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## Granites of the Lachlan Fold Belt



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by

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Geochronology, Cosmochronology and Isotope Geology

# GRANITES OF THE LACHLAN FOLD BELT

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# INTRODUCTION

That part of the Lachlan Fold Belt (LFB) exposed in southeastern Australia has a total area of close to 300,000 $km^2$. The full width is seen only in Victoria where it is some 750 km wide at right angles to the dominant structural trends. 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 ( $km^2$) | % of type I | % of type S | % of type 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 a distinctive mineralogical and chemical composition. It is extremely quartz-rich (~ 50%) and contains cordierite, andalusite and sillimanite. It is very low in $Na_2O$ and CaO which is thought to result from its derivation from the clay-rich Ordovician sediments. Such an origin is supported by isotopic data (Pidgeon & Compston, 1965; McCulloch & Chappell, 1982). The Cooma Granodiorite is grouped with the Gap unit of the Murrumbidgee Batholith in the Cooma Suite. That suite, together with the Geehi Suite in the Maragle Batholith further west, make up the Cooma Supersuite. Members of that Supersuite differ from the more abundant S-type granites of the LFB (the "batholithic S-types" of White & Chappell, 1988b), which are higher in $Na_2O$ and CaO and are thought to have been derived from less mature pre-Ordovician sedimentary rocks (Chappell, 1984; White & Chappell, 1988).

For a sketch map of the Cooma Complex, see page 89.

# 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.

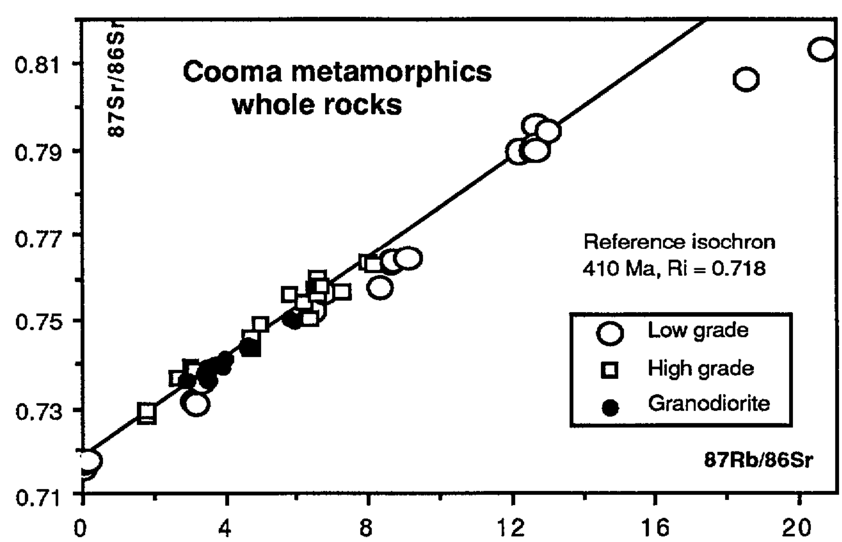


Figure 1. Whole-rock Rb-Sr analyses of the Cooma Granodiorite, and high and low grade sediments in its regional metamorphic aureole.

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.

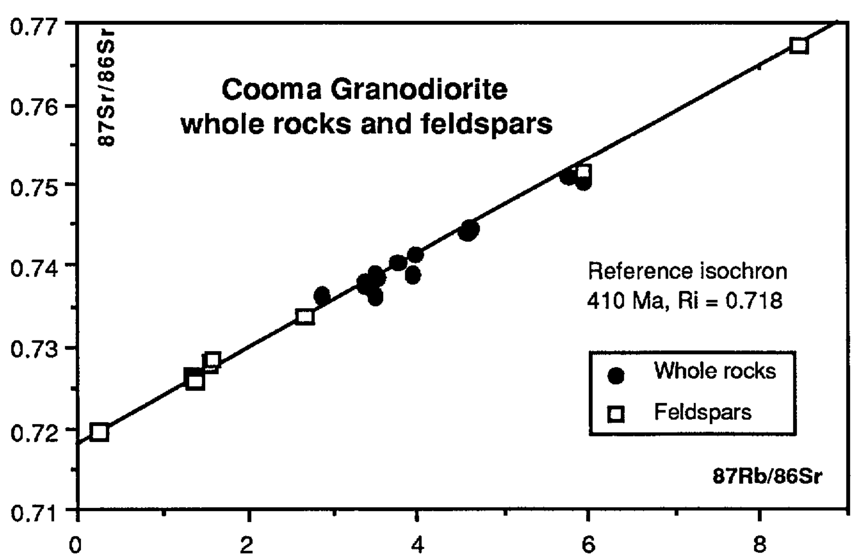


Figure 2. Whole-rock and feldspar Rb-Sr analyses from the Cooma Granodiorite and an associated microgranite dyke.

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.

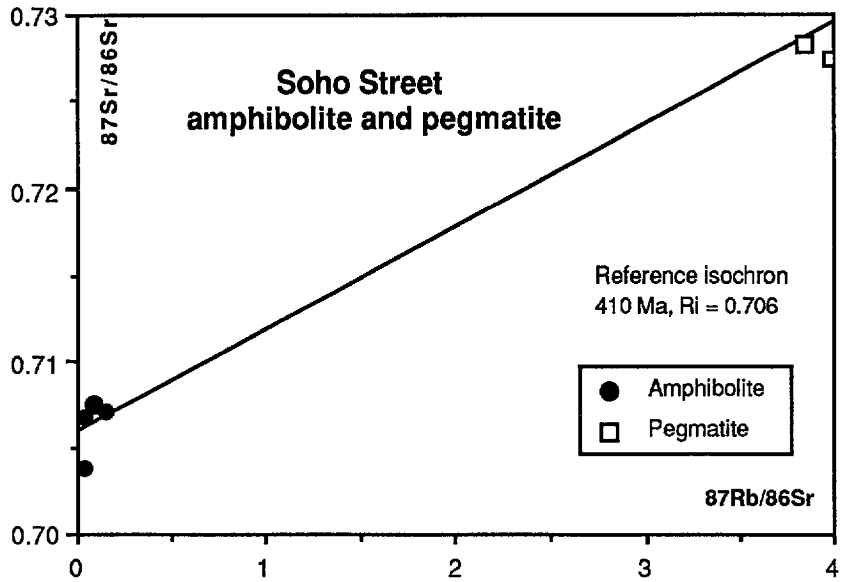


Figure 3. Rb-Sr whole-rock analyses from the Soho Street pyroxene amphibolite enclave in the Cooma Granodiorite, and an associated pegmatite.

