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Cooma Granodiorite and Berridale Batholith

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COOMA GRANODIORITE AND BERRIDALE BATHOLITH

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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. It 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). For the eastern third of the belt, in which the granites are more abundant, their occurrences are given in more detail in Fig. 2 of White & Chappell (1983), which paper also described the geological setting of the granites. All units recognized in Victoria were 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). 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). These notes are concerned with studies that have been made of those granites now occurring in south-eastern Australia and the term LFB used here refers to that region.

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 in the 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 of the eastern part of the belt (White & Chappell, 1983).

Radiometric ages on granites of the LFB are sparse. Most ages are in the 420 to 390 Ma interval with some plutons to 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) is present in the most easterly part of the belt; this is 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, 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 (km²)	% 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. It has been conventional to group these lithological units into separate batholiths, particularly in the eastern part of the LFB, and this is here extended 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. However, it has for over fifty years been a focus of attention as the core rock of the Cooma Metamorphic Complex and this separate identity is retained here. While some aspects of this subdivision in batholiths and complexes are arbitrary it is nevertheless very useful in geographically 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 lithologically 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 and 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 the Stawell and Grampians-Stavely Basement Terranes. The Bassian Batholith comprises all of the granites extending from Wilsons Promontory across Bass Strait and through north-eastern 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 fractionated S-type granites that sometimes contain concentrations of garnet, and these rocks should clearly be grouped into one structural unit. Finally, the Taswegia Granites are those of Devonian age 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 has been discussed by White & Chappell (1983). Granites assigned to a single suite share distinct textural, modal and chemical features and chemical characters. Rocks within a suite must also have the same isotopic composition and this is an excellent test because of the high precision available and the insensitivity to chemical composition, except where the age correction is large. Some of the suites in the LFB have been tested with Sr and Nd isotopes (Compston & Chappell, 1979; McCulloch & Chappell, 1982). 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 and 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 than those produced from sedimentary sources (S-type). This is thought to result from the I-type sources being of more uniform composition. 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 can be grouped with others that share broadly similar chemical features, but differ in detail. 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). Pitcher, working in an area of excellent exposure, emphasized relative ages determined in the field, modes, texture, and fabric, with confirmation to be sought from the chemistry. Bateman & Dodge (1970) again emphasized age relations in applying the term sequence to related rocks in the Sierra Nevada Batholith. Granites of the LFB are not so 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 concluded that these suites should be abondoned, or defined differently. However suites can be clearly separated among the granites of 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

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

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 between 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, in the LFB, differences between suites 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.

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 on 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 on the presence of sillimanite with the mineral assemblages being mainly quartz + orthoclase + cordierite + biotite + muscovite + sillimanite + andalusite.

5. *Migmatite zone* in which abundant granitic veins occur in a sillimanite-andalusite biotite gneiss.

The Cooma Granodiorite is a regional-aureole granite which is sometimes foliated, but more often massive, and with 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, 1988b).

For a sketch map of the Cooma Complex, see page 49.

GEOCHRONOLOGY OF THE COOMA COMPLEX

Browne (*in* David, 1950) divided the granites of southeastern Australia into three groups 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 the 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.

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.

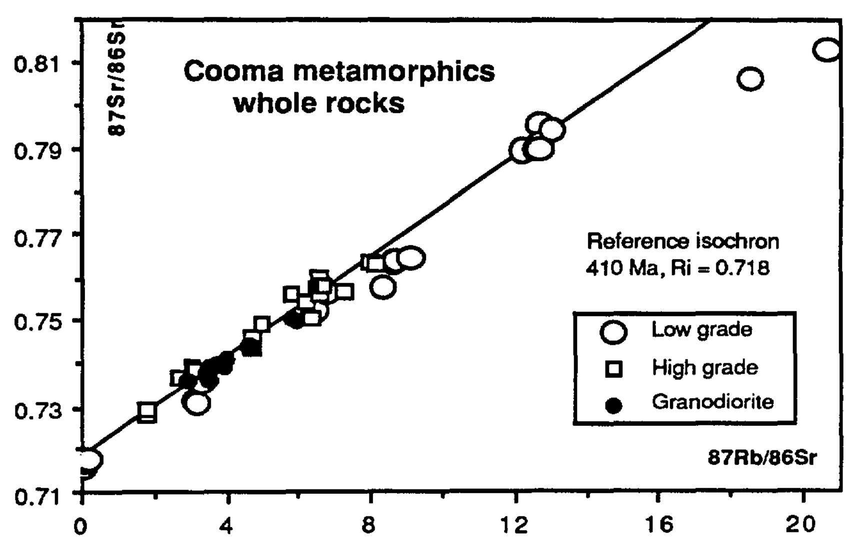

Figure 1. Whole-rock Rb-Sr analyses of the Cooma Granodiorite, and high and low grade sediments in its regional metamorphic aureole.

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.

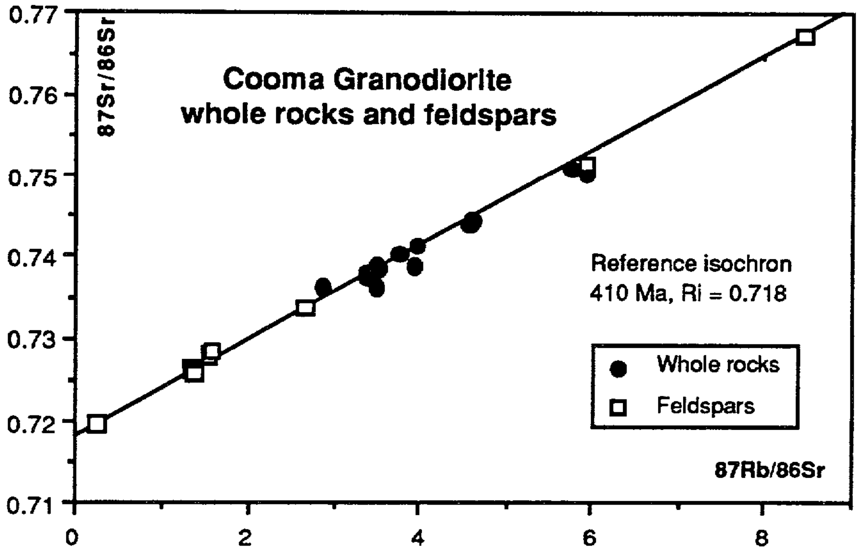

Figure 2. Whole-rock and feldspar Rb-Sr analyses from the Cooma Granodiorite and an associated microgranite dyke.

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.

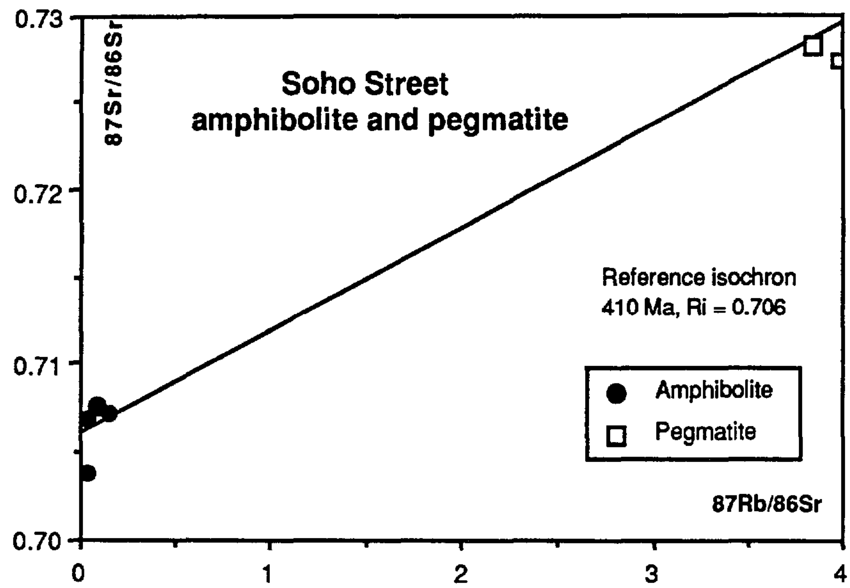

Figure 3. Rb-Sr whole-rock analyses from the Soho Street pyroxene amphibolite enclave in the Cooma Granodiorite, and an associated pegmatite.

