	29
Cr	31	13	<1	<1	18	35	50	8	4	5
Ni	8	6	<1	<1	12	20	24	4	2	1
Zn	49	57	116	106	54	50	98	66	59	40
Ga	15.8	16.8	20.0	20.0	16.8	17.0				
Pb	13	16	37	33	18	11	14	22	22	14
Th	10	12	27	22	14	12	7	15	35	38
U	3.3	2.3	6.8	5.8	3.8	2.5	2.4	3.4	10.6	9.4
Modes										
Quartz	24.5	35.0	34.8	34.7	29.3	16.5	0.5	3.0	13.8	13.7
K-feldspar	12.2	9.3	45.0	46.4	9.5	15.7	32.6	55.7	50.2	41.7
Plagioclase	48.3	43.2	16.6	15.4	48.6	45.2	31.7	25.9	29.4	39.8
Biotite	10.2	12.1	3.3	3.0	8.4	12.7	7.9	3.7	2.4	0.1
Hornblende	3.8	<0.1			3.7	8.9	1.1	10.5	3.2	3.1
Opaques	0.6	0.2	0.2	0.3	0.3	0.6	4.4	0.7	0.9	1.1
Sphene	0.1				0.1	<0.1		0.2		0.4
Apatite	0.2	0.2	0.1	<0.1	0.1	0.1	1.8	0.3	0.1	0.1
Allanite	0.1		<0.1	0.2						
Pyroxene							20.0			

Isotopic composition: ε_{Nd} = -1.3, $^{87}Sr/^{86}Sr(I)$ = 0.70456, $^{206}Pb/^{204}Pb$ = 18.193, $^{207}Pb/^{204}Pb$ = 15.601, $^{208}Pb/^{204}Pb$ = 38.132, T^{Nd} = 1070 Ma. The $\delta^{18}O$ composition is 8.7‰.

Continue north on highway for 2.3 km and turn right into the Bega Valley Lookout.

Stop 6-3: Bega Valley Lookout (Bega 523408; map 9)

This lookout is on the southwestern side of the elliptically-shaped Brogo Granodiorite. The western boundary of this pluton is a narrow screen (Numbugga Screen) 500 to 1000 m wide, separating the Brogo pluton from the more felsic Kameruka Granodiorite. The screen is seen from the lookout as a line of rounded hills to the west.

From the lookout continue north for 1.6 km to the Snowy Mountains Highway and then travel west through the Numbugga Screen between 2.1 and 2.7 km west of Highway 1. Stop at 5.1 km from the Highway 1 at a small granite exposure on the south side of the road.

Stop 6-4: Kameruka Granodiorite (Bega 477416; map 9) sample AB40

The Kameruka Granodiorite (570 km^2) and the smaller Illawambra Adamellite (60 km^2) comprise the Kameruka Suite, part of the supersuite of the same name (1354 km^2) which is the most easterly of the three relatively large supersuites in the central parts of the Bega Batholith. Kameruka is a distinctive coarse-grained granodiorite in which there are prominent large crystals of K-feldspar up to 50 mm across; some show rapakivi texture. There are what appear to be mafic Kameruka inclusions also containing large crystals of quartz, K-feldspar and plagioclase within a fine-grained biotite-rich matrix, and within these inclusions there are mafic microgranular inclusions - "double-enclaves".

Petrographic description: This is very coarse-grained containing large (up to 50 mm) K-feldspars, some showing rapakivi texture. In thin-section these are seen to be weakly perthitic and to have microcline twinning. Quartz crystals up to 10 mm have undulose extinction. Plagioclase up to 10mm in longest dimension, has a composition around An_{25}-An_{20}. Biotite (α = straw-yellow, $\beta = \gamma$ = dark chocolate-brown) appears as irregularly shaped crystals 1-2 mm across, ragged, and sometimes altered around the edges to chlorite. A few biotites contain strips of secondary chlorite and sphene. Large sphenes and allanites (zoned partly metamict crystals), a good sprinkling of opaques (mostly magnetite), apatite prisms mostly less than 1 mm in size, and tiny zircons are accessory phases. Small veinlets containing calcite, epidote and chlorite cut across the rock.

Chemical composition: This is a slightly more felsic rock than AB82 from the previous stop. The Kameruka Supersuite in the eastern central part of the Bega Batholith is the only supersuite that does not extend to more mafic compositions.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 420 Ma has been measured on this sample. Many of the grains contain inherited cores. The ages of the inheritance are very well defined; there is one inherited component between 500 and 600 Ma old, a second inherited component 900 to 1200 Ma old, and a couple of grains which are late Archaean and early Proterozoic. This pattern epitomises the inheritance found in the Bega Batholith as a whole and defines very clearly the ages of the components which are contributing to the granite melts. Components of the same ages dominate the granites' host sediments, showing that both the granites and the sediments were derived from the products of the same episodes of igneous activity.

Isotopic composition: ε_{Nd} = -3.7, $^{87}Sr/^{86}Sr(I)$ = 0.70560, $^{206}Pb/^{204}Pb$ = 18.154, $^{207}Pb/^{204}Pb$ = 15.619, $^{208}Pb/^{204}Pb$ = 38.179, T^{Nd} = 1190 Ma. The $\delta^{18}O$ composition is 9.5‰.

Return to Highway 1 and travel north. Take the road to the right across the Greendale Bridge after 4.5 km. At 4.1 km turn right on Clarkes Road and 7.5 km further on stop at boulders of Mumbulla Granite.

Stop 6-5: Mumbulla Granite (Bega 566486; map 9) sample AB116

The Mumbulla Granite is medium-grained very felsic granite *sensu stricto*, with an area of 56 km^2, and comprising the prominent Mumbulla Mountain. This unit and the Ellery Granite (64 km^2), in the Kosciusko Basement Terrane, are the largest A-type plutons in the LFB. Together with the Dr George Mountain Granite (13 km^2), this granite comprises the Mumbulla Suite, occurring some 100 km north of the Watergums Granite of Stop 5-14. This is a very felsic granite. The K-feldspar is a dull pink whereas the plagioclase is white to greenish. Scattered flakes of biotite are mostly altered. This locality is at an altitude of 400 m.

Petrographic description: The Mumbulla granite is medium to coarse and even-grained and dominated by pink K-feldspar and quartz and with lesser amounts of plagioclase that is greenish because of alteration. Biotite (α = pale yellow, $\beta = \gamma$ = very dark brown) is the sole primary mafic mineral forming irregularly-shaped crystals which are commonly interstitial to quartz and K-feldspar. Chlorite is a common secondary alteration product whereas red-brown alteration products, presumably after fayalite, are rare. Accessory minerals include magnetite, fluorite, zircon, apatite and allanite.

Chemical composition: The Mumbulla Granite has many of the very distinctive trace element features of A-type granites, as did the less felsic A-type granites of the Gabo Suite, discussed above. Thus the REE and Ga contents are high but Zr and Nb are only a little higher than felsic I-type granites. Ba contents are high for such felsic rocks, from 500 to 655 ppm, and so the rocks do not seem to have undergone any significant feldspar fractionation. The compositions are probably very close to an unmodified primary A-type melt.

Isotopic composition: Sample AB119 from this unit gave values of ε_{Nd} = -2.3, $^{87}Sr/^{86}Sr(I)$ = 0.70608 and T^{Nd} = 1410 Ma.

Smaller vehicles can drive to the summit of Mumbulla Mountain although the track is sometimes in a poor condition. Take the road to the left a few hundred metres past Stop 6-5. There are several exposures of granite on this road including the "type" locality AB118, 2 km from the road junction.