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.

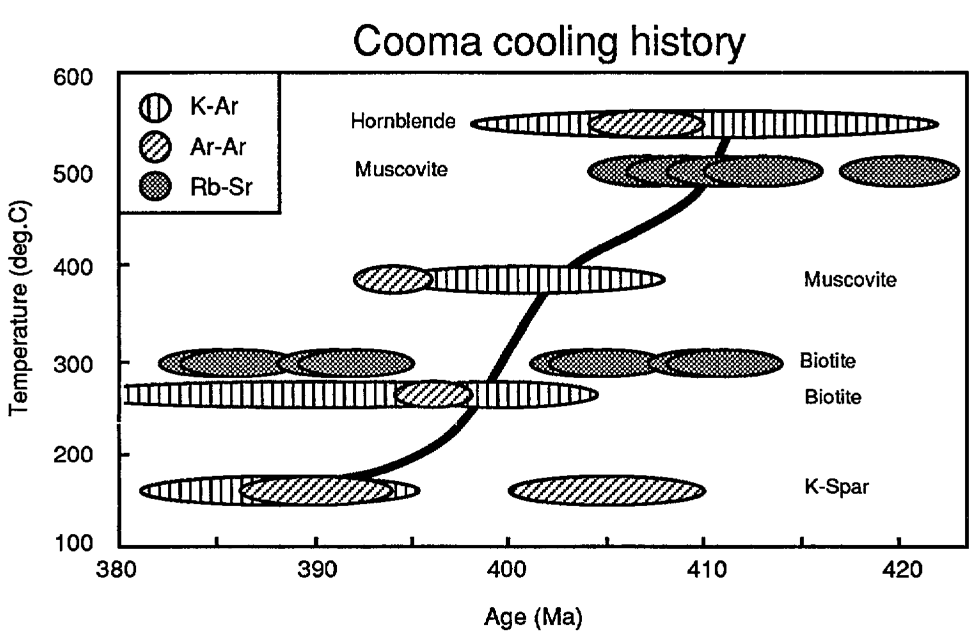


Figure 4. Mineral ages measured on the Cooma Complex plotted against their effective closure temperatures.

The mineral ages measured on the Cooma Complex are listed below in Table 3 and illustrated in Fig. 5. 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 $2\sigma$ 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 91.

# 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 (D. 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 $km^2$, 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 91.

# BEGA BATHOLITH

The Bega Batholith (8620 $km^2$) is the largest in the LFB. It was originally named and briefly described by Brown (1933) who recognized it as a composite body. More recent field data have been provided in BSc theses by Richards (1966), Cameron (1973), Vincent (1973), Beams (1975), Lesh (1975), Hill (1975), Banfield (1981) and Graham (1985). These observations, with additional mapping by Beams (1980) and by Wyborn & Owen (1986) have shown that the batholith consists of more than 130 separate lithological units, ranging in area up to 970 $km^2$. The country rock is mainly Ordovician sandstones and shales (quartz-rich flysch) but in a few localities the granites intrude Silurian limestones. The batholith is overlain unconformably by Upper Devonian (Frasnian) volcanic and sedimentary rocks in a few places.

The Moruya Batholith (263 $km^2$) has traditionally been separated from the Bega Batholith despite its small size and its close compositional association with the larger complex. It consists of nine lithological units of granite (Griffin *et al.*, 1978), one of which, the Tuross Head Tonalite, extends out to sea. On the basis of aeromagnetic data, there is at least one other pluton under the Tasman Sea to the south-east. There are two small areas of exposure of mafic rocks, the Bingie Bingie Gabbroic Diorite, on the south-eastern edge of the batholith, at Bingie Bingie Point and at Tuross Head. The Gabo Island Granites consist of nine small plutons with a total area of 59 $km^2$ in the south-eastern corner of mainland Australia. These rocks have been described by Collins (BSc thesis, 1977) and Collins *et al.* (1982).

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

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

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

TABLE 4. SUPERSUITES IN THE BEGA BATHOLITH

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

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

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

## MORUYA SUPERSUITE

Granitic rocks of the Moruya Batholith are subdivided into two suites, Moruya and Nelligen. Griffin (BSc. thesis, 1971) and Griffin *et al.* (1978) described this batholith and grouped all of these rocks together as a single Moruya Suite but they pointed out that the most northerly Nelligen pluton is slightly different in composition from the other bodies, containing higher K and the related trace elements Rb, Pb, Th and U. This difference was confirmed by Compston & Chappell (1979) who showed that Nelligen has a slightly higher initial $^{87}Sr/^{86}Sr$ than the other Moruya rocks. For these reasons the two suites are distinguished but they are grouped in the same supersuite on the basis of similarity of other elements, particularly the high Na contents. All rocks in the Moruya Batholith are I-type. Compston & Chappell (1979) give Rb-Sr total-rock ages of 389 Ma for the Moruya Tonalite and 395 Ma for the Nelligen Granodiorite.

TABLE 5. ISOTOPIC COMPOSITION OF BEGA BATHOLITH SUPERSUITES

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

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

COBARGO SUPERSUITE

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

The Xmas Quartz Monzonite (1.0 $km^2$) and Stringy Road Granodiorite (0.7 $km^2$) constitute the Xmas Suite. Rocks of this suite are similar to the Cobargo and Brogo Suites but compared with those two suites, the Xmas Suite is lower in Ti, Mg, K, Rb, Th, Zr, Sc and Zn and higher in $Fe^{3+}$, Na, Ba and Sr. The Sr content of these rocks (~ 800 ppm) is higher than in any other Silurian--Devonian granite so far analyzed from the LFB, except for some samples from the Boggy Plain Suite in the Kosciusko Batholith (Wyborn *et al.*, 1987). The Carboniferous Wuuluuman Granite in the north-eastern part of the LFB has Sr contents in excess of 1200 ppm.