Rb-Sr analyses of the large (50m) 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.

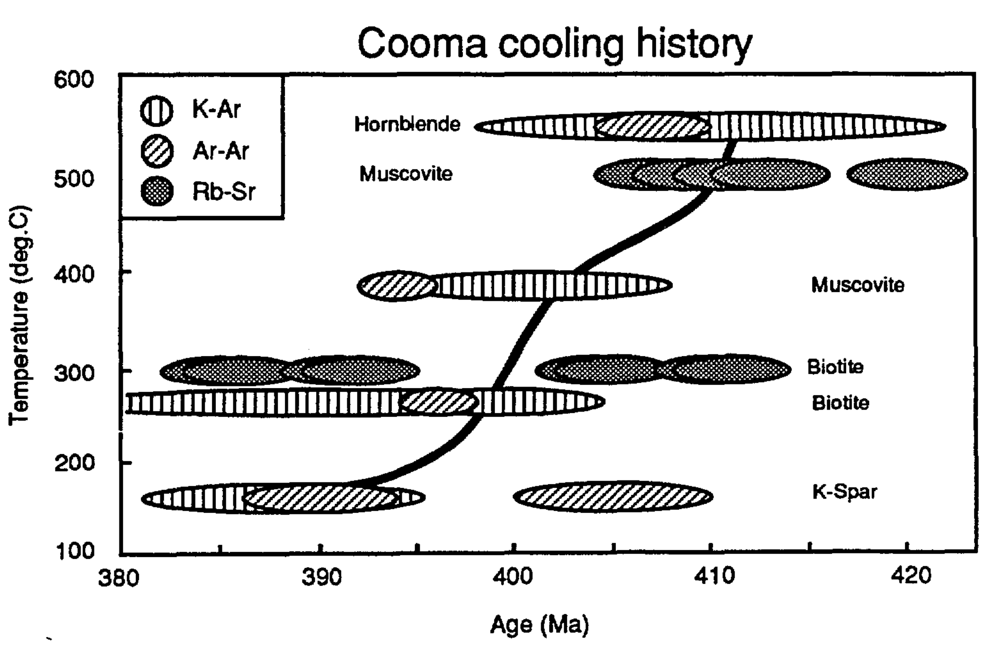

Figure 4. Mineral ages measured on the Cooma Complex plotted against their effective closure temperatures.

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 consistently greater than the 410 Ma recorded by hornblende K-Ar, sufficiently so 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 sediments the same as those presently at the surface, or derivation from somewhat different sediments at depth.

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 north-west. A set of conjugate right-lateral faults is also present. The large Gygederick Screen extends along the centre of much of the batholith; this is part of the IS-line (White *et al.*, 1976a) which 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). Lambert (1963), Black (1965) and Patterson (1968) have contributed BSc theses. 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 north-eastern part of the batholith, and it 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 and is sometimes strongly deformed to the extent that most samples are altered, sometimes very badly. Cootralantra is a mafic S-type granite that is part of the Bullenbalong Suite that occurs also in the Gingera Granites and extensively in the Kosciusko Batholith. The composition of this suite will be discussed in later consideration of the Kosciusko Batholith.

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 rocks are not as peraluminous as the Bullenbalong Suite 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 chemical 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 with 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.

For a map of that part of the Berridale Batholith covered by this excursion, see page 51.

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 the area studied in a 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 a PhD thesis. BSc theses have been contributed by Hine (1971), I.S. Williams (1973) and C.R. Williams (1974). Fifty six lithological units are recognized; S-types are dominant (94%) but some important 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, but the I-type granites seldom show strong foliation. This is attributed to the S-types having higher quartz contents, which mineral is relatively brittle and easily deformed, 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, in addition to 434 km^2 of the same suite to the east in the McLaughlins Flat and Cootralantra plutons of the Gingera Granites and the Berridale Batholith. 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 north-east. 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 widespread character 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 (Wyborn, 1983). It is a concentrically zoned body that has been cut into two parts by a wrench fault. Zoning is from mafic gabbros near the contact through a progressively 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 in area, 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.

For a map of that part of the Kosciusko Batholith covered by this excursion, see page 51.

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), in southeast Asia and eastern China, in the eastern United States, in the British Isles, Europe and Antarctica. A consistent feature of this episode is that dominantly it involved crustal redistribution rather than the generation of new crust, with most of the magmas being the products of partial melting of preexisting crustal rocks. The result is a generation of igneous rocks with a geochemical and isotopic character that 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. Isotopic work has lagged behind the major and trace element studies, but this is being remedied.

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 wideranging study, using both K-Ar and Rb-Sr, Richards & Singleton (1981) extended the area sampled to include the full 650 km width of the Lachlan Fold Belt in Victoria.

Plutonism in the southern Lachlan Fold Belt appears to have started in the late Ordovician with batholiths 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 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. In the Carbonifeous several isolated plutons were emplaced north-east of the main batholiths.

Most recent isotopic work has been concentrated on the batholiths of southeastern New South Wales, where mapping and geochemical studies have 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 had 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 their 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 in not all cases did the Rb-Sr and $^{40}Ar/^{39}Ar$ ages agree - 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 the source to be at least as old as early Ordovician.

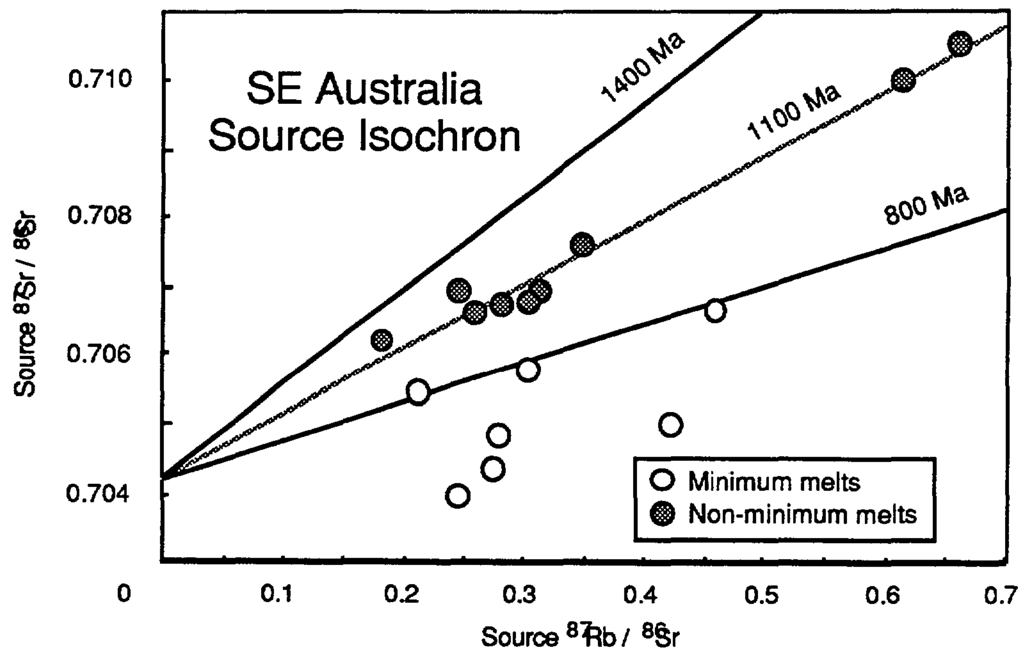

Figure 5. Source isochron for granites of the Berridale and Kosciusko batholiths constructed by inferring the source Rb/Sr for a number of plutons and plotting that against the plutons' initial $^{87}Sr/^{86}Sr$.