Stop 6-6: Mumbulla Granite (Bega 571500; map 9) sample AB118

This is sample 4473 of Collins *et al.* (1982) at an altitude of 550 m.

Petrographic description: This is a very felsic rock in which the dominant minerals, quartz, perthitic K-feldspar and lesser amounts of plagioclase are all up to 5 to 6 mm across. The plagioclase (zoned from about An_{30}-An_{40} down to An_{10}) is distinguished in hand-sample by its greenish colour resulting from alteration. Biotite (α = yellow-brown, $\beta = \gamma$ = very dark brown) is interstitial and amounts to only a few per cent. It is commonly altered to bright green chlorite. There are a few small, ragged, khaki-coloured amphiboles. Rare rusty brown patches having crudely rectangular cross-sections are presumably after early fayalite. A few fluorite grains are up to 1 mm across. Stumpy apatites, opaques, zircons and moderately large allanites are also accessory. The amphiboles and some of the opaques are surrounded by rusty brown tufts of secondary stilpnomelane.

Chemical composition: This rock is very similar in composition to sample AB116 at Stop 6-5.

Return to Highway 1 and travel north following the west bank of the Brogo River. Note the *Casuarinas* (River Oaks) in the river. These are thought to have covered most of Australia before the aboriginals burnt the forests to help in hunting. Unlike *Eucalyptus*, these are not fire resistant. At the Brogo River bridge after 8.8 km the road moves into the Quaama Granodiorite. The steep hills on the skyline to the east are the Mumbulla Granite of Mumbulla Mountain. At 12.6 km the highway passes through the small McLeods Hill Gabbro (4.8 km^2) - the only gabbro on the journey so far. Stop at the picnic spot after 19 km, near the Quaama road junction, and walk 150 m north into a cutting to examine granite exposures.

Stop 6-7: Quaama Granodiorite (Cobargo 566604; map 9) sample AB190

The Quaama Granodiorite (159 km^2) is the largest of four units in the Cobargo Suite, at the eastern side of the Bega Batholith. It is a moderately mafic medium-grained hornblende granodiorite with some fairly large (20 mm) K-feldspar crystals showing weak zoning. Biotite is dark-brown and mostly 1 to 2 mm across; stumpy prisms of hornblende are mostly 2 to 5 mm in length. There are some clots of mafic minerals and a moderate number of mafic inclusions, some of which have a tabular shape and are banded.

Petrographic description: Plagioclase appears as well-shaped crystals with rectangular sections ranging from small crystals up to 6 mm. Plagioclase is strongly zoned from around An_{45} in prominent cores to outer parts around An_{20}. It also has many oscillatory zones. Quartz appears as interstitial grains or as grains and aggregates up to about 5 mm across, that commonly include crystals of plagioclase. K-feldspar is microperthite and is always interstitial. Biotite (α = dark straw-yellow, $\beta = \gamma$ = dark chocolate-brown) has some good crystal shapes, as does hornblende. Magnetite is quite abundant as well-shaped small crystals. Sphenes appear as large individuals but no well-shaped crystals were found in the thin-section examined. Zircon and apatite are also accessory phases. Allanite is rarely seen but there is secondary green epidote as interstitial patches and in aggregates along with secondary chlorite.

Chemical composition: This rock is very similar in composition to sample AB82 at Stop 6-2 and both belong to the Cobargo Supersuite.

Isotopic composition: $\varepsilon_{Nd} = -2.7$, $^{87}Sr/^{86}Sr(I) = 0.70556$, $T^{Nd} = 1190$ Ma, $\delta^{18}O = 9.2‰$.

Approaching Cobargo, the hills on the right are a screen between the Cobargo and Quaama intrusions. Mt Dromedary is seen on the skyline to the north. At Cobargo, 11.5 km from Stop 6-7, take the Bermagui Road to the east through the Cobargo pluton. Hornfels ridges are seen to the south and later to the north around this intrusion. At 5.2 km from the highway the road enters the Coolagolite pluton at the point where where the Coolagolite Road leaves to the right. Stop at exposures on the north side of road near Green Tyrrells Road at 7.1 km.

Stop 6-8: Coolagolite Granodiorite (Cobargo 650671; map 8) sample AB128

The Coolagolite Granodiorite (25 km^2) is a more mafic member of the Cobargo Suite. This is a mafic medium- to fine-grained granite dominated by fairly well-shaped plagioclase prisms up to 5 mm in length, some of which contain tiny black spots seen in thin-section to be ortho- and clinopyroxenes, attesting to the early presence of these minerals in the magma. K-feldspar is inconspicuous but is seen as interstitial plates. The hornblende appears as well-shaped prisms mostly up to 5 mm in length. There are many clots of mafic minerals and mafic inclusions.

Petrographic description: This is a mafic granite. Plagioclases, mostly in the size range 1-4 mm, are more or less rectangular in cross-sections and have a composition ranging from An_{40}-An_{20}; oscillatory zoning is common. Tiny unaltered pyroxene grains occur within some of the plagioclase cores. Quartz grains rarely exceed 3 mm and are mostly interstitial. K-feldspar is microperthite and is similar in abundance and mode of occurrence to quartz. Unlike the hornblende, biotite (α = dark straw-yellow, $\beta = \gamma$ = dark chocolate-brown) rarely displays any crystal boundaries. Hornblende (α = yellow-brown with greenish tint, β = olive-green, γ = dark green) occurs as long prisms with good shapes. It has relict clinopyroxene in the cores. Magnetite is abundant and occurs as good crystals. There is no lozenge-shaped sphene but there are some fairly large lumps particularly in some hornblendes, and interstitial stringers that are irregular in shape. Apatite (stumpy prisms), zircon and allanite are also accessory minerals.

Chemical composition: This is the most mafic rock examined to date in the Bega Batholith and it has the characteristic chemical features of rocks from the eastern side of that complex, particularly the relatively high Na and Sr contents. Compare this composition with that of the Bombala Granodiorite AB149 from Stop 5-10 to see these differences.

Isotopic ages: Despite the Coolagolite Granodiorite having only a slightly positive ε_{Nd} (+0.2), it contains less inherited zircon than any other analyzed granite from the Bega Batholith - two grains of the 64 surveyed. The age of the zircon precipitated from the melt is well-defined at about 395 Ma, a result supported by conventional analyses by Fanning (*pers. comm.*) of some of the same crystals dated by ion-probe.

Isotopic composition: $\varepsilon_{Nd} = +0.2$, $^{87}Sr/^{86}Sr(I) = 0.70466$, $^{206}Pb/^{204}Pb = 18.179$, $^{207}Pb/^{204}Pb = 15.599$, $^{208}Pb/^{204}Pb = 38.132$, $T^{Nd} = 1000$ Ma, $\delta^{18}O = 8.2‰$.

Return to Cobargo noting the Mt Dromedary massif on the right. Travel north on Highway 1 noting the typical wooded hornfels ridge to the north of the road while crossing the Cobargo Granodiorite. At Sams Creek, 5.3 km from Cobargo, the road is almost at the hornfels ridge and it crosses into the Coolagolite intrusion. There is a typical re-entrant in the granite-hornfels contact at this point. At 8.0 km the road climbs the ridge on the northeastern side of the Coolagolite intrusion. Continue through the Ordovician sedimentary rocks to the Tilba deviation where the Dromedary Complex is reached. Turn left and 2.1 km beyond Tilba Tilba turn left again through Central Tilba 700 m to the quarry.