The Cobargo Suite is represented by the Coolagolite Granodiorite, Cobargo Quartz Monzonite, Quaama Granodiorite and Murrabrine Quartz Diorite. The Coolagolite Granodiorite (25 $km^2$) is an elliptically-shaped pluton occurring east of Cobargo. It ranges from quartz monzodiorite to granodiorite. Mafic inclusions up to 20 cm across are common throughout the unit. Plagioclase is the dominant mineral, with prominent oscillatory zoning. Magnetite is the opaque phase, and apatite occurs as tiny needles scattered through all minerals. The Cobargo Quartz Monzonite (23 $km^2$) is a more felsic member of the Cobargo Suite in which mafic inclusions are rare. The mineral assemblage is the same as for Coolagolite but the proportions are different: hornblende with inclusions of quartz and magnetite is more abundant than biotite. The biotites appear either as ragged flakes intergrown with hornblende and magnetite, or as perfect crystals enveloped by interstitial K-feldspar. Again the plagioclase has irregularly shaped cores with rare inclusions of clinopyroxene, magnetite, hornblende and apatite, surrounded by a rim of oligoclase giving the crystals a tabular outline; oscillatory zoning is prominent in the outer zones. The Quaama Granodiorite (159 $km^2$) is the largest pluton in the Cobargo Suite. It contains large crystals (up to 1.5 cm) of the complexly zoned plagioclases typical of the suite. Quartz is more abundant in the Quaama body compared with other members of the Cobargo Suite. The Murrabrine Quartz Diorite (1.4 $km^2$) is a small body occurring 500 m west of Cobargo. The compositional range of the Cobargo Suite is from 59% $SiO_2$ (Murrabrine Quartz Diorite) to 73% $SiO_2$ (Cobargo Quartz Monzonite). On Harker Diagrams, all members of the suite lie along one line for Ti, K, Ba, Sr, Zr, Nb, Sc, V, Mn, Ni, and Ga. These elements distinguish the suite from all others in the batholith. For other elements there appear to be differences between plutons that might become more significant with more intensive sampling. Thus the Cobargo Suite is not as well constrained as most other suites.

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

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

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

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

## KAMERUKA SUPERSUITE

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

The Kameruka Suite consists of two plutons, the Kameruka Granodiorite and the Illawambra Adamellite. The Kameruka Granodiorite (570 km$^2$) is very coarse-grained porphyritic and distinctive. It is cut by two northeast trending, right-lateral wrench faults. Pink K-feldspar crystals, commonly 2 to 8 cm across, are abundant in this unit. Some of the K-feldspars are mantled by plagioclase in a typical rapakivi texture. The virtual absence of hornblende, even in the mafic samples, distinguishes the Kameruka Granodiorite from all other Bega Batholith granites of similar $SiO_2$ content. Mafic inclusions are fairly common in the Kameruka Granodiorite. The Illawambra Adamellite (60 km$^2$) occurs at the northern end and apparently intruded the Kameruka pluton. It is again coarse-grained but more equigranular than the Kameruka Granodiorite and K-feldspar is distinctly more abundant. Relative to other granites of comparable $SiO_2$ range in the Bega Batholiith, the Kameruka Suite is higher in Ca and lower in K and Al. It is also higher in Na than all other granites except members of the Moruya and Cobargo Supersuites. Ga is higher than any other I-type granites of similar $SiO_2$ content in the batholith. The Illawambra Adamellite contains slightly more Ba and Sr than the Kameruka Granodiorite but this is insufficient to justify it being regarded as a separate suite.

The Jingo Creek Adamellite 6.4 km$^2$) is the only member of the Jingo Creek Suite. It is a small body 2 km east of the southern part of the Kameruka Granodiorite. In contrast with that body, mafic inclusions are absent and K-feldspar occurs as irregularly-shaped grains (up to 1 cm) rather than as large well-shaped crystals. This suite shares many chemical characteristics with the Kameruka Suite but can be distinguished by its slightly higher Na, Nb, Mn and Cu, and lower Ti, K, Pb, Th and Zr.

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

The Wallagaraugh Suite forms most of the eastern arm of the southern part of the Bega Batholith. Several rocks types are present, ranging from the moderately mafic Yambulla and Croajingalong Adamellites to the extremely felsic Wallagaraugh Adamellite. Each of these rock types may form several distinct intrusions however they have not been completely mapped. The

Wallagaraugh Adamellite (210 $km^2$) is a coarse-grained, pink, felsic granite covering an extensive area on the eastern side of the batholith, south of Mt Imlay. The Croajingalong Adamellite (315 $km^2$) is coarse to very coarse-grained, outcropping both north and south of Genoa. The unit has a variable composition and more than one intrusion may be present. It is more mafic than the Wallagaraugh Adamellite. The Yambulla Adamellite (55 $km^2$) occurs to the west of the Wallagaraugh Adamellite. The chemical composition of the Wallagaraugh Suite lies near the felsic end of the Kameruka Suite. However, the Wallagaraugh rocks contain less Ti, Sc, P and Ga, and more Pb, Th and Y, than Kameruka Suite rocks of similar $SiO_2$ content. Rocks of this suite provide an excellent example of extensive feldspar fractionation with progressive changes among which are the prominent decrease in Ba and Sr and increase in Rb. Other elements vary in a concomitant way.

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

## CANDELO SUPERSUITE

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

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

The Braidwood Granodiorite (590 $km^2$) forms the Braidwood Suite. It is a large, meridionally trending body centred on the town of Braidwood. It has many of the same petrographic features as the Candelo Suite. Magnetite is abundant and amounts to 1 to 1.5% of most specimens. On the basis of twelve chemical analyses, this unit has a rather restricted compositional range

(61-67% $SiO_2$), like that of the Candelo Suite. It is also similar to the latter suite in having high K and moderate Na. It can, however, be distinguished from the Candelo Suite by slightly lower Al, $Fe^{3+}$, Ba, Sr and higher Fe, Mg, Ca and Ga:Al. The compositions are however sufficiently similar for these two large suites to be distinguished from all other Bega Batholith suites, and to be grouped within the same supersuite.