Compston & Chappell (1979) specifically addressed the question of Rb-Sr in the granites' 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 rocks 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, provided only tantalising 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.

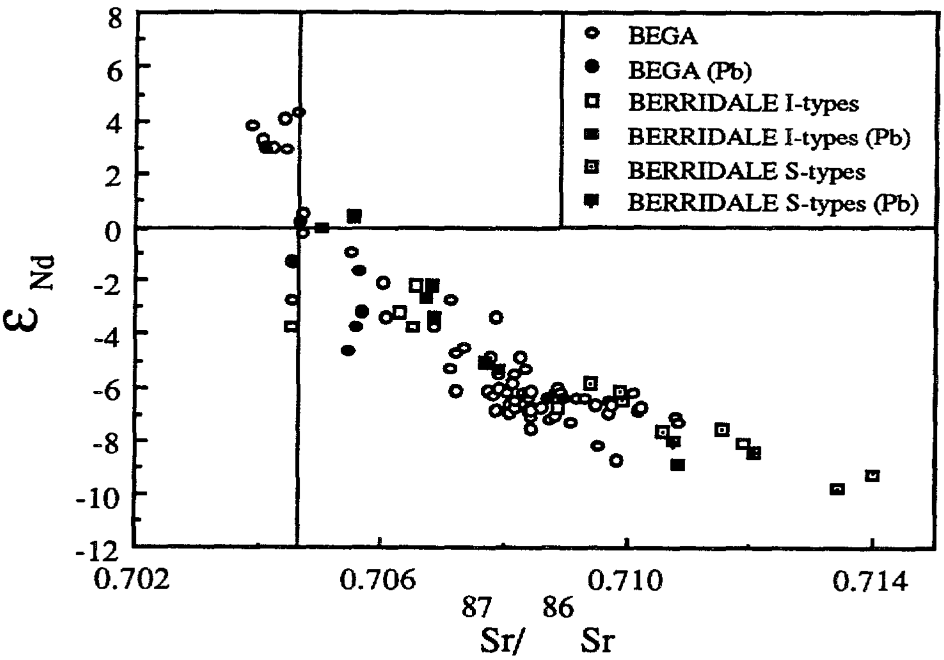

Figure 6. Initial Nd-Sr isotopic compositions of Palaeozoic I- and S-type granites from the Bega and Berridale Batholiths. Solid symbols indicate samples for which Pb isotopic analyses have been undertaken.

The most recent work on the Lachlan Fold Belt 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 wideranging 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, 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 is 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 (Fig. 7), suggesting later rehomogenisation of the Pb isotopic compositions in the granites sources on a large scale. Comparison between the Nd-Pb isotopic systems is shown in Figs 8 and 9. In Fig. 8, a plot of ε_{Nd} versus $^{207}Pb/^{204}Pb$, several striking features of the Pb-Nd isotopic covariation is exemplified. First, the data are highly correlated, forming a colinear array consistent with the mixing of two well-defined components. Second, the most negative ε_{Nd} values and hence older continental crust has the highest $^{207}Pb/^{204}Pb$ ratio of 15.65 of which the S-types appear to be representative. The more primitive, mantle-like isotopic component with the lowest $^{207}Pb/^{204}Pb$ ratio (15.58) and positive ε_{Nd} value (+3.0) is represented by the most easterly suite, Moruya. Finally, the total range in $^{207}Pb/^{204}Pb$ ratios, of 0.07, is extremely limited in comparison to modern island arcs.

Single-stage Pb-Pb model ages for the feldspars range from 327 Ma to 443 Ma which overlaps with the crystallization age of the rocks (~390 Ma to 420 Ma). The youngest model ages are present in the easternmost coastal Moruya Supersuite of the Bega Batholith while the oldest ages are in the Berridale S-types. There is an excellent positive correlation between the Pb single-stage model ages and the T^{Nd} depleted mantle Sm-Nd model ages. This is shown in Fig. 9, with samples having the youngest Pb single-stage model ages (~325 Ma) also having the youngest T^{Nd} model ages (~810 Ma). In addition to the excellent correlation between the Pb and Nd model ages, the interesting feature of this result is the relative ranges in the model ages. The Pb single-stage model ages have a relatively restricted range of ~100 Ma which includes the crystallization ages of the granites (400-420 Ma), while the Nd model ages have a factor of x10 larger range (1000 Ma) and are significantly older (810-1770 Ma). These observations indicate that in contrast to Nd (and Sr) the initial Pb composition of the granite source rocks has been thoroughly homogenized

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.