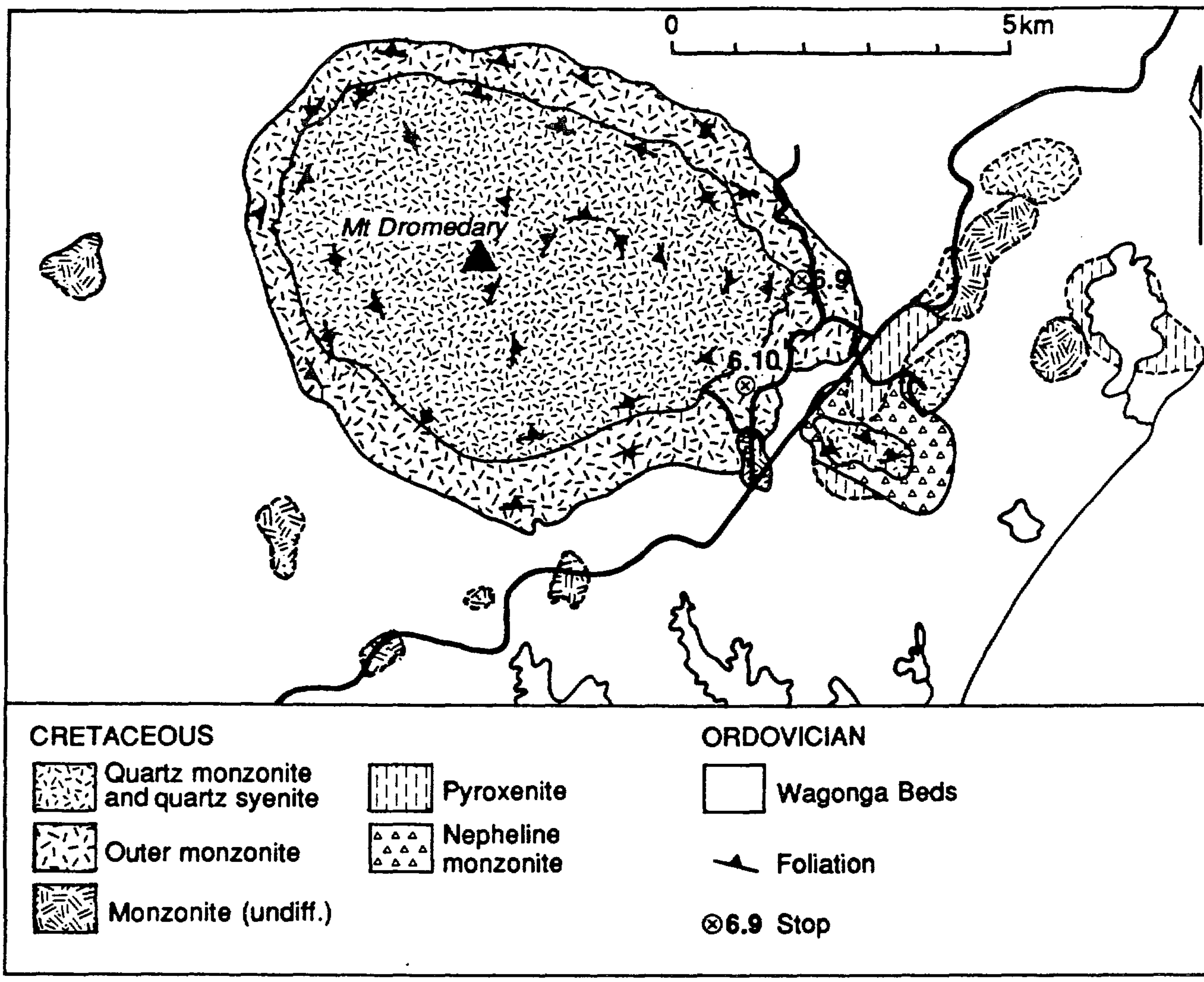


Figure 10. Geological map of the Mt Dromedary Complex (after Boesen, 1972, and Smith *et al.*, 1988)

Stop 6-9: Mt Dromedary Monzonite at Tilba Quarry (Narooma 370776; map 10) MD1

This quarry is situated in coarse-grained, dark-coloured, monzonite in which large biotite crystals 10 mm or more across and larger K-feldspar crystals are conspicuous; these minerals contain numerous inclusions of other minerals, chiefly clinopyroxene, plagioclase and amphibole. The foliation, outlined by schlieren of mafic minerals, is vertical or near vertical. The pegmatitic patches are K-feldspar-rich with biotite, sometimes as perfect crystals. Blocks of light-coloured monzonite in the quarry are from nearby road cuttings.

Biotite from this quarry is used as the ANU K-Ar and ^{40}Ar-^{39}Ar age standard GA1550 (97.9 Ma) (McDougall & Roksandic, 1974). Williams *et al.* (1982) obtained a Rb-Sr mineral isochron age of 98.8 Ma, with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7046. A summary of the geochronology of the Dromedary Complex is given by those authors. Harrison *et al.* (1985) studied the diffusion of Ar in the biotite from this quarry and Miller *et al.* (1985) studied the fission tracks in apatite from this rock.

The change in slope at the foot of Mt Dromedary 200 m west of the quarry marks the contact between the monzonite and the inner quartz-monzonite of the Dromedary pluton. The knife-sharp contact is exposed beneath a clump of Moreton Bay figs and the contact dips steeply to the east. Laths of K-feldspar in the inner rock are oriented parallel to the contact. This leaves no doubt that the Dromedary pluton is a stock-like body.

Approximately 2 km to the south there is a track leading to the summit of the mountain.

Stop 6-10: Mt Dromedary Pluton (Narooma 370776 to ; map 10) MD8 to MD12

Samples MD8, MD10 and MD12 (Table 13) represent a sequence of compositions through to the centre of the zoned inner intrusion. The petrology of the Mt Dromedary pluton has been discussed in detail by Smith *et al.* (1988).

Continue on Highway 1 for 16 km to Narooma.

DAY 7. NAROOMA TO CANBERRA
PARTS OF THE MORUYA AND BEGA BATHOLITHS

The last day of the excursion examines localities in the small Moruya Batholith which are the most easterly of the Devonian I-type granites in the LFB. The northern parts of the Bega Batholith are crossed while returning to Canberra, and two granites are examined. Chemical and modal analyses of rocks from these localities are provided in Table 14.

Continue north from Narooma on Highway 1. After 11.9 km at the crossing of Wittakers or Brou Creek, boulders of granite can be seen in the far bank of the creek on the western side of the road. These are part of the Bodalla Adamellite which is the most southerly of the ten plutons in the Moruya Batholith. Pull off on left of road 100 m past bridge over creek.

Stop 7-1: Bodalla Granodiorite (Narooma 381973; map 11) sample MG20

The Bodalla Granodiorite (29 km^2) is a felsic granite at the southern end of the Moruya Batholith and includes the most felsic parts of the Moruya Suite. There is a track to the east on the northern side of the creek that leads to a large quarry in the Bodalla Adamellite 700 m from the highway. If this track is not in good condition then boulders from that quarry can be examined in a culvert where that track crosses a small creek 20 m east of the highway.

Petrographic description: This is a very felsic rock. Quartz grains or aggregates of grains are up to 5 mm across. Plagioclase crystals mosly 1-2 mm across but some up to 5 mm, have irregular crystal outlines. Some plagioclases are zoned around the dominant composition of about An_{20} and some have outermost rims around An_{10}. Sericite patches within some plagioclases are suggestive of made-over cores but the most calcic composition measured optically was only An_{30}-An_{35}. K-feldspar is microperthitic and appears as small irregularly-shaped crystals about 1 mm across. Biotite (α = straw-yellow, $\beta = \gamma$ = chocolate-brown) occurs as poorly shaped crystals commonly 1-2 mm across, a few having alteration strips of chlorite. There are a few small flakes of muscovite scattered throughout the rock. Some stumpy apatites and some prominent zircons are seen in the biotites. Both zircon and monazite can be identified as tiny inclusions around which there are pleochroic haloes within biotites.