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

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

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

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

## BEMBOKA SUPERSUITE

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

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

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

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

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

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

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

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

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

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

## GLENBOG SUPERSUITE

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

The Glenbog Suite occurs over a distance of 265 km along the western edge of the Bega

Batholith (see Fig. 1 in Chappell *et al.*, 1987). The more mafic members of this suite, the Anembo (157 $km^2$), Frogs Hollow (92 $km^2$), Yalgatta (74 $km^2$), Glenbog (335 $km^2$), Towamba (181 $km^2$), and Weeragua (21 $km^2$) plutons are all granodiorites and very similar rock types. They are coarse-grained and a most conspicuous textural feature of these rocks is the occurrence of quartz as large equidimensional grains (10-20 mm), commonly surrounded by a rim of hornblende and generally with embayed margins. Larger lumps of quartz, 4 cm across, are occasionally present. The Boro Granodiorite (135 $km^2$) is the northernmost member of the Glenbog Suite sampled to date. It is very coarse-grained and slightly more felsic than the Glenbog and Anembo Granodiorites. The Ballallaba Granodiorite (240 $km^2$) occurs south of the Boro Granodiorite. The Towneys Creek (85 $km^2$), Nimmitabel (131 $km^2$), Cannabul (7.8 $km^2$) and Cann Mountain (48 $km^2$) Adamellites are the felsic members of the Glenbog Suite. Within this suite there is a continuous range in composition from 63% to 74% $SiO_2$, although each individual pluton has a relatively narrow compositional range. In spite of the significant range in composition of this suite and the large area from which the samples come, the whole suite displays the most remarkable chemical coherence, e.g. for Sr (see Fig. 1 in Chappell *et al.*, 1987). Compared to the other Bega Batholith Suites the Glenbog Suite is characterized by high Fe, Ca, Rb, Sc, V, Mn and Co and low Na, P, Ba, Sr, Nb and Ni.

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

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

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

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

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

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

TONGHI SUPERSUITE

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

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

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

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

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

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

UNASSIGNED SUITES

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

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

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

A-TYPE SUITES

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

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

Rocks of the Mumbulla Suite are very felsic granites (*sensu stricto*) dominated by K-feldspar and quartz, with lesser amounts of greenish plagioclase. Biotite (<5%) is the sole primary mafic mineral and is commonly interstitial. Accessory minerals include magnetite, fluorite, zircon, apatite and allanite. The granites are very rich in $SiO_2$, ranging from 76.8 to 77.8%. Data on some elements not listed in Section 2 of this report, Cs, Hf, Ta and full REE, are given by Collins *et al.* (1982). The Mumbulla Suite has many of the very distinctive trace element features of A-type granites, as did the less felsic A-type granites of the Gabo Suite, discussed earlier. Thus the REE and Ga contents are high but Zr and Nb are only a little higher than felsic I-type granites. Ba contents are high for such felsic rocks, from 500 to 655 ppm, and so the rocks do not seem to have undergone any significant feldspar fractionation. The compositions are probably very close to primary A-type melts.

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

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

For a sketch map of the Bega Batholith, see page 93. See also the frontispiece.

# 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.

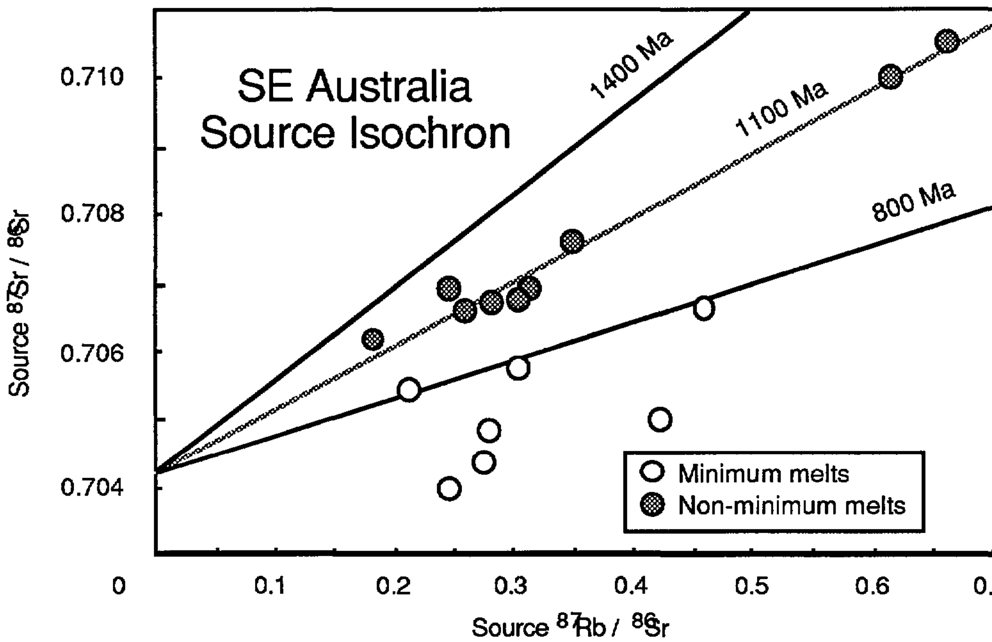


Figure 5. Source isochron for granites of the Berridale and Kosciusko batholiths constructed by inferring the source Rb/Sr for a number of plutons and plotting that against the plutons' initial $^{87}Sr/^{86}Sr$.

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 $\varepsilon_{Nd}$, 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.