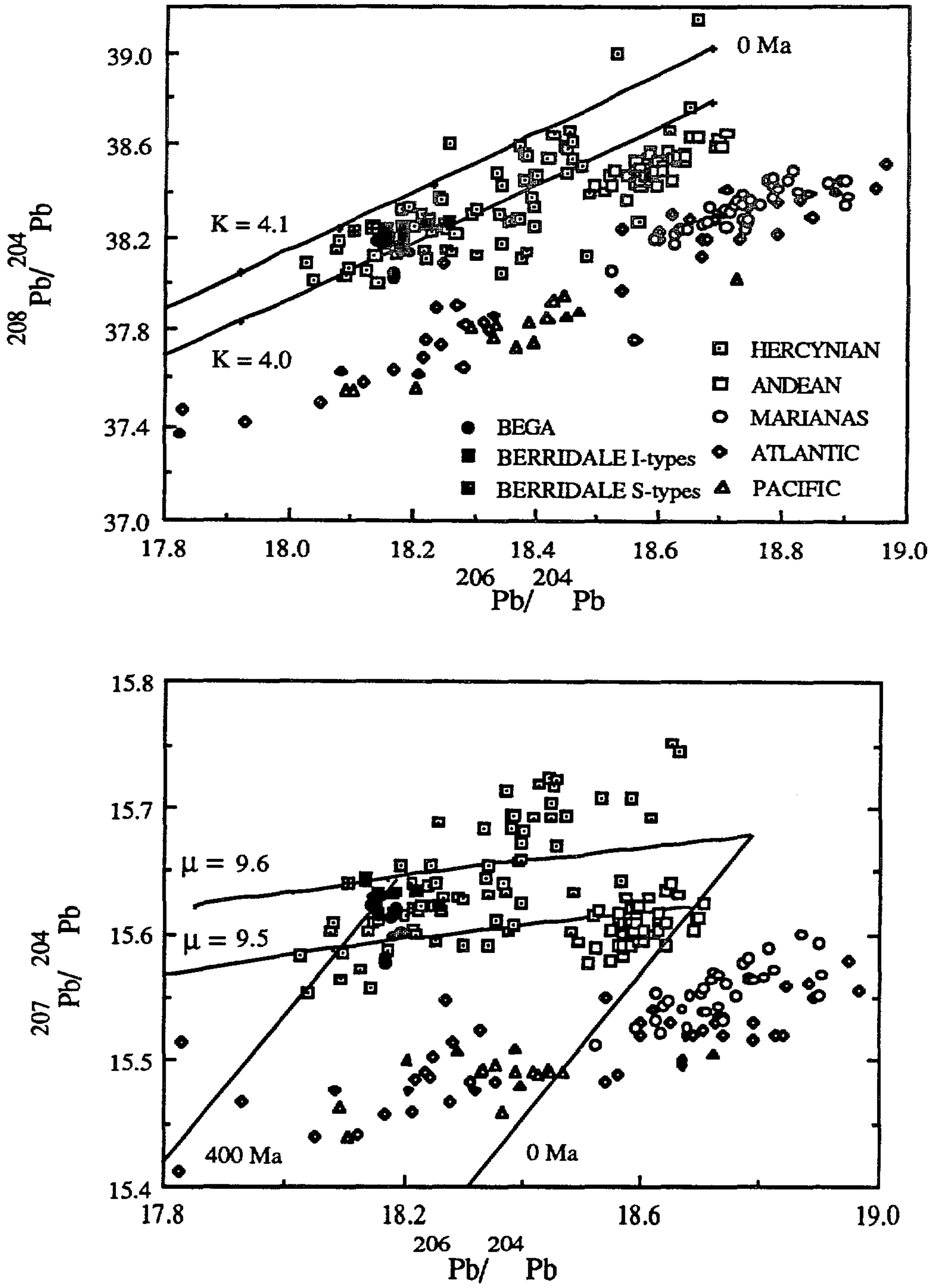

Figure 7. Comparison of $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ with $^{206}Pb/^{204}Pb$ ratios from the LFB with modern island arcs, MORB and Hercynian granites (Michard-Vitrac *et al.*, 1980, 1981) of Europe and eastern N. America. Reference isochrons and single stage evolution curves are calculated using initial Pb of Tatsumoto *et al.* (1973) and modern Pb of Stacey & Kramers (1975).

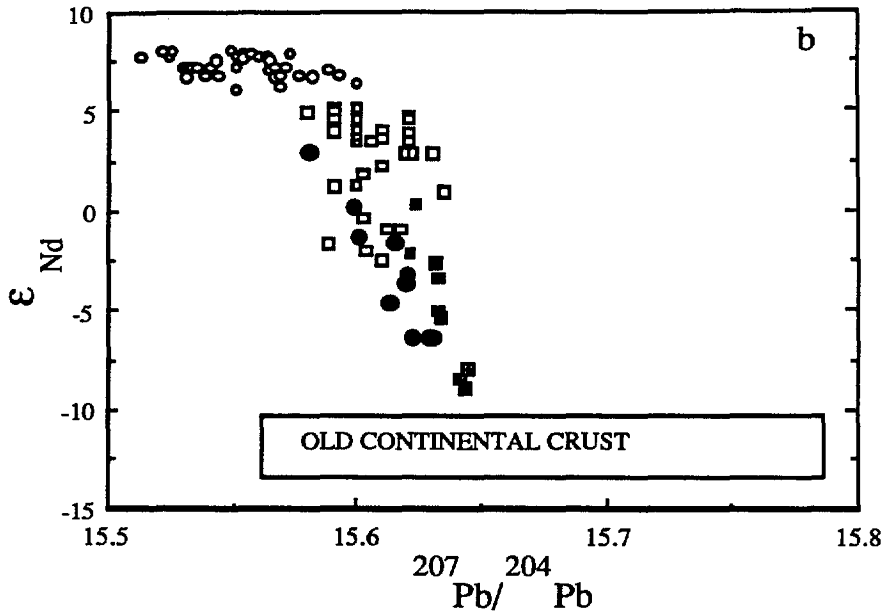

Figure 8. Comparison of Pb and Nd initial isotopic compositions derived from analyses of feldspars and whole rocks respectively from the LFB (solid symbols). Despite the large variations in ε_{Nd} values the LFB exhibits a very restricted range in Pb isotopic compositions compared to the Marianas (Woodhead, 1988) oceanic arc (open circles) and the Andean (Hickey *et al.*, 1986, Hildreth & Moorbath, 1988, and McMillan *et al.*, 1989) continental margin arc (open squares). When allowance is made its older age, the Pb-Nd data for the LFB are consistent with mixing of a younger island arc type component with an older crustal component. The relatively limited variation in the Pb isotopic composition of the LFB granites is attributed to partial mixing in a crustal fluid circulation system.

Granites from the LFB have a surprisingly restricted range in Pb isotopic compositions despite the large range in crust formation ages (Fig. 7). This suggests that a large heat source and long-lived (~20 Ma) fluid circulation system was in operation prior to and during granite magmatism.

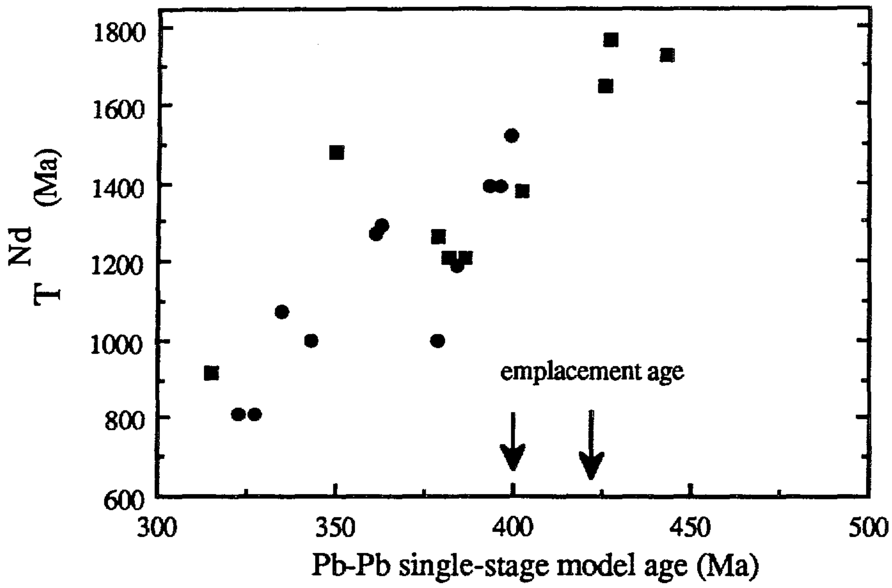

Figure 9. Comparison of $^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ single stage model ages with Sm-Nd model ages. The positive correlation between the Pb-Pb and T^{Nd} model ages is consistent with mixing of an old (negative ε_{Nd}) upper crustal Pb component, represented by the S-type granites, with a more primitive Pb component probably derived from younger crustal protoliths, represented by the Moruya suite (positive ε_{Nd}). The substantially more restricted range of younger Pb-Pb (~320-440 Ma) compared to T^{Nd} (800-1800 Ma) model ages is attributed to partial rehomogenisation of Pb isotopic compositions in fluid circulation systems.

EXCURSION NOTES

This excursion proceeds initially from Canberra to Cooma, where the Cooma Granodiorite and two of the higher grades of metamorphism are examined. It then continues to the Berridale and Kosciusko Batholiths where a variety of both I-type and S-type granites are seen. Chemical and modal analyses of granites from these localities are listed in Table 4, and chemical analyses of inclusions and two sedimentary rocks are given in Table 6. A summary of mineral ages from the Cooma Complex has been given in Table 3 and a full summary of mineral isotopic data for the Berridale Batholith is given in Table 5.

The Monaro Highway from Canberra to Cooma is is located to the east of the Murrumbidgee Batholith in the wide screen between that complex and the Bega Batholith. As the highway leaves Canberra there are good views to the west showing the more rugged country of the Murrumbidgee Batholith (Snelling, 1960; Joyce, 1973) that forms most of the southern part of the Australian Capital Territory. The eastern margin of the batholith is marked by the Murrumbidgee Fault, which is part of the IS-line that marks the boundary between the Kosciusko and Bega Basement Terranes. The Murrumbidgee River, one of Australia's most important inland rivers, follows the line of the Murrumbidgee Fault from near Cooma north to the western edge of Canberra. The Clear Range, immediately west of the Murrumbidgee Fault, is comprised of the Clear Range Granodiorite, a large S-type pluton with an area of 415 km^2, which includes the most mafic sample of S-type granite analyzed from the LFB. That body is equivalent in composition to the Hawkins Volcanics (Wyborn *et al.*, 1981), a unit on which some of the western suburbs of Canberra are built, that extends NNW from Canberra. The rocks lying to the east of the Murrumbidgee Fault are a complexly deformed sequence of sedimentary and volcanic rocks of Ordovician age. The light-coloured and altered volcanic rocks are seen in several road cuttings south of Canberra.