Chemical composition: This is a felsic unfractionated composition containing 0.80% normative C that is very close to a minimum-temperature melt composition. Note, however, the high Na:K ratio for such a rock. This composition is taken to represent that of the melt component of the Moruya Suite.

Isotopic composition: $\varepsilon_{Nd} = +4.3$, $^{87}Sr/^{86}Sr(I) = 0.70461$, T^{Nd} = 730 Ma, $\delta^{18}O = 8.7‰$.

Continue north through Bodalla to the turn-off to Tuross Head after 17 km. Follow that road (Hector McWilliam Drive) to the T-junction at 5.1 km, then turn left for two blocks (250 m) on Allenby Road, and right into Morwong Street. Follow that street towards beach (400 m) and then turn right for 100 m to a position next to the rocks on the beach. Vehicles can continue along this road for 1.0 km to a parking area near the end of the road.

Stop 7-2: Tarandore Point, Tuross Head (Narooma 424062 to 423051; map 11) MG39

Strongly foliated tonalite crowded with elongated mafic inclusions is exposed in the small cove at the eastern edge of Morwong Street. The foliation dips to the north-east at 60°; it is parallel to the tonalite contact and it thought to have resulted from the flattening of the inclusions during emplacement of the pluton.

On the south side of the cove is the first of many composite dykes that occur along this part of the coast. The dyke is 1 to 2 m thick and consists of rounded blocks of dacite of varying size but commonly around 250 mm in diameter, in a matrix of aplite. 200 m south of the bay towards Tarandore Point, an aplite-dacite dyke dipping gently south is cut by a vertical east-west trending Cainozoic mafic dyke containing large feldspars and trains of vesicles oriented parallel to the walls.

TABLE 14. CHEMICAL ANALYSES: MORUYA AND BEGA BATHOLITHS

	MG20	MG39	MG42	MG24	MG14	MG29	MG3	AB299	AB280
Stop	7-1	7-2	7-3	7-3	7-4	7-4	7-5	7-6	7-8
SiO_2	74.91	66.32	60.13	53.39	67.18	62.88	71.50	64.44	69.12
TiO_2	0.15	0.67	0.99	1.38	0.51	1.02	0.34	0.61	0.43
Al_2O_3	13.37	15.08	16.42	14.77	15.50	15.90	14.18	14.97	14.07
Fe_2O_3	0.38	1.37	2.04	2.26	0.88	1.55	0.39	2.18	1.20
FeO	1.16	2.62	3.73	6.42	2.76	4.19	1.89	3.02	2.46
MnO	0.07	0.08	0.11	0.14	0.08	0.09	0.06	0.09	0.07
MgO	0.24	1.95	3.27	6.19	1.80	2.42	0.70	2.45	1.21
CaO	1.10	4.05	5.91	9.68	4.08	3.95	2.08	5.23	3.34
Na_2O	4.21	4.18	3.94	3.44	3.81	3.78	3.84	2.57	2.87
K_2O	3.50	2.31	1.41	0.59	2.21	2.46	3.70	2.95	3.27
P_2O_5	0.06	0.19	0.28	0.10	0.16	0.34	0.12	0.16	0.09
H_2O+	0.58	0.79	1.03	1.08	0.76	1.11	0.72	1.07	1.46
H_2O-	0.18	0.15	0.18	0.19	0.09	0.12	0.07	0.14	0.11
CO_2	0.02	0.14	0.28	0.24	0.11	0.16	0.36	0.08	0.18
total	99.93	99.90	99.72	99.87	99.93	99.99	99.95	99.96	99.88
Trace elements (ppm)									
Rb	90	72	36.5	5.6	61	92	141	115	156
Sr	123	380	487	532	327	326	215	363	122
Ba	580	440	325	185	445	545	585	625	480
Zr	102	187	168	94	138	273	155	165	142
Nb	12.0	12.5	14.0	6.5	11.5	17.0	12.5	7.5	9.5
Y	25	20	23	15	18	14	25	27	38
Ce	42	47	51	30	50	52	61	62	73
Sc	3	13	15	31	9	10	5.4	21	15
V	6	79	113	240	63	97	26	109	64
Cr	1	16	37	184	23	33	2	31	9
Ni	<1	11	26	56	10	16	<1	10	4
Zn	37	52	68	77	54	83	38	62	61
Ga	15.0	15.6	17.4	14.8	15.8	17.6	14.0	16.0	15.6
Pb	15	9	6	4	9	9	19	14	21
Th	8	12	5	4	8	5	14	12	20
U	3.6	2.8	1.8	1.0	2.7	1.4	5.9	2.2	2.0
Norm. C	0.80						0.36		
Modes									
Quartz	34.6			3.3	27.7		32.7	26.2	36.6
K-feldspar	26.2			0.2	6.4		22.0	13.6	19.8
Plagioclase	34.7			57.8	50.6		39.7	40.8	34.2
Biotite	4.5			18.0	11.2		5.6	8.7	6.7
Hornblende				18.6	3.9			8.9	2.6
Opaques				1.8				1.3	
Sphene				0.2				0.3	
Apatite				0.1	0.2			0.2	
Allanite									0.1

Three types of inclusion can be recognized in the Tuross Head Tonalite between Morwong Street and Tarandore Point. Elongate and flattened inclusions are the typical "cognate" type found over the whole pluton; these are thought to be restite fragments. Rounded mafic inclusions are locally incorporated from an earlier gabbroic intrusion, seen as a large mass on Tarandore Point. Sedimentary xenoliths, derived from local wall-rock, are present but comprise less than 1% of the total inclusion population. Some of the rounded mafic inclusions themselves contain inclusions ("double enclaves").

The block of gabbroic-diorite at Tarandore Point is clearly an earlier intrusion engulfed by the Tuross Head Tonalite. It is intruded by irregular veins and dykes of tonalite containing rounded inclusions. Vernon *et al.* (1988) have described these relations in detail.

At Boogumgoridgee Point, projecting from the beach between Tarandore Point and Tuross Head, the tonalite is typical of the main mass not associated with the gabbroic-diorite. This tonalite (9.6 km^2) is the most mafic unit in the Moruya Batholith and in the Moruya Suite (see also Stop 7-3). Sample MG39 from this locality is the most felsic sample of this body that has been analyzed.

The southern contact of the tonalite with the Wagonga slates and sandstones is located just north of Tuross Head.

Petrographic description of sample MG39: Plagioclase is crudely rectangular in cross-section and is mostly 1-5 mm in longest dimension. It is zoned from An_{35} to outer rims near An_{20}. There are cores that may be more calcic. Quartz grains (up to 3 mm) have undulose extinction. K-feldspar also up to about 3 mm across, is finely perthitic. Ragged biotites (α = straw-yellow, $\beta = \gamma$ = chocolate-brown) are only rarely altered to bright green chlorite. Hornblendes (α = pale yellow-green, β = olive-green, γ = dark green) appear as crystals up to 5 mm. Irregularly-shaped magnetites are common. Sphenes (1 mm) occur as perfect lozenge-shaped crystals. Tiny prisms of apatite and small zircons are scattered throughout but are readily seen as inclusions in the the biotites and hornblendes. No allanites were found in the thin-section examined. Hornblendes may occur in clots or aggregates with ragged biotites but these are much less common than in the more mafic Tuross Head Tonalite sample MG42 of the next stop.