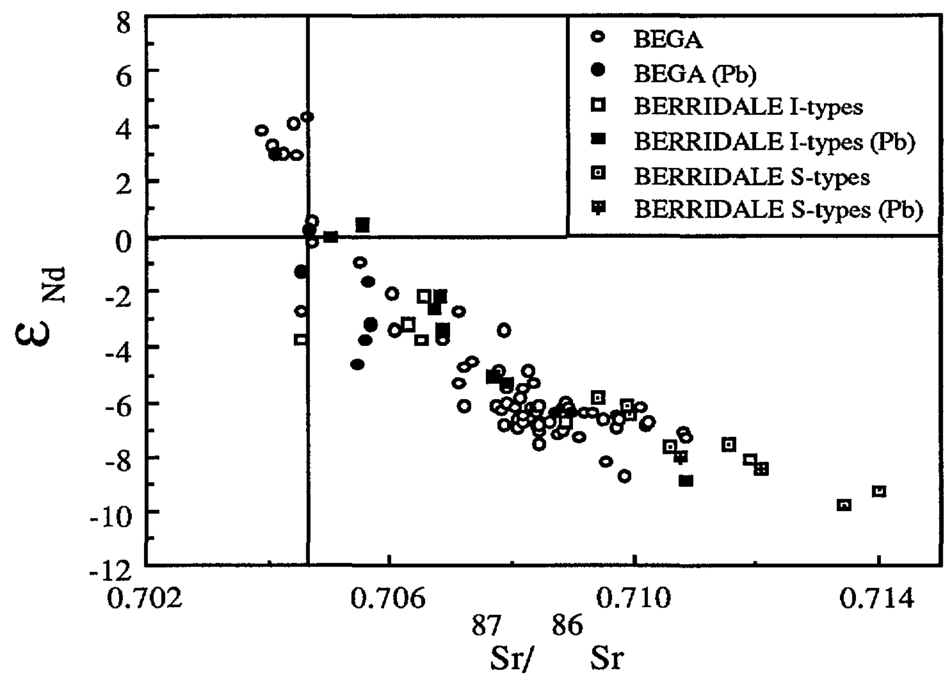


Figure 6. Initial Nd-Sr isotopic compositions of Palaeozoic I- and S-type granites from the Bega and Berridale Batholiths. Solid symbols indicate samples for which Pb isotopic analyses have been undertaken.

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 $\varepsilon_{Nd}$ and $\varepsilon_{Sr}$. 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 $\varepsilon_{Nd}$ 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 $\varepsilon_{Nd}$ 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 $\varepsilon_{Nd}$ 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 $\delta D$ 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.

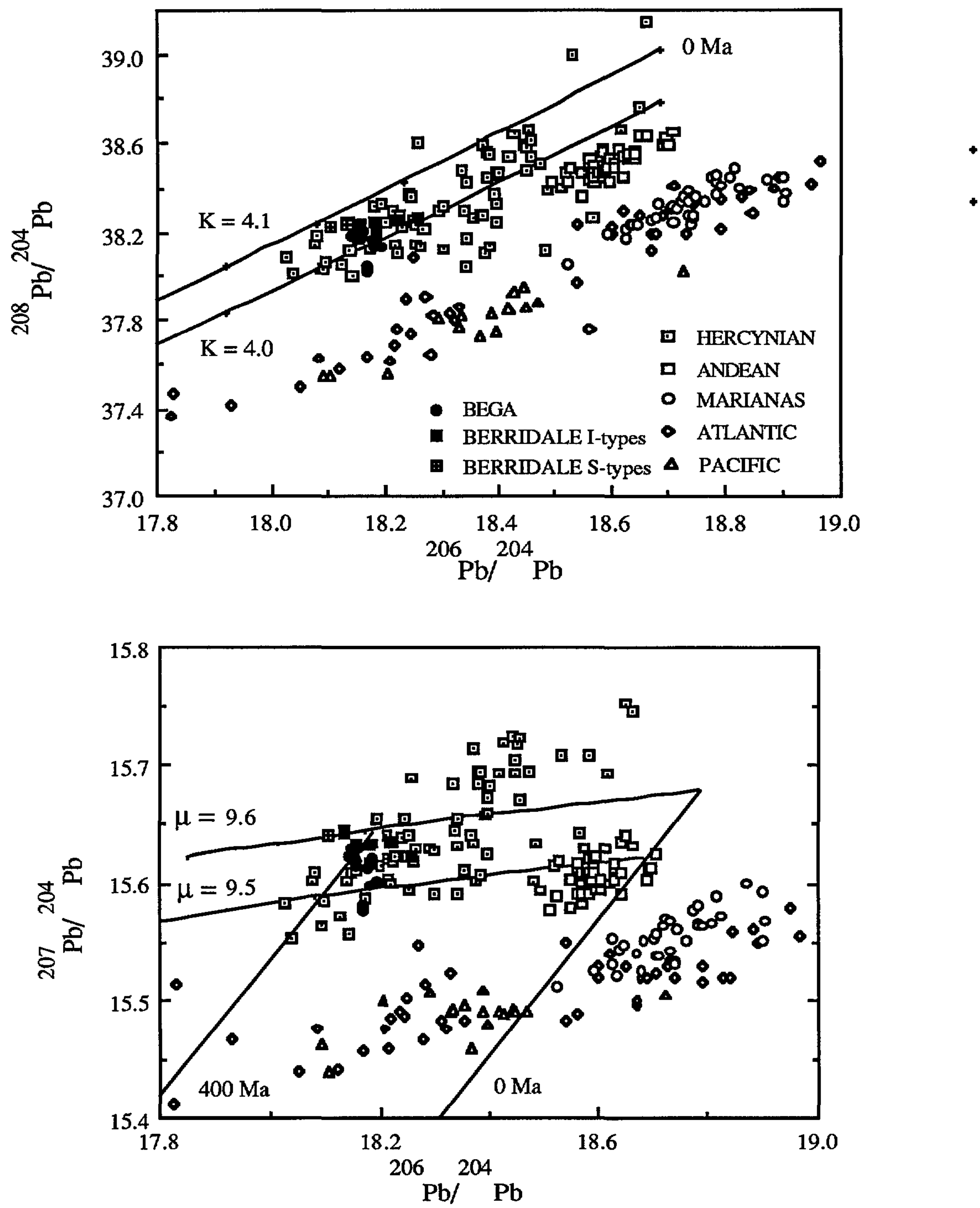


Figure 7. Comparison of $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ with $^{206}Pb/^{204}Pb$ ratios from the LFB with modern island arcs, MORB and Hercynian granites (Michard-Vitrac *et al.*, 1980, 1981) of Europe and eastern N. America. Reference isochrons and single stage evolution curves are calculated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