For a few kilometres beyond Michelago, some 50 km from Canberra, there are fine views of the Tinderry Range to the east. Those hills are made up of felsic granite on the western edge of the large Bega Batholith. About 50 km further south, 7 km beyond the Numeralla River, flat-topped hills of the Monaro basalt province come into view to the south. This is an extensive area of alkali basalt located south from Cooma (Kesson, 1973). K-Ar total rock ages on the rocks of this province range from 53 to 36 Ma (Wellman & McDougall, 1974).

Cooma is reached 120 km from Canberra. Immediately after the city centre, turn right on Soho Street and left on Massie Street, and then drive to the top of the hill and turn right to the lookout.

Stop 1: Cooma Granodiorite, Nanny Goat Hill (Cooma 902876) sample CC1

Nanny Goat Hill, within Cooma, 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 that has moved up from the source during intrusion of the granite (restite). The lumps of milky and clear quartz are consdered to 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; this is characteristic of many S-type granites in the LFB.

TABLE 4. CHEMICAL AND MODAL ANALYSES OF GRANITES

	CC1	BB83	BB86	BB3	KB4	KB12	KB22	KB32	BB 2	BB 11
SiO_2	72.00	67.82	67.32	67.71	60.56	68.94	62.29	67.68	73.48	70.89
TiO_2	0.54	0.61	0.47	0.58	0.56	0.59	0.54	0.64	0.22	0.35
Al_2O_3	13.72	14.47	15.24	14.29	17.25	14.11	16.46	14.70	13.41	13.92
Fe_2O_3	0.59	0.54	1.17	0.84	1.99	0.87	1.85	0.68	0.44	0.72
FeO	3.48	4.09	2.68	3.75	3.48	3.27	3.41	4.03	1.47	2.26
MnO	0.06	0.07	0.08	0.07	0.11	0.06	0.10	0.07	0.04	0.06
MgO	1.76	2.33	1.67	2.23	3.40	1.91	2.85	2.22	0.71	1.00
CaO	0.95	3.05	4.33	2.95	6.71	2.46	6.05	2.26	1.70	2.31
Na_2O	1.49	2.06	3.23	2.00	2.66	2.22	2.60	1.92	2.63	2.56
K_2O	3.73	3.40	2.24	3.41	1.55	3.53	2.01	3.60	4.63	3.96
P_2O_5	0.13	0.14	0.13	0.14	0.11	0.13	0.11	0.15	0.08	0.09
H_2O+	1.28	1.13	1.03	1.48	1.24	1.20	1.20	1.51	0.74	1.39
H_2O-	0.14	0.19	0.13	0.21	0.10	0.31	0.20	0.22	0.14	0.15
CO_2	0.13	0.18	0.14	0.12	0.06	0.14	0.10	0.12	0.11	0.29
total	100.00	100.08	99.86	99.78	99.78	99.74	99.77	99.80	99.80	99.95
Trace elements (ppm)										
Rb	153	169	86	166	62	170	89	183	236	178
Sr	127	139	252	134	254	128	254	139	97	198
Ba	765	445	440	470	275	460	355	475	350	625
Zr	201	174	126	169	85	194	112	187	100	136
Nb	9.0	11.5	9.0	11.0	5.0	10.5	6.5	13.0	10.0	10.5
Y	39	28	22	29	20	31	21	27	33	40
Ce	68	64	65	69	38	68	47	69	49	70
Sc	12	17	14	18	25	15	23	15	7	12
V	64	88	65	89	154	81	131	87	25	42
Cr	56	65	12	71	28	47	25	61	10	13
Ni	24	20	3	21	9	15	7	20	4	6
Zn	71	70	48	72	61	64	62	82	28	47
Ga	15.0	16.8	15.4	16.8	15.2	16.8	16.4	18.2	13.8	15.2
Pb	35	26	13	25	7	26	9	27	37	33
Th	21.5	17.2	11.0	17.8	7.6	19.2	9.2	19.2	19.2	18.0
U	3.8	3.8	2.2	2.4	1.4	3.8	1.4	4.0	6.4	4.2
Modes										
Quartz	48.3	34.8	32.1	36.1	22.3	35.1	25.2	34.5	34.4	37.5
K-feldspar	8.8	9.5	8.6	4.9	0.4	9.7	3.0	7.7	29.5	24.5
Plagioclase	18.9	33.7	46.6	38.0	52.3	33.8	49.9	27.7	27.1	27.1
Biotite	17.4	21.6	9.7	20.8	16.0	19.0	14.7	26.7	8.7	10.7
Hornblende			2.4		8.2		6.7			
Muscovite	4.0					1.9		3.4	0.2	
Opaques	0.1	0.1	0.4	0.1	0.7	0.4	0.4		0.1	0.1
Apatite	0.1	0.3	0.2	0.1	0.1	0.1	0.1			0.1
Andalusite	2.4									

The most distinctive chemical features of this rock are the very low CaO and Na_2O contents which result 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 corundum) and therefore contains Al-rich minerals. The Fe^{3+}:Fe^{2+} ratio is very low.

Isotopic ages: see detailed discussion on pages 11-15.

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

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 are more or less tabular with well defined inner cores (An_{40} to An_{35}) 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 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 centimetre-sized blue cordierite is sometimes seen in hand specimens of this rock, fresh cordierite is rare in thin section; 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 appear to replace cordierite pseudomorphs and may surround mattes of fibrolite. Stout crystals of apatite, zircon, monazite and some tourmaline are accessory minerals.

Continue through the city on the Berridale road (Alpine Way) for 4 km from Cooma to the Gladstone Lookout turn-off on the left. Walk back 30 m down the road to the outcrop on the north side, while admiring the basalt flows in the distance beyond Cooma.

Stop 2: Migmatites (Cooma 867872)

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 5mm or more across are seen in some of the granitic patches. This shows the birth of a cordierite granite! The amount of partial melting in this particular outcrop is fairly small.

Continue west on the Snowy Mountains Highway. At the crest of the hill after a few hundred metres, there is a good view of the Snowy Mountains further west. After 2.6 km , stop at the junction of the Alpine Way. From that point walk 250 m along the Alpine Way to exposures of gneiss south of the road and fresh boulders on the north side.

Stop 3: Mottled gneiss of the sillimanite zone (Cooma 840863) sample CC4

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. There is an analysis of a pelitic band (sample CC4) from this locality in Table 6. McCulloch & Chappell (1982) reported ε_{Nd} = -8.3, $^{87}Sr/^{86}Sr(I)$ = 0.71837 and T^{Nd} = 1620 Ma for that sample.

If there is a desire to see lower grade sediments, continue on the Alpine way for 2.0 km to a cutting in which retrogressed spotted schists occur. The knots were formerly andalusite or cordierite or both but they have been retrogressed to aggregates of mica.

Continue on the Snowy Mountains Highway and after a further 2.1 km turn left on the Middlingbank Road. Follow that road west towards the wooded Coolringdon Hill, across the

TABLE 5. MINERAL AGES FOR THE BERRIDALE AND KOSCIUSKO BATHOLITHS

Sample	Mineral	Method	Age (±1σ)	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 5. MINERAL AGES FOR THE BERRIDALE AND KOSCIUSKO BATHOLITHS

Sample	Mineral	Method	Age (±1σ)	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)

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 highly 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: Cootralantra Granodiorite (Berridale 693872) 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 Suite. 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 darkish-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. An analysis of the granodiorite (BB83) is given in Table 4 and analyses of four inclusions (BB137, BB130, BB139 and BB131) are given in Table 6. 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 inclusions 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 - this type may represent crystallized pieces of the granodiorite that have been reincorporated in the melt. The composition of the granite shows that it is a fairly typical member of the extensive Bullenbalong Supersuite (White & Chappell, 1988b), with the low Na_2O content, just over 2%, being very typical of those rocks.