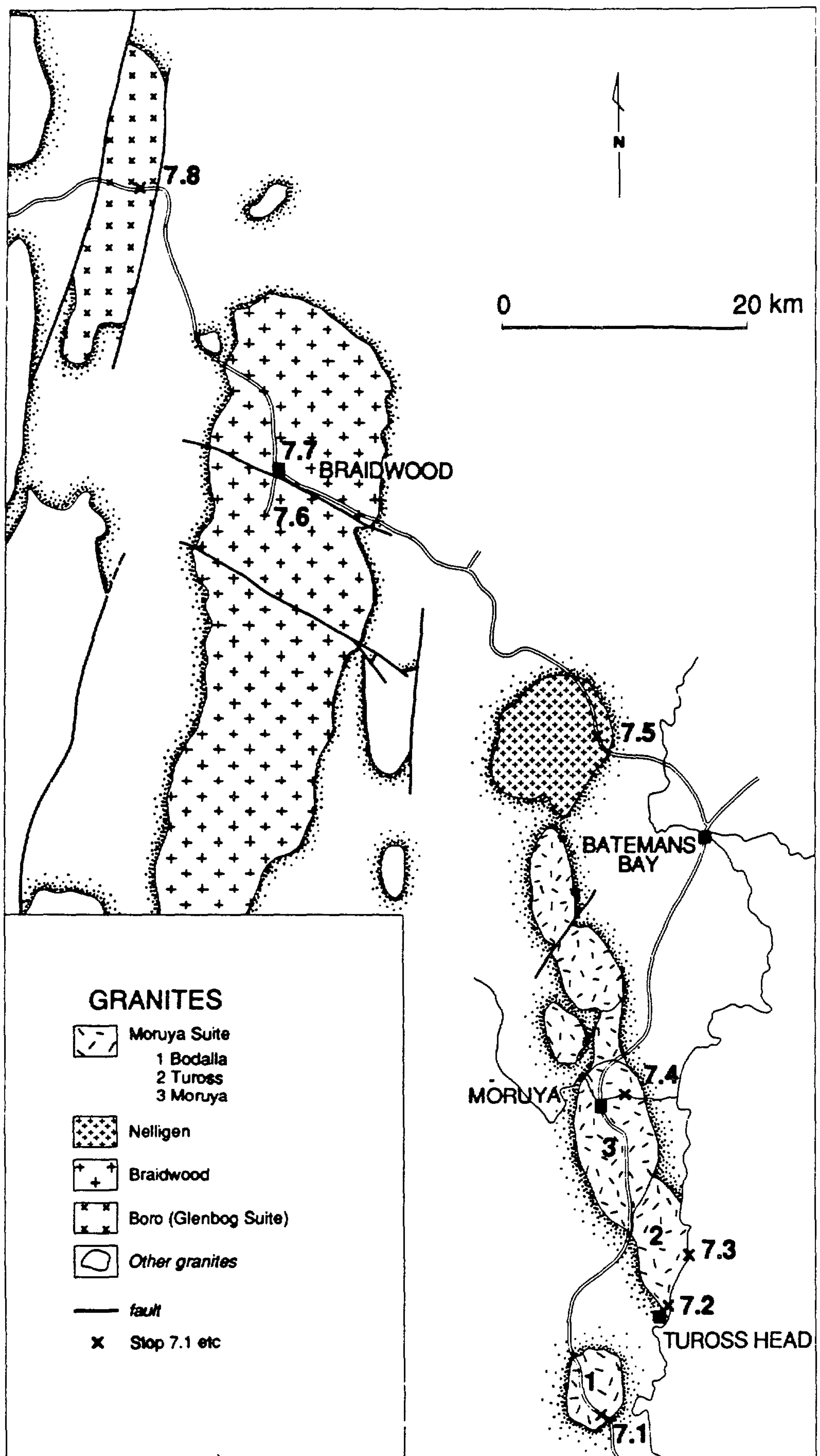
Chemical composition: This is the most felsic composition obtained from the Tuross Head Tonalite.

Return to Highway 1 and turn to north. The ridge that is crossed after 3.3 km comprises contact rocks at the southern end of the Moruya Tonalite. After 4.8 km take the road to the right and then turn right again after 1.1 km on the road to "Bingi". At 5.3 km take the track to the east to the parking area at 6.9 km. Small vehicles may be able to drive a further 500 m to the beginning of Bingie Bingie Point.

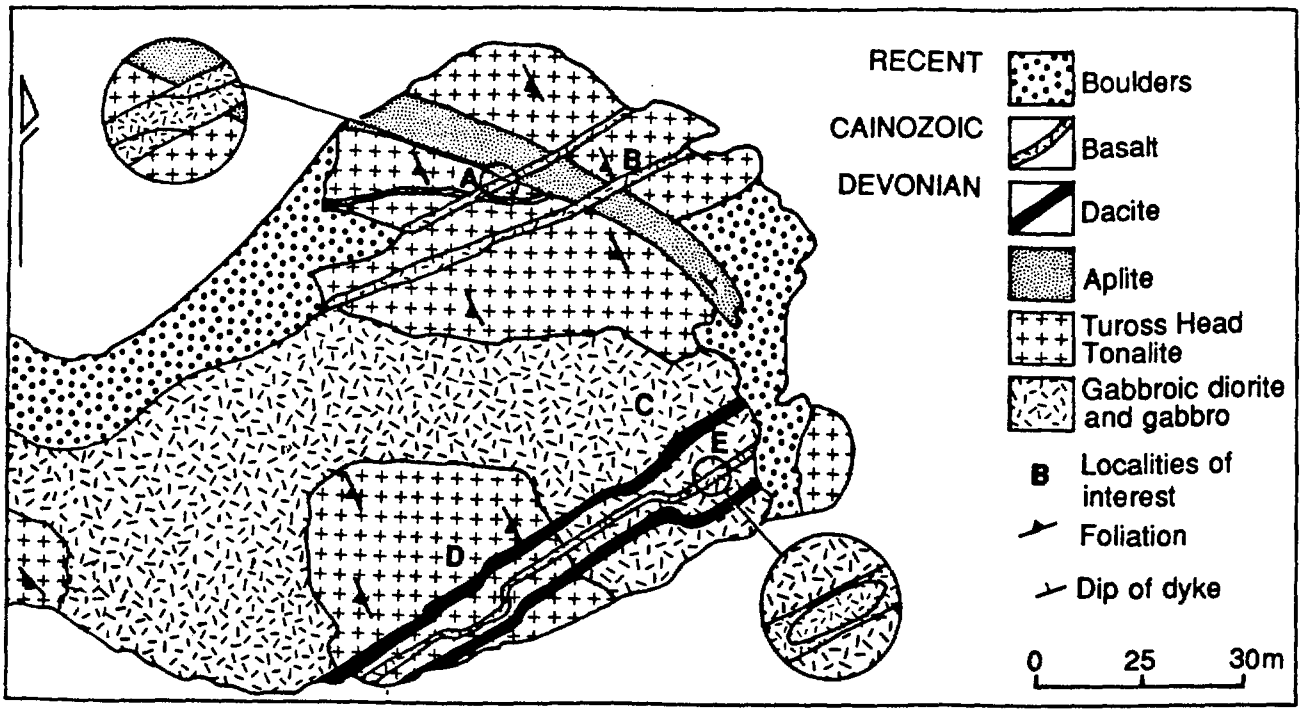
Stop 7-3: Tuross Head Tonalite at Bingie Bingie Point (Narooma 442107; maps 12) MG42

The Tuross Head Tonalite is a heterogeneous body, varying from quartz-diorite to granodiorite in composition. A mafic variety, crowded with inclusions is well exposed on the point. Both the inclusions and the mafic minerals show a very strong preferred orientation with the foliation trending 330° and dipping steeply. MG42 is the most mafic granite collected from the Moruya Batholith, for which the compositions range continuously from 60 to 75% SiO_2. The composition of this rock is fairly similar to a typical andesite, and granites for which that comparison can be made are only found in the LFB in the Moruya Batholith and close by in the eastern side of the Bega Batholith. As at Stop 7-2, the tonalite is intrusive into a body of gabbroic diorite (MG24) at this locality and a coarse-grained big-hornblende rock is often developed near contacts.