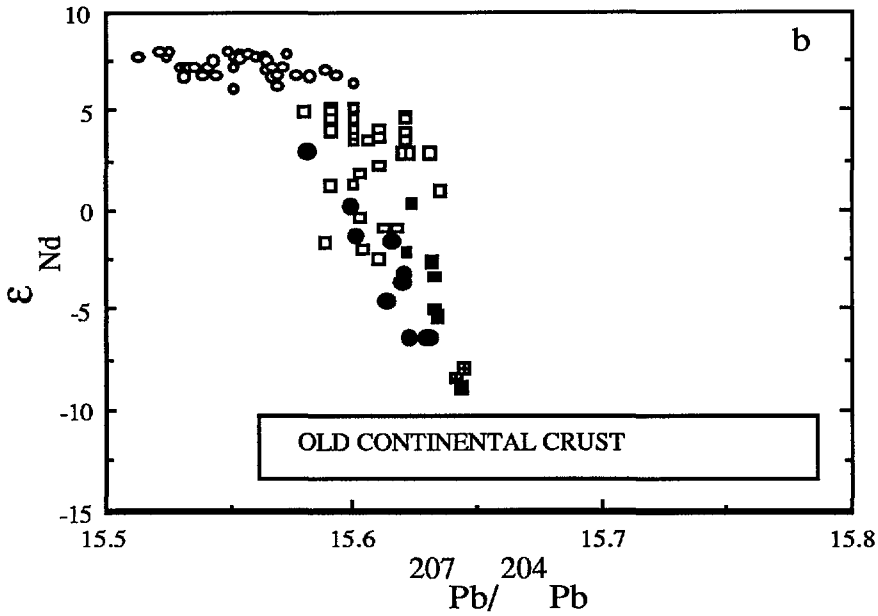


Figure 8. Comparison of Pb and Nd initial isotopic compositions derived from analyses of feldspars and whole rocks respectively from the LFB (solid symbols). Despite the large variations in $\varepsilon_{Nd}$ values the LFB exhibits a very restricted range in Pb isotopic compositions compared to the 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.

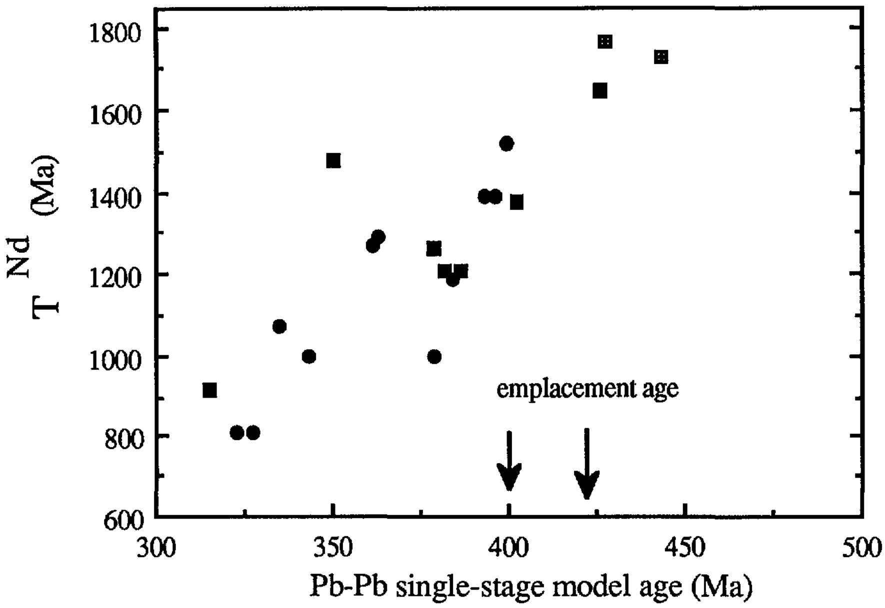


Figure 9. Comparison of $^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ single stage model ages with Sm-Nd model ages. The positive correlation between the Pb-Pb and $T^{Nd}$ model ages is consistent with mixing of an old (negative $\varepsilon_{Nd}$) upper crustal Pb component, represented by the S-type granites, with a more primitive Pb component probably derived from younger crustal protoliths, represented by the Moruya suite (positive $\varepsilon_{Nd}$). 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.

## DAY 1. CANBERRA TO BERRIDALE
## THE COOMA COMPLEX AND PARTS OF THE BERRIDALE BATHOLITH

On the first day of the excursion, there are three stops showing increasing grade in the metamorphic zones of the Cooma Complex, followed by an examination of the central granodiorite and a body of amphibolite. These are followed by visits to three S-type and two I-type granites of the Berridale Batholith. Chemical and modal analyses of rocks from these localities are listed in Table 6. A full summary of mineral isotopic data for the Berridale Batholith is given in Table 7.

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 reached120 km from Canberra. Continue through the city on the Berridale road (Alpine Way) for 9.2 km beyond the Cooma Flags to a road cutting 2 km west of junction with Highway 18 (Snowy Mountains Highway).