Isotopic ages: Biotite from this locality gives 418.0 ± 1.9 Ma and 416.4 ± 2.4 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 421.1 ± 1.3 Ma, 417.2 ± 2.0 Ma and 422.1 ± 1.1 Ma by Rb-Sr, K-Ar and Ar-Ar respectively. It is highly likely that none of these ages record emplacement.

More than 30 Rb-Sr whole rock granodiorite and inclusion analyses from the Cootralantra scatter widely (MSWD 116) in a broad band with 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 so, the emplacement age of the Cootralantra Granodiorite

TABLE 6. CHEMICAL ANALYSES OF INCLUSIONS AND SEDIMENTS

	BB137	BB130	BB139	BB131	BB116	KB65	CC4	LW106	LW102
SiO_2	41.46	51.50	60.25	66.40	54.45	55.37	55.50	57.49	74.60
TiO_2	1.37	1.05	1.10	0.77	0.84	0.64	0.75	0.75	0.61
Al_2O_3	30.51	24.32	15.07	15.45	17.51	15.80	22.29	21.27	12.06
Fe_2O_3	2.34	1.03	1.07	1.09	2.34	2.23	1.09	0.72	1.33
FeO	8.12	6.31	7.93	2.96	5.66	5.17	6.22	4.93	2.52
MnO	0.15	0.13	0.15	0.07	0.25	0.23	0.06	0.07	0.04
MgO	5.00	3.81	3.11	1.77	4.06	6.32	4.20	2.60	1.49
CaO	2.03	4.54	6.66	3.77	5.81	8.43	0.26	0.75	0.75
Na_2O	1.32	2.23	1.03	2.56	3.76	2.48	1.15	2.02	1.85
K_2O	2.43	2.35	0.95	3.15	2.91	1.31	6.02	6.97	2.80
P_2O_5	0.21	0.13	0.15	0.22	0.19	0.09	0.11	0.20	0.15
H_2O+	4.06	1.83	1.92	1.10	1.71	1.75	1.80	1.99	1.46
H_2O-	0.52	0.25	0.17	0.23	0.21	0.13	0.29	0.16	0.15
CO_2	0.21	0.30	0.24	0.13	0.17	0.09	0.13	0.16	0.01
total	99.73	99.78	99.80	99.67	99.87	100.04	99.87	100.08	99.82
Trace elements (ppm)									
Rb	107	134	46.5	151	125	48	263	305	164
Sr	112	192	161	176	221	215	114	203	107
Ba	140	475	140	410	590	170	745	1220	380
Zr	209	190	145	229	118	52	112	136	264
Nb	26.5	17.5	7.0	13.0	16.0	5.5	14.0	15	12
Y	47	32	36	32	63	55	32	26	39
Ce	141	107	55	50	59	57	76	85	84
Sc	32	22	34	16	43	62	20	13	11
V	208	175	259	102	176	203	121	92	55
Cr	179	121	9	4	7	219	112	76	47
Ni	68	28	5	10	7	55	54	26	22
Zn	290	178	114	60	108	91	141	108	76
Ga	46.2	35.2	19.2	17.6	19.2	16.0	29.6	25	15
Pb	16	24	14	30	14	7	64	61	23
Th	36.0	24.5	11.8	11.2	7.4	6.4	18.6		
U	18.6	3.8	2.2	1.8	2.4	1.6	4.4		

Sample details:

BB137	Cordierite-rich gneiss inclusion in the Cootralantra Granodiorite	Stop 4
BB130	Cordierite-rich gneiss inclusion in the Cootralantra Granodiorite	Stop 4
BB139	Ca-rich inclusion in the Cootralantra Granodiorite	Stop 4
BB131	Even-grained inclusion in the Cootralantra Granodiorite	Stop 4
BB116	Microgranular inclusion in the Tara Granodiorite	Stop 5
KB65	Microgranular inclusion in the Round Flat Tonalite	Stop 7
CC4	Mottled sillimanite gneiss	Stop 3
LW106	Shale, Snowy Mountains region	
LW102	Sandy-shale, Snowy Mountains region	

is almost certainly less than the whole rock age. The initial $^{87}Sr/^{86}Sr$ for Cootralantra 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, the remnants of which survive in the magma as lithic inclusions.

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 5: Tara Granodiorite (Berridale 634924) 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, fairly 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 this body. Sample BB116 (Table 6) is from this locality. 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.

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 ± 1 Ma, biotite K-Ar 414 ± 3 Ma, biotite Ar-Ar 424 ± 1.1 Ma, hornblende K-Ar 411 ± 4 Ma and hornblende Ar-Ar 409 ± 2 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. 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

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 6: Cootralantra Granodiorite (Berridale 613910) 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.

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 ± 1 and 413 ± 3 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 14).

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 5) 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.

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; β = γ = 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.

Continue west from Middlingbank Church and turn left after 2.7 km. This road crosses the Cootralantra Granodiorite and passes sample locality BB19 after 7.3 km, a rock of that unit on which U-Pb ages of zircons have been measured on the ion probe. McCulloch & Chappell (1982) also studied this rock and 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. At 13.5 km there are extensive outcrops of Ordovician sedimentary rocks, in the screen between the Berridale and Kosciusko Batholiths. The Eucumbene Dam road is reached after 14.4 km. Turn to the south on that road, reaching outcrops of the Kosciusko Batholith after 3.1 km. Take the road to the south after another 4 km, and after a further 900 m stop at boulders of granite beside the road.

Stop 7: Hornblende-rich Round Flat Tonalite (Berridale 499887) sample KB4

This locality in the Round Flat Tonalite is one of the most mafic samples of tonalite in the Kosciusko Batholith. It is part of the Jindabyne Suite. It contains approximately 60% SiO_2, but because of its low K content, free quartz is 22%. There is less than 0.5% K-feldspar. Biotite and hornblende occur in equal proportions. Magnetite is abundant and small allanite crystals are present, but there is no titanite, a feature of all Jindabyne Suite rocks. The rock contains mafic inclusions but their abundance is low compared with many other tonalites of the LFB; an analysis of one inclusion (KB65) is given in Table 6.

Isotopic age: The Rb-Sr biotite age of the Round Flat Tonalite at this locality is 413 ± 2 Ma.

Continue south across the Round Flat Tonalite, which lies in a valley enclosed by older Kalkite Adamellite. The southern contact of the tonalite is crossed just before the road passes up the incline out of the valley. The tonalite is much poorer in hornblende at its southern side. The Kalkite Adamellite at this locality is strongly foliated. The foliation, trending about 30°, persists into the tonalite but is much weaker in that rock,

Just beyond the top of the incline, a north-west trending left-lateral wrench fault is crossed as the road steps to the left as it crosses a small stream. Follow this road south through S-type granites for a further 6 km to the place where broken boulders occur on the eastern side of road near a small lake.

Stop 8: Bullenbalong Granodiorite (Berridale 498808) 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 containing many inclusions of cordierite-gneiss and other metasedimentary rocks, 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. 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 quartz crystals have a bluish tint indicative of deformation.

Isotopic ages: Biotite from KB12 has not been dated, but a Rb-Sr age of 412 ± 2 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 in 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 south for 7.3 km to the Alpine Way and turn west towards Jindabyne. After 10.5 km pull into the parking area just past the Jindbyne Dam spillway.

Stop 9: Contact between Jindabyne and Bullenbalong units (Berridale 463666)

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. There is a Cainozoic basalt dyke in the south wall of the spillway. 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. Second boiling causes fracturing that reaches the surface, followed by sudden release of magma pressure, and hence quenching. Second boiling produces a supercritical fluid which can also account for the hydrothermal alteration.