A large aplite dyke cuts the tonalite and several east-west trending mafic dykes cut the gabbroic diorite-tonalite-aplite complex. These are of two types and different ages although all are parallel. One set is dacitic in composition, whereas the others are alkali basalts or hawaiites, presumably closely related to the nearby Cainozoic basalt flows. These younger dykes are easily distinguished by an abundance of large (usually 10 - 30 mm long) oriented plagioclase crystals. All of the



Map 11. Map of the granites of the Moruya Batholith and the Braidwood and Boro plutons



Localities of special interest:

A. Composite basaltic dyke
B. Concentration of inclusions in basaltic dyke (garnet, spinel pyroxenite, anorthosite)
C. Analysed gabbroic diorite locality (MG24)
D. Analysed quartz diorite (Tuross Head Tonalite) (MG42)
E. Composite dyke

Map 12. Sketch of the rock units at Bingie Bingie Point (after Brown, 1928, and Halford, 1970)

Cainozoic dykes contain inclusions but these have been concentrated in the central dyke. These inclusions include anorthosites, hornblende anorthosites and spinel pyroxenites, as well as xenocrysts of amphibole, garnet, labradorite, and rare biotite and olivine, with some inclusions of country rock. The pyroxenes are an aluminous variety similar to those found on the liquidus at 1 GPa (10 kb) by Green & Ringwood (1967). Halford (MSc thesis, 1970) has shown that the compositions of some of these minerals are consistent with a high-pressure origin and they are considered to be deep-seated crystallization products of the alkali basalt itself, rather than samples from the lower crust of the area.

Petrographic description: Plagioclase is the dominant mineral in this rock. It is seen in thin-section to have squat mostly rectangular shapes up to 4 mm in length, with complex oscillatory zoning around irregular calcic cores. The inner zones are mostly near An_{35} with outermost zones near An_{20}. The inner zones of the plagioclase crystals are commonly outlined by strings of sericite, and were interpreted as restite by White & Chappell (1977). Hornblendes (α = pale yellow-green, β = olive green, γ = dark green with bluish tint) usually appear as ragged crystals that are crowded near their centres with small magnetites. They may occur as isolated crystals or more commonly in clots or aggregates with equally ragged biotites (α = straw-yellow, $\beta = \gamma$ = dark sepia-brown to chocolate-brown) and irregularly- -shaped magnetites. Biotite and to some extent hornblende are partly replaced by chlorite. Quartz grains have irregular shapes (up to 2 mm) and are mostly interstitial to the dominant plagioclase. Magnetite and tiny apatite prisms are common. Zircon crystals are conspicuous but when they occur in biotite there are no pleochroic haloes. Sphene is minor and occurs as poorly-shaped interstitial crystals or as strings of irregularly-shaped individuals, mainly in close association with secondary chlorite; it is either late or secondary.

Chemical composition: This is the most mafic composition obtained from the Tuross Head Tonalite, and the most mafic granite seen on this excursion. Relative to the bulk of I-type granites in the LFB this rock is high in Na_2O and Sr. Chappell & Stephens (1988) pointed out that there is a striking similarity between the chemical composition of this rock and of rocks from the Peninsular Ranges Batholith containing close to 60% SiO_2, with total Fe and CaO being a little lower in MG42 and Na_2O a little higher. They argued that this did not imply that the production of the MG42 magma was closely related to active subduction, and suggested that the composition was produced by a process of *remagmatization* (partial melting and mobilization of the resulting melt + residue as magma) of an older subduction-related source rock, with little change in composition.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 390 Ma has been measured on this sample. The rock contains less inherited zircon than most of the Bega Batholith granites, but the ages of inheritance cover a wide range, from Archaean to Proterozoic.

Isotopic composition: $\varepsilon_{Nd} = +3.3$, $^{87}Sr/^{86}Sr(I) = 0.70404$, $T^{Nd} = 790$ Ma.

Return to Highway 1 and then travel north through Moruya and turn to the east on the road immediately after crossing the Moruya River just north of Moruya. Follow this road for 3.3 km to the Dorman Long Quarry.

Stop 7-4: Moruya Tonalite in Dorman Long Quarry (Batemans Bay 396227; map 11) MG14

The Moruya Tonalite is the equal largest body in the Moruya Batholith, with a area of 69 km^2. It is an elliptically-shaped body with its long axis oriented north-south. It is even-grained and transitional from granodiorite to tonalite, with fairly abundant mafic inclusions. Both the inclusions and the mafic minerals are oriented to give a strong primary foliation. This quarry is located about 100 m from the eastern contact of the tonalite. A Cainozoic basaltic dyke cuts the granodiorite. The rock in this quarry was quarried here as early as 1868. The stone was shipped by sea to Sydney and used, for example, in the GPO building, Martin Place (1872). Dorman, Long and Co. selected this rock for a construction stone in the Sydney Harbour Bridge and commenced quarrying in 1924.

Petrographic description: This member of the Moruya Suite is intermediate between the mafic Tuross Head Tonalite (MG42) seen at Bingie Bingie and the most felsic member (Bodalla MG20). It is much more felsic than the Tuross Head Tonalite from Bingie Bingie, but plagioclase is still the dominant mineral, occurring as large crystals up to 10 mm long with more or less rectangular cross-sections. These have oscillatory zoning superimposed on normal zoning with compositions ranging down to about An_{20}, superimposed on prominent cores (in the thin-section examined, one good section gave a symmetrical extinction angle around 27° and hence a composition of An_{50}, whereas Griffin *et al.* (1978) record cores with the composition An_{75}). Quartz aggregates 6-8 mm across, consist of many smaller crystals with triple junctions. Some quartz also occurs as small interstitial grains. K-feldspar occurs as small irregularly-shaped interstitial grains 1-2 mm across. Biotites (α = straw-yellow, $\beta = \gamma$ = chocolate-brown) are up to 3 mm across but most are ragged. Hornblendes (α = straw-yellow, β = dark olive-green, γ = green with slight bluish tint) commonly occur in aggregates with biotite, magnetites and sphenes. Primary sphenes are up to 0.5 mm but most are small and there are some skeletal crystals; some ragged patches of sphene associated with secondary chlorite after biotite are clearly secondary. Small magnetites also occur throughout other parts of the rock and pyrite is seen in hand-sample. Allanite are commonly yellow-brown and zircons are prominent.

Chemical composition: This is a moderately mafic rock with the high Na and Sr contents characteristic of the Moruya Batholith. With 67% SiO_2, it is about half-way between the most mafic rock MG42, (60% SiO_2, Stop 7-3) and the most felsic one MG20 (75% SiO_2, Stop 7-1) of the Moruya Suite.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 395 Ma has been measured on this sample. Even though the Moruya Tonalite has the highest ε_{Nd} measured in the Bega Batholith (+3.0) it still contains an appreciable component of inherited zircon cores. Most of the inheritance is between 500 and 600 Ma old, one grain is about 1000 Ma old, and there is nothing older. It appears that the eastward progression towards more positive ε_{Nd} is associated with a decrease both in the age and abundance of the inherited components, although the Coolagolite result (Stop 6-8) shows that even where the abundance of inheritance is very low, very old cores still survive.