### Stop 1-1: Retrogressed spotted schists (Cooma 824856)

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

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

### Stop 1-2: 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.

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

TABLE 6. CHEMICAL ANALYSES: COOMA COMPLEX AND BERRIDALE BATHOLITH

| | CC1 | BB83 | BB137 | BB130 | BB139 | BB131 | BB86 | BB3 | BB9 | BB93 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 72.00 | 67.82 | 41.46 | 51.50 | 60.25 | 66.40 | 67.32 | 67.71 | 68.21 | 74.77 |
| $TiO_2$ | 0.54 | 0.61 | 1.37 | 1.05 | 1.10 | 0.77 | 0.47 | 0.58 | 0.53 | 0.26 |
| $Al_2O_3$ | 13.72 | 14.47 | 30.51 | 24.32 | 15.07 | 15.45 | 15.24 | 14.29 | 14.25 | 13.24 |
| $Fe_2O_3$ | 0.59 | 0.54 | 2.34 | 1.03 | 1.07 | 1.09 | 1.17 | 0.84 | 0.93 | 0.61 |
| FeO | 3.48 | 4.09 | 8.12 | 6.31 | 7.93 | 2.96 | 2.68 | 3.75 | 3.10 | 0.92 |
| MnO | 0.06 | 0.07 | 0.15 | 0.13 | 0.15 | 0.07 | 0.08 | 0.07 | 0.07 | 0.05 |
| MgO | 1.76 | 2.33 | 5.00 | 3.81 | 3.11 | 1.77 | 1.67 | 2.23 | 1.68 | 0.44 |
| CaO | 0.95 | 3.05 | 2.03 | 4.54 | 6.66 | 3.77 | 4.33 | 2.95 | 3.11 | 1.45 |
| $Na_2O$ | 1.49 | 2.06 | 1.32 | 2.23 | 1.03 | 2.56 | 3.23 | 2.00 | 2.23 | 3.89 |
| $K_2O$ | 3.73 | 3.40 | 2.43 | 2.35 | 0.95 | 3.15 | 2.24 | 3.41 | 3.77 | 3.16 |
| $P_2O_5$ | 0.13 | 0.14 | 0.21 | 0.13 | 0.15 | 0.22 | 0.13 | 0.14 | 0.13 | 0.06 |
| $H_2O+$ | 1.28 | 1.13 | 4.06 | 1.83 | 1.92 | 1.10 | 1.03 | 1.48 | 1.28 | 0.60 |
| $H_2O-$ | 0.14 | 0.19 | 0.52 | 0.25 | 0.17 | 0.23 | 0.13 | 0.21 | 0.12 | 0.21 |
| $CO_2$ | 0.13 | 0.18 | 0.21 | 0.30 | 0.24 | 0.13 | 0.14 | 0.12 | 0.29 | 0.04 |
| total | 100.00 | 100.08 | 99.73 | 99.78 | 99.80 | 99.67 | 99.86 | 99.78 | 99.70 | 99.70 |
| Trace elements (ppm) | | | | | | | | | | |
| Rb | 153 | 169 | 107 | 134 | 46.5 | 151 | 86 | 166 | 179 | 130 |
| Sr | 127 | 139 | 112 | 192 | 161 | 176 | 252 | 134 | 167 | 186 |
| Ba | 765 | 445 | 140 | 475 | 140 | 410 | 440 | 470 | 530 | 580 |
| Zr | 201 | 174 | 209 | 190 | 145 | 229 | 126 | 169 | 158 | 152 |
| Nb | 9.0 | 11.5 | 26.5 | 17.5 | 7.0 | 13.0 | 9.0 | 11.0 | 11.5 | 15.5 |
| Y | 39 | 28 | 47 | 32 | 36 | 32 | 22 | 29 | 30 | 25 |
| Ce | 68 | 64 | 141 | 107 | 55 | 50 | 65 | 69 | 63 | 101 |
| Sc | 12 | 17 | 32 | 22 | 34 | 16 | 14 | 18 | 18 | 6 |
| V | 64 | 88 | 208 | 175 | 259 | 102 | 65 | 89 | 95 | 11 |
| Cr | 56 | 65 | 179 | 121 | 9 | 4 | 12 | 71 | 32 | 5 |
| Ni | 24 | 20 | 68 | 28 | 5 | 10 | 3 | 21 | 10 | <1 |
| Zn | 71 | 70 | 290 | 178 | 114 | 60 | 48 | 72 | 57 | 25 |
| Ga | 15.0 | 16.8 | 46.2 | 35.2 | 19.2 | 17.6 | 15.4 | 16.8 | 16.2 | 14.0 |
| Pb | 35 | 26 | 16 | 24 | 14 | 30 | 13 | 25 | 24 | 16 |
| Th | 21.5 | 17.2 | 36.0 | 24.5 | 11.8 | 11.2 | 11.0 | 17.8 | 15.8 | 16.0 |
| U | 3.8 | 3.8 | 18.6 | 3.8 | 2.2 | 1.8 | 2.2 | 2.4 | 2.6 | 5.4 |
| Modes | | | | | | | | | | |
| Quartz | 48.3 | 34.8 | | | | | 32.1 | 36.1 | 35.6 | 34.0 |
| K-feldspar | 8.8 | 9.5 | | | | | 8.6 | 4.9 | 13.8 | 21.0 |
| Plagioclase | 18.9 | 33.7 | | | | | 46.6 | 38.0 | 34.7 | 40.2 |
| Biotite | 17.4 | 21.6 | | | | | 9.7 | 20.8 | 15.6 | 4.1 |
| Hornblende | | | | | | | 2.4 | | | |
| Muscovite | 4.0 | | | | | | | | | 0.3 |
| Opaques | 0.1 | 0.1 | | | | | 0.4 | 0.1 | 0.2 | 0.3 |
| Apatite | 0.1 | 0.3 | | | | | 0.2 | 0.1 | 0.1 | 0.1 |
| Andalusite | 2.4 | | | | | | | | | |

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

## Stop 1-3: 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 on road through the migmatite zone to the town of Cooma. Cross Cooma Back Creek and take Creek Street to the left then first right (Massie Street) and drive to top of hill and turn left to Nanny Goat Hill Lookout.

## Stop 1-4: 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.

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 $\varepsilon_{Nd}$ = -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 ($\alpha$ = 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

TABLE 7. MINERAL AGES FOR THE BERRIDALE AND KOSCIUSKO BATHOLITHS

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

TABLE 7. MINERAL AGES FOR THE BERRIDALE AND KOSCIUSKO BATHOLITHS

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

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

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.

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

## Stop 1-5: Soho Street Amphibolite (Cooma 909869)

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

Isotopic ages: Harrison (1981) studied diffusion of Ar in hornblende from this locality.

Isotopic composition: The present-day $^{87}Sr/^{86}Sr$ composition of the amphibolite is 0.7038 (Pidgeon & Compston, 1965). See also discussion on pp 11-15.

Return to the Snowy Mountains Highway and follow it south and west towards the Berridale Batholith. At 4.1 km from Soho St, at the top of the hill, there is a good view of the Snowy Mountains in the distance. Continue on the Snowy Mountains Highway to the right at the junction at 6.3 km and then after a further 2.1 km turn left on the Middlingbank Road. Follow that road west towards the wooded Coolringdon Hill, across the poorly exposed low-grade part of the Cooma Complex, partly covered on both sides of the road by alkali basalt. Watch for kangaroos when passing through the more 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 1-6: 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. Analyses of the granodiorite (BB83) and 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 the case, the emplacement age of the Cootralantra Granodiorite is almost certainly less than the whole rock age. The initial $^{87}Sr/^{86}Sr$ for Cootralantra 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 1-7: 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. 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 $\varepsilon_{Nd}$ = -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 1-8: 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 1-10).

Isotopic composition: O'Neil & Chappell (1977) determined values of $\delta^{18}O = 9.96‰$ and $\delta D = -50‰$ for this locality. Miller *et al.* (1988) have pointed out that the significant difference in $\delta D$ between this locality and the Tara pluton (Stop 1-7) 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 ($\alpha$ = pale yellow; $\beta = \gamma$ = foxy red-brown) are ragged, most having recrystallized around the edges. Some biotites are aggregates of smaller crystals that have clearly replaced the original biotite. The biotite of these recrystallized patches may be more greenish-brown suggesting more oxidizing conditions during alteration. Patches of secondary epidote may occur in biotites. Large cordierites with secondary micas along cracks are still preserved but unaltered crystals with ragged outlines appear within recrystallized aggregates. Small more-or-less equidimensional zircons and stumpy apatites are accessory minerals. Small monazite crystals within biotites were tentatively identified.