Continue on the Alpine Way for 2.8 km to Jindabyne. The large statue on the edge of the lake is of Sir Paul Edmund Strzelecki FRS (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.

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).

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 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 path over 10 km to the summit of Mt Kosciusko which is made up of mylonitized Rawson Pass Granite. Return to Jindabyne.

Turn south on the Barry Way, from the Alpine Way 1.3 km west of Jindabyne, and stop at the deep road cutting at the top of the hill after 850 m.

Stop 10: Jindabyne Tonalite (Berridale 442677) 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 hornblende up to 20 mm in length is the most conspicuous mineral. There are some small mafic inclusions.

Griffin *et al.* (1978) compared the compositions of the tonalites of the Jindabyne Suite and the Moruya Suite 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: The only radioisotopic data for the Jindabyne Tonalite are ion probe zircon U-Pb analyses. The preliminary results available indicate moderate inheritance ranging in age from early Proterozoic to early Palaeozoic, and a poorly defined magmatic age a little over 400 Ma.

Isotopic composition: McCulloch & Chappell (1982) report values ε_{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,

Petrographic description: Plagioclase is distinctive and the dominant mineral amounting to almost 50% of the rock. Under a microscope, the plagioclase 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 titanite seen in many tonalites, is not present 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 recognisable in hand sample as black specks surrounded by tiny radiating cracks resulting from expansion during metamictization. There is no titanite in this or any other rock of the Jindabyne Suite.

Continue south on the Barry Way and turn left along Gullies Road after 8.9 km. The flat topped hill to the south is a Cainozoic flow of nephelinite. Boulders of Jillamatong Granodiorite are seen on the north side of the road 5.1 km from Barry Way.

Stop 11: Jillamatong Granodiorite (Numbla 429569) 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 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 ; these have been described by Chen *et al.* (1989).

Isotopic ages: The Jillamatong Granodiorite has yet to be dated by Rb-Sr or K-Ar. Ion probe analyses of zircons from KB32 show every zircon crystal to consist predominantly of inherited zircon (incontrovertibly restite). The inheritance is 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‰.

Petrographic description: This is a bluish-grey, mafic cordierite 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 all the quartz grains in all specimens 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 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, $\beta = \gamma$ = 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.

Return to the Barry Way and after going towards Jindabyne for 4.5 km take the road to the east. After a further 12 km there is a good view over the Berridale Plateau, followed by a steep descent down the 300 m high escarpment of Barneys Range. Süssmilch (1910) pointed out that the Southern Tablelands of New South Wales from Canberra to the Victorian border comprises a group of tablelands separated from one another by abrupt differences in elevation. The Barneys Range escarpment is a good example, separating the Berridale Plateau (mean altitude 900 m) from the Beloka Plateau (1100 - 1200 m). It results from recent movements on the Barneys Range Fault, a thrust fault dipping towards the west (White *et al.*, 1977).

A small ridge 6 km from the foot of the scarp is made of hornfelses on the western side of the Dalgety Granodiorite. From this point, there is a good panorama over the southern part of the Dalgey Granodiorite which lies in a semi-circular depression to the east. The prominent wooded hill in the distance is Wullwye Hill which is within the screen at the eastern side of the Dalgety pluton. Bobundara Hill, further in the distance to the right of Wullwye Hill is comprised of basalt, as are other hills in the far distance. Continue to the intersection with the Dalgety-Jimenbuen road, reached after a further 7.5 km. If time permits, take that road south for Stop 12, or else continue 500 m across the Snowy River to Dalgety and then 2.1 km further on the Berridale road to Stop 13.

The crest of the ridge on the Jimenbuen road 11 km south of the Jindabyne-Dalgety road is close to the contact between the Dalgety and Numbla Vale Granodiorites. 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.

Stop 12: Numbla Vale Adamellite (Numbla 627414) sample BB2

The Numbla Vale Adamellite (49 km^2) occurs immediately south of, and is intruded by, the Dalgety Granodiorite. It is poorly exposed and is the most felsic S-type granite of the Berridale Batholith. 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 appearing as large well-formed crystals that show various stages of alteration to micas and pinite.

Isotopic ages: The Numbla Vale Adamellite has proved difficult to date because of deep weathering and consequent poor exposure. Mica ages measured from this locality, one of the few fresh samples, are 418 ± 1 Ma (Rb-Sr), 422 ± 2 Ma (K-Ar) and 430 ± 1 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, 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.

Zircons from the Numbla Vale analyzed conventionally 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‰.

Petrographic description: It 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 plagioclase - K-feldspar boundaries. 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 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.

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. Boulders of that body occur next to the road 5.7 km south of Stop 12 at Numbla 653368. Further south, the road 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 12 and this point. Return north to Dalgety and then 2.1 km further on the Berridale road to Stop 13. Note that Dalgety was on the short list for selection as Australia's Capital!

Stop 13: Dalgety Granodiorite (Berridale 645600) sample BB11

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, compared to which it contains less CaO and Na_2O; it is therefore less peraluminous (1.16% normative corundum). It is thought to have been derived from a slightly more feldspar-rich (less mature) sedimentary source. K-feldspar crystals are up to 40 mm long, and there is a small amount of cordierite at this locality. Inclusions at this locality include large (400 mm) more mafic Dalgety Granodiorite which themselves contain relatively coarsely crystalline inclusions; these are presumably re-incorporated early Dalgety Granodiorite. There are also inclusions of quartz 50 mm across and some fine-grained microgranular inclusions.

Isotopic composition: McCulloch & Chappell (1982) report data for sample BB12, near to BB11. Those are ε_{Nd} = -6.5, $^{87}Sr/^{86}Sr(I)$ = 0.70991, T^{Nd} = 1510 Ma.

Continue north on the road to Berridale, traversing the axis of the northern part of the Dalgety Granodiorite. From Berridale, follow the Alpine Way towards Cooma. This road crosses various intrusions of the northern part of the Berridale Batholith. Berridale itself is located on the Dalgety Granodiorite; at 2.1 km from Berridale 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 S-type Cootralantra Granodiorite and at 5.3 km the road passes into the Wullwye Granodiorite, a felsic I-type with large buff-coloured tors, and at 8.3 km back into the Cootralantra Granodiorite. At that contact of Wullwye and Cootralantra there are boulders on the south side of the road.

Stop 14: Wullwye Granodiorite (Berridale 695783) 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, or any sign of contamination. Note the difference in the size and colour of the tors between these two units.

Isotopic ages: The biotite Rb-Sr age measured on BB93, 413 ± 2 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 ± 2 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: For another sample of this unit (BB62), very similar in composition to

BB93, McCulloch & Chappell (1982) reported $\varepsilon_{Nd} = +0.4$, $^{87}Sr/^{86}Sr(I) = 0.70555$ 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 to Cooma and then on to Canberra.