Isotopic composition: $\varepsilon_{Nd} = +4.0$, $^{87}Sr/^{86}Sr(I) = 0.70408$, $^{206}Pb/^{204}Pb = 18.170$, $^{207}Pb/^{204}Pb = 15.581$, $^{208}Pb/^{204}Pb = 38.042$, $T^{Nd} = 810$ Ma, $\delta^{18}O = 8.1‰$.

Either return to Highway 1 and then drive north for approximately 27 km to Batemans Bay. This road leaves the Moruya Batholith some 5 km north of Moruya and enters Ordovician sedimentary rocks which are well exposed in some deep cuttings.

Or continue on road towards the east and then north near Moruya Airport and follow the coastal road to Batemans Bay. The rocks exposed on the headlands are Ordovician sediments.

Continue north from Batemans Bay across the Clyde River to the junction of the highway to Canberra 500 m north of the bridge. Travel along the Canberra road for 14.3 km to the Nelligen Quarry. This road is through typical coastal forest dominated by Spotted Gums (*Eucalyptus maculata*) with an underbrush of Wattles (*Acacia*) and She-oaks (*Casuarina*). The bright purple flowering creeper is a purple coral-pea (*Hardenbergia violacea*) sometimes called 'sarsparilla'. The bedrock comprises steeply dipping Palaeozoic slates and sandstones that are well exposed in the road cutting near the approaches to the Nelligen bridge over the Clyde River, 7.1 km west of Highway 1. Nelligen was the old port for the gold mining town of Braidwood situated on the plateau to the west. West of the Clyde River the road follows Nelligen Creek, along the banks of which are abundant River Oaks and exotic California Pines and European Willows. About 500 m west of the Nelligen Creek bridge (13.1 km from the Highway), the cordierite hornfels that forms a contact aureole around the Nelligen Granodiorite can be seen in the shallow road cutting. A small granite quarry is located about 100 m south of the road and 1200 m west of Nelligen Creek, set in a Spotted Gum Forest with Dwarf Palms covering the floor that are primitive Cycads (*Macrozamia communis*).

Stop 7-5: Nelligen Granodiorite (Batemans Bay 359522; map 11) sample MG3

The Nelligen Granodiorite is a relatively homogeneous circular-shaped body 69 km^2 in area, at the northern end of the Moruya Batholith. This rock has similarities with more felsic members of the Moruya Suite, but in detail there are differences and it is grouped with those other units in the Moruya Supersuite. It is a moderately felsic medium-grained granite in which the pink-coloured K-feldspars and the presence of magnetite are both indicative of crystallization under oxidizing conditions. There is no hornblende in the granite but it is present in the inclusions which are more metaluminous. Biotite (chocolate-brown) is the only ferromagnesian mineral and since biotite is always peraluminous this indicates that the rock is slightly peraluminous. Consistent with this, sphene is absent although it is recorded in more mafic members of the Moruya Supersuite.

Petrographic description: Quartz grains ranging up to 5mm have undulose extinction and are sometimes broken and recrystallized to a few separate individuls. Plagioclases zoned from An_{30} to An_{15} range in size from about 0.2 mm to 5 mm and show good crystal shapes when in, or projecting into, K-feldspar. However, the K-feldspars are large microcline microperthites (10 mm or more) that include other minerals. Biotite (α = pale yellow-brown, $\beta = \gamma$ = dark chocolate-brown) also has a large range of grain size from small crystals only a fraction of a mm across to individuals that are 3 mm across. Most biotites are irregular in outline but there are rare well-shaped crystals. Only a few are altered to chlorite. Biotite shows abundant micro-kinks under high magnification. The only accessory minerals are small prismatic apatites, zircons and some magnetites.

Chemical composition: This is a moderately felsic composition that is slightly corundum-normative (0.36%).

Continue east on the road to Canberra. The western contact of the Nelligen Granodiorite is crossed 7.2 km west of the quarry. Later, the "Great Escarpment" is climbed at Clyde Mountain. Most of the road cuttings in this range are in steeply dipping Ordovician sediments, with Devonian rocks inclined at about 45° towards the east, near the top. The eastern contact of the large Braidwood Granodiorite unit is crossed 37 km from the quarry. Continue to Braidwood and turn left (south) on the Araluen Road. Take the turn to Majors Creek after 3.5 km and stop after a further 700 m to examine boulders of the Braidwood Granodiorite.

Stop 7-6: Braidwood Granodiorite (Braidwood 527703; map 11) sample AB299

Braidwood is one of the large I-type plutons of the LFB (590 km^2), and is part of the Candelo Supersuite. The body is rich in magnetite (average 1.1%) and the pluton has the largest magnetic anomaly of any in the LFB. This pl;uton is associated with Au mineralization.

Petrographic description: Quartz, mostly 1-2 mm across, includes other minerals or is interstitial to abundant plagioclase and mafic minerals. K-feldspar is about the same size as quartz but much less abundant. Plagioclase ranges from 1 to 3 mm, is more or less equidimensional and has some good crystal shapes against quartz. Plagioclase is zoned from cores near An_{50} to outer rims near An_{20}. Biotite (α = straw-yellow, $\beta = \gamma$ = chocolate-brown) ranges in size from 0.5 to 2 mm. Hornblende (α = pale yellow-green,

β = olive-green, γ = grass-green) also has a large size range from 0.5 mm or less to about 3 mm. Relict clinopyroxene occurs in some of the hornblendes. The abundant magnetite crystals may also be a large size, crystals up to 0.2 mm being fairly common. Many of the magnetites contain inclusions of tiny apatites and zircons. Many of the zircons are quite large (0.1 mm) and some are seen to have rounded cores. Apatites are only seen as tiny prisms particularly in the mafic minerals. No large crystals of sphene were seen in the thin-section examined but a few small irregularly-shaped crystals were present and it is also seen in unaltered hornblende as skeletal growths. It appears to have been a very late mineral. Rare late or subsolidus calcite occurs as interstitial patches.

Chemical composition: This is a rather mafic rock from the "central" supersuite of the batholith, the Candelo Supersuite (AB195 from Stop 5-11 was also representative of this supersuite). Note the high Fe_2O_3 content of this granite which produces the strong aeromagnetic anomaly.

Isotopic ages: An ion-probe U-Pb zircon magmatic crystallization age of approximately 400 Ma has been measured on another sample (AB293) from the Braidwood Granodiorite. That sample also gave a pattern of inheritance that is now familiar, namely a cluster of ages between 500 and 600 Ma representing the immediate source of the granites, a couple of analyses near 1000 Ma representing that source's possible precursor, and a couple of early Proterozoic grains probably derived from a small amount of sediment in the source.

Isotopic composition: Isotopic data on another sample from this unit, AB293 are: ε_{Nd} = -3.2, $^{87}Sr/^{86}Sr(I)$ = 0.70566, $^{206}Pb/^{204}Pb$ = 18.185, $^{207}Pb/^{204}Pb$ = 15.620, $^{208}Pb/^{204}Pb$ = 38.197, T^{Nd} = 1290 Ma.

Return to Braidwood and stop at junction of Araluen road with the Canberra road, to examine Braidwood Granodiorite used in building the church on the north-eastern corner of the road intersection.

Stop 7-7: St Bede's Church, Braidwood (Braidwood 540738; map 11)

Church of the Holy Restite (St Bede's Catholic Church). The abundant inclusions in the Braidwood Granodiorite are well-displayed in the walls of this church.