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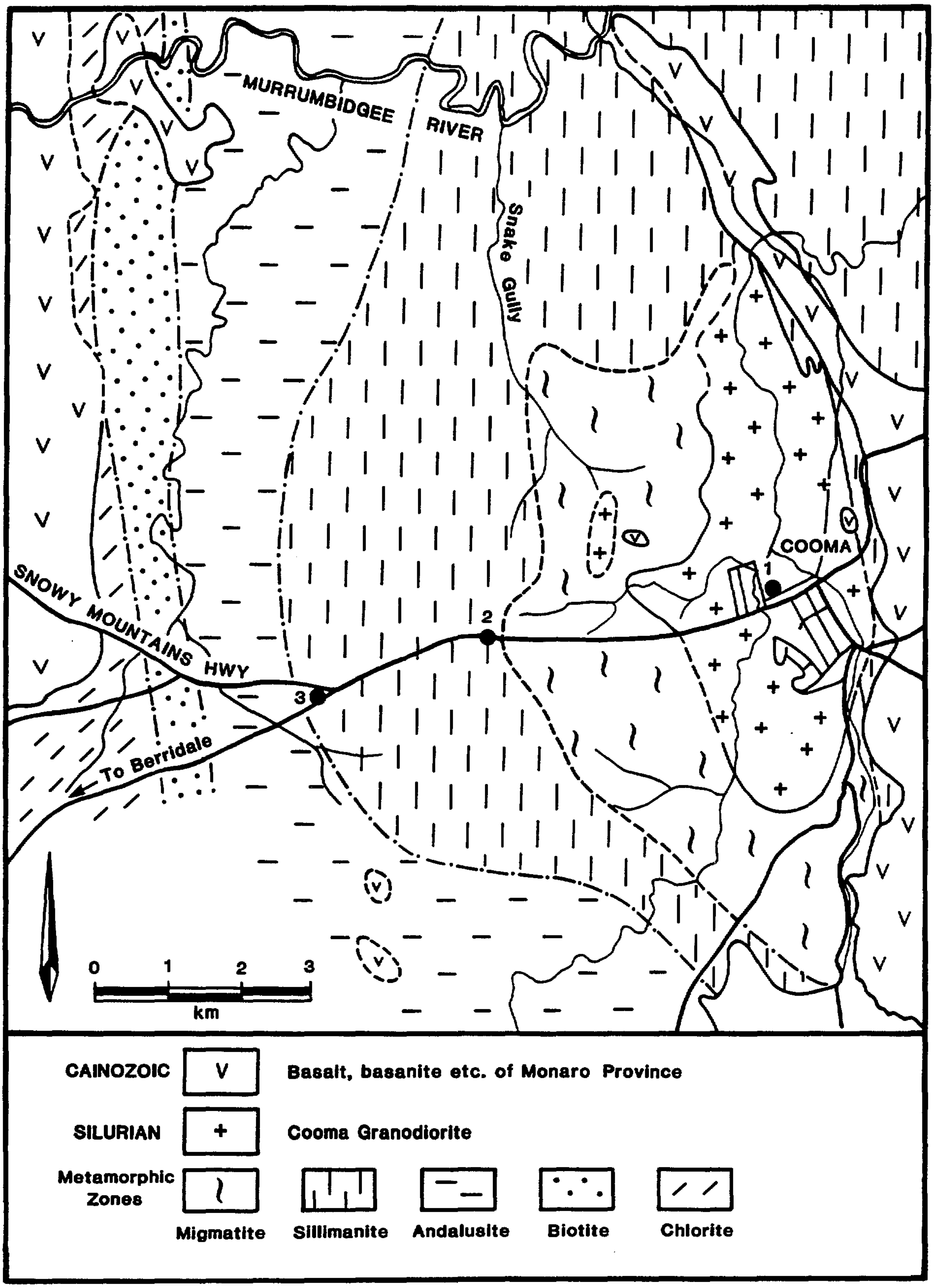


GEOLOGICAL SKETCH MAP OF THE COOMA COMPLEX

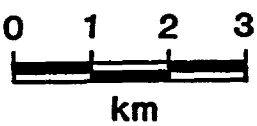
THE ILLUSTRATION ON THE OPPOSITE PAGE SHOWS THE GRANITES OF THE BERRIDALE AND KOSCIUSKO BATHOLITHS SOUTH FROM LAKE EUCUMBENE.

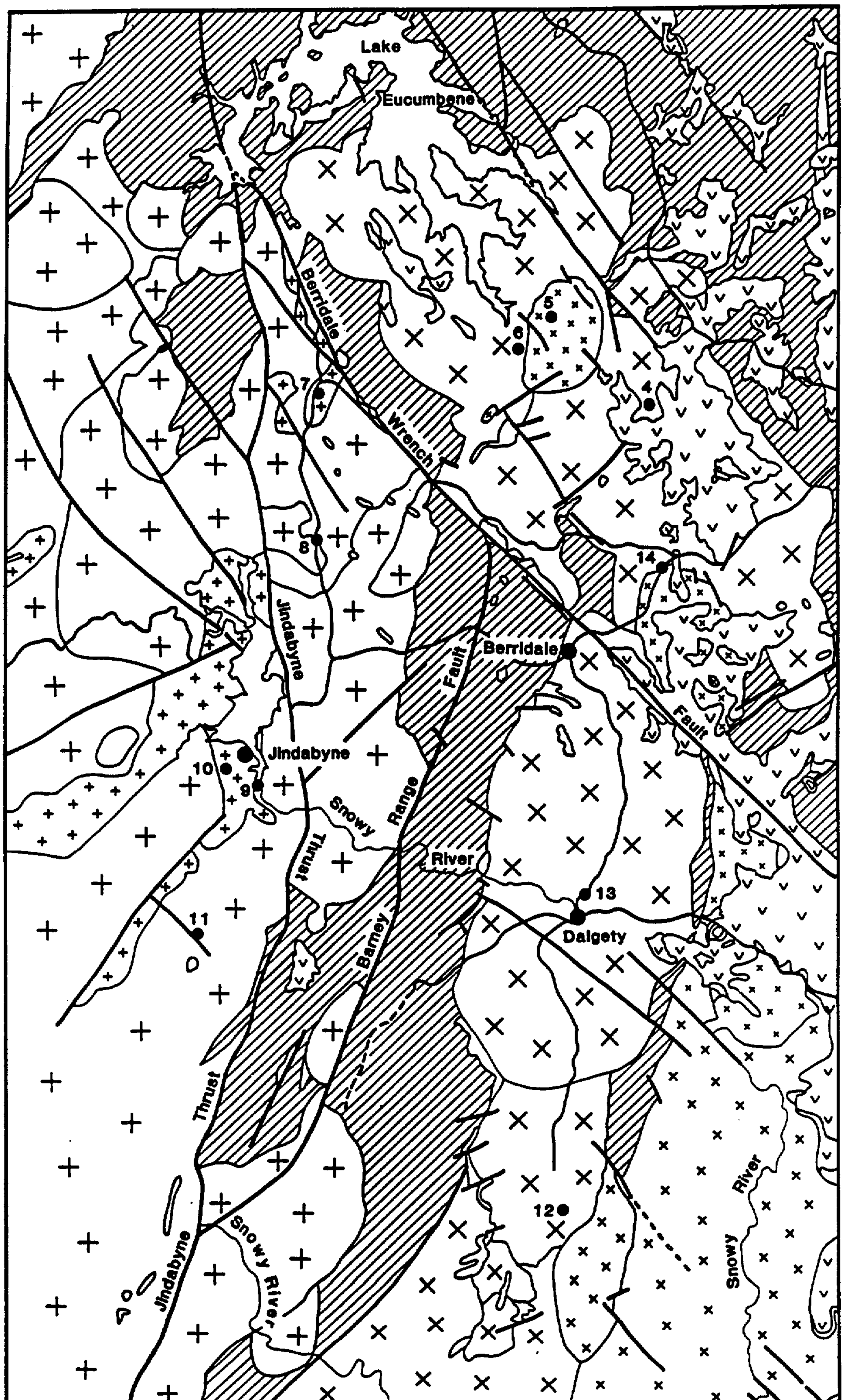
This information is taken from :

Wyborn, D., Owen, M. & Wyborn, L., 1990. Geology of the Kosciusko National Park (1 : 250 000 scale map). *BMR, Canberra.*

LEGEND

v v	Cainozoic volcanics
× ×	Berridale Batholith - I-type granites
×	Berridale Batholith - S-type granites
+ +	Kosciusko Batholith - I-type granites
+	Kosciusko Batholith - S-type granites
//////	Ordovician sediments




Lake
Eucumbene
Berridale
Wrench
Fault
Jindabyne
Thrust
Berridale
Fault
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Snowy
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Barney
Thrust
Dalgety
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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.