Continue on Canberra road past the turn-off to Goulburn after 27 km, to boulders beside the road after a further 1.7 km.

Stop 7-8: Boro Granodiorite (Braidwood 413963; map 11) sample AB280

The Boro Granodiorite (135 km^2) is the most northerly pluton in the Glenbog Suite. The rock at this locality shows the distinctive features seen earlier in the Glenbog Granodiorite at Stop 5-7, such as the prominent large crystals of quartz.

Petrographic description: This is a member of the Glenbog Suite and like all such rocks it is characterized by prominent large quartz crystals or aggregates of crystals (10-20 mm). In this rock the large quartz individuals have undulose extinction. Plagioclase is very altered to sericite and epidote and there are separate epidotes up to 1 mm long or aggregates of epidotes interstitial to other minerals or within plagioclase, K-feldspar and altered biotite. K-feldspar is fine microperthite with weak microcline twinning, that commonly includes other minerals. Biotite up to 3 mm across, is only seen as altered individuals. When in K-feldspar, the pseudomorphs may have perfect crystal shapes. On the other hand, hornblende (α = pale yellow-green, β = olive-green, γ = grass-green) as small crystals (rarely exceeding 2 mm long and 0.5 mm across), is unaltered and is mostly seen as perfect shapes, particularly when surrounded by quartz and K-feldspar. Large allanites, small prismatic apatites, small zircons and a few tiny insignificant opaque minerals are accessory minerals.

Chemical composition: This rock shows the characteristic chemical features of the Glenbog Suite, notably the relatively low Na and Sr contents characteristic of the western side of the Bega Batholith. It shares these features with sample AB6 seen previously at Stop 5-7, but is a little more felsic, containing 1.73% more SiO_2, with corresponding differences in the other components.

Isotopic composition: The isotopic composition of another sample of this pluton, AB281 is ε_{Nd} = -4.9, $^{87}Sr/^{86}Sr(I)$ = 0.70827, T^{Nd} = 1470 Ma. Compare with the data from sample AB6 at Stop 5-7.

Continue towards Canberra. The Great Divide is crossed after 7.2 km and the road enters the internal drainage of the Lake George Basin. After a further 5.6 km there is a panorama to the west showing Lake George on the front right with the western side of the lake marked by the Lake George Fault. That fault lies on the IS-line and recent movements on that fault, at the boundary between the Bega and Kosciusko Basement Terranes, have produced the internal drainage basin. To the front left is a hill made of felsic granites which are the most westerly in the Bega Batholith.

Continue through Bungendore and then turn left, climbing the Lake George Fault escarpment 7 km from that turn. Here, the road crosses the IS-line and enters the province of voluminous S-type granites and volcanic rocks. Continue to Canberra, by road some 35 km west of the IS-line at this point.

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THE MAN FROM SNOWY RIVER

by

A.B. ('Banjo') Paterson

There was movement at the station, for the word had passed around
That the colt from old Regret had got away,
And had joined the wild bush horses—he was worth a thousand pound,
So all the cracks had gathered to the fray.
All the tried and noted riders from the stations near and far
Had mustered at the homestead overnight,
For the bushmen love hard riding where the wild bush horses are,
And the stock-horse snuffs the battle with delight.

There was Harrison, who made his pile when Pardon won the cup,
The old man with his hair as white as snow;
But few could ride beside him when his blood was fairly up—
He would go wherever horse and man could go.
And Clancy of the Overflow came down to lend a hand,
No better horseman ever held the reins;
For never horse could throw him while the saddle-girths would stand—
He learnt to ride while droving on the plains.

And one was there, a stripling on a small and weedy beast;
He was something like a racehorse undersized,
With a touch of Timor pony—three parts thoroughbred at least—
And such as are by mountain horsemen prized.
He was hard and tough and wiry—just the sort that won't say die—
There was courage in his quick impatient tread;
And he bore the badge of gameness in his bright and fiery eye,
And the proud and lofty carriage of his head.

But still so slight and weedy, one would doubt his power to stay,
And the old man said, "That horse will never do
For a long and tiring gallop—lad, you'd better stop away,
Those hills are far too rough for such as you."
So he waited, sad and wistful—only Clancy stood his friend—
"I think we ought to let him come," he said;
"I warrant he'll be with us when he's wanted at the end,
For both his horse and he are mountain bred.

"He hails from Snowy River, up by Kosciusko's side,
Where the hills are twice as steep and twice as rough;
Where a horse's hoofs strike firelight from the flint stones every stride,
The man that holds his own is good enough.
And the Snowy River riders on the mountains make their home,
Where the river runs those giant hills between;
I have seen full many horsemen since I first commenced to roam,
But nowhere yet such horsemen have I seen."

So he went; they found the horses by the big mimosa clump,
They raced away towards the mountain's brow,
And the old man gave his orders, "Boys, go at them from the jump,
No use to try for fancy riding now.
And, Clancy, you must wheel them, try and wheel them to the right.
Ride boldly, lad, and never fear the spills,
For never yet was rider that could keep the mob in sight,
If once they gain the shelter of those hills."

So Clancy rode to wheel them—he was racing on the wing
Where the best and boldest riders take their place,
And he raced his stock-horse past them, and he made the ranges ring
With the stockwhip, as he met them face to face.
Then they halted for a moment, while he swung the dreaded lash,
But they saw their well-loved mountain full in view,
And they charged beneath the stockwhip with a sharp and sudden dash,
And off into the mountain scrub they flew.

Then fast the horsemen followed, where the gorges deep and black
Resounded to the thunder of their tread,
And the stockwhips woke the echoes and they fiercely answered back
From the cliffs and crags that beetled overhead.
And upward, ever upward, the wild horses held their way,
Where the mountain ash and kurrajong grew wide;
And the old man muttered fiercely, "We may bid the mob good day,
No man can hold them down the other side."

When they reached the mountain's summit, even Clancy took a pull—
It well might make the boldest hold their breath;
The wild hop scrub grew thickly, and the hidden ground was full
Of wombat holes, and any slip was death.
But the man from Snowy River let the pony have his head,
And he swung his stockwhip round and gave a cheer,
And he raced him down the mountain like a torrent down its bed,
While the others stood and watched in very fear.

He sent the flint-stones flying, but the pony kept his feet,
He cleared the fallen timber in his stride,
And the man from Snowy River never shifted in his seat—
It was grand to see that mountain horseman ride.
Through the stringy barks and saplings, on the rough and broken ground,
Down the hillside at a racing pace he went;
And he never drew the bridle till he landed safe and sound
At the bottom of that terrible descent.

He was right among the horses as they climbed the farther hill,
And the watchers on the mountain, standing mute,
Saw him ply the stockwhip fiercely; he was right among them still,
As he raced across the clearing in pursuit.
Then they lost him for a moment, where two mountain gullies met
In the ranges—but a final glimpse reveals
On a dim and distant hillside the wild horses racing yet,
With the man from Snowy River at their heels.

And he ran them single-handed till their sides were white with foam;
He followed like a bloodhound on their track,
Till they halted, cowed and beaten; then he turned their heads for home,
And alone and unassisted brought them back.
But his hardy mountain pony he could scarcely raise a trot,
He was blood from hip to shoulder from the spur;
But his pluck was still undaunted, and his courage fiery hot,
For never yet was mountain horse a cur.

And down by Kosciusko, where the pine-clad ridges raise
Their torn and rugged battlements on high,
Where the air is clear as crystal, and the white stars fairly blaze
At midnight in the cold and frosty sky,
And where around the Overflow the reed-beds sweep and sway
To the breezes, and the rolling plains are wide,
The Man from Snowy River is a household word today,
And the stockmen tell the story of his ride.