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

**Stop 1-9: Dalgety Granodiorite (Berridale 631837) sample BB9**

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

Isotopic ages: The biotite in this sample of Dalgety Granodiorite has been dated by Rb-Sr, K-Ar and Ar-Ar, giving 415 ± 2, 410 ± 2 and 422 ± 1 Ma respectively. As in the the Tara Granodiorite, the Ar-Ar age is significantly older than the other two. However, in this case the release pattern is in no way anomalous and we consider the Ar-Ar age may be closer to the emplacement age of the granodiorite than the Rb-Sr and K-Ar results. As in the Cootralantra, it appears that the Rb-Sr and K-Ar systems in biotite have been partly reset.

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

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

Isotopic composition: For this locality, McCulloch & Chappell (1982) found $\varepsilon_{Nd} = -6.1$, $^{87}Sr/^{86}Sr(I) = 0.70986$, $T^{Nd} = 1510$ Ma. O'Neil & Chappell (1977) reported $\delta^{18}O = 9.6‰$, with three samples of the Dalgety unit ranging from 9.6 to 10.3‰, and $\delta D$ for BB9 of -54‰.

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

Continue towards Berridale on the Dalgety Granodiorite. The town of Berridale comes into view; the wooded hills to the west are Ordovician sedimentary rocks that separate the Berridale and Kosciusko Batholiths. The hills to the east are the northern end of a screen that runs for 70 km to the southern end of the Berridale Batholith, the Gygederick Screen, which will be seen further south at Stop 3.2. After 4.5 km turn left on the Rocky Plains Road towards Cooma. The road passes onto the Gygederick Screen after 1.1 km; the screen is only 700 m wide at this point. At this northern end of the batholith, the screen separates the Dalgety and Cootralantra Granodiorites, and the characteristic small tors of the latter are seen again on crossing to the eastern side. After 8.2 km turn right on the Alpine Way towards Berridale. Stop after 1.0 km at large granite blocks on the south side of the road at the boundary of the Cootralantra and Wullwye Granodiorites.

## Stop 1-10: 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: McCulloch & Chappell (1982) studied a sample (BB19) of the Cootralantra Granodiorite from another locality. They found $\varepsilon_{Nd}$ = -8.4, $^{87}Sr/^{86}Sr(I)$ = 0.71206 and $T^{Nd}$ = 1730 Ma. Unpublished data for Pb in feldspar are $^{206}Pb/^{204}Pb$ = 18.107, $^{207}Pb/^{204}Pb$ =15.641 and $^{208}Pb/^{204}Pb$ = 38.229. O'Neil & Chappell (1977) determined a value of $\delta^{18}O$ of 10.55‰ for this locality and a range of 9.96 to 10.55‰ for four samples of this unit; corresponding values for $\delta D$ were -74 and -74 to -50‰.

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 $\delta D$ of -89‰.

Continue on the Alpine Way to Berridale. This road crosses the northern part of the Wullwye Granodiorite, which is easily recognized in the distance by its large buff-coloured and more isolated tors. The bare hills without tors south of the road are covered by a veneer of basalt. The road re-enters the Cootralantra Granodiorite 3.1 km from the eastern contact at Stop 1-10. To the north of the road, the large wooded Gygederick Hill again marks the screen at western edge of the Cootralantra Granodiorite. East of the summit of that hill, black graptolitic shales of Ordovician age are interbedded with quartzites and contain small chiastolite crystals. The southern extension of this screen has been faulted 11 km to the south-east by the left-lateral movement of the Berridale Wrench Fault (Lambert & White, 1965). At Gygederick Creek, the trace of that fault may be seen by the line of springs south of the road. The granite outcrops north of the road are of Buckleys Lake Adamellite, which will be seen further south at Stop 3-1. The Berridale Fault is crossed just before entering Berridale.

## DAY 2. BERRIDALE-JINDABYNE DISTRICT
## PARTS OF THE KOSCIUSKO AND BERRIDALE BATHOLITHS

Day 2 of the excursion examines examples of the S-type granites and the slightly younger I-type granites of the Kosciusko Batholith. These are followed by further localities in the Berridale Batholith. Chemical and modal analyses of rocks from these localities are listed in Table 8. A full summary of mineral isotopic data for the Berridale and Kosciusko Batholiths is given in Table 6.

Follow the Alpine Way towards Jindabyne. The road enters Ordovician sediments soon after leaving Berridale and the wooded slopes of Barneys Range then come into view to the west. 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). The road climbs onto the Beloka Plateau with some good exposures of Ordovician sediments in road cuttings. At 11 km from Berridale the appearance of granite boulders marks the edge of the Kosciusko Batholith. The Eucumbene road is taken to the north15 km from Berridale. Follow this road north through S-type granites for 7.3 km to place where broken boulders occur on eastern side of road near a small lake.

### Stop 2-1: 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.

TABLE 8. CHEMICAL ANALYSES: KOSCIUSKO AND BERRIDALE BATHOLITHS

| | KB12 | KB2 | KB4 | KB65 | KB22 | KB32 | BB2 | BB100 | BB11 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 68.94 | 66.71 | 60.56 | 55.37 | 62.29 | 67.68 | 73.48 | 64.54 | 70.89 |
| $TiO_2$ | 0.59 | 0.41 | 0.56 | 0.64 | 0.54 | 0.64 | 0.22 | 0.45 | 0.35 |
| $Al_2O_3$ | 14.11 | 15.76 | 17.25 | 15.80 | 16.46 | 14.70 | 13.41 | 14.71 | 13.92 |
| $Fe_2O_3$ | 0.87 | 1.34 | 1.99 | 2.23 | 1.85 | 0.68 | 0.44 | 0.98 | 0.72 |
| FeO | 3.27 | 2.42 | 3.48 | 5.17 | 3.41 | 4.03 | 1.47 | 4.34 | 2.26 |
| MnO | 0.06 | 0.08 | 0.11 | 0.23 | 0.10 | 0.07 | 0.04 | 0.10 | 0.06 |
| MgO | 1.91 | 1.87 | 3.40 | 6.32 | 2.85 | 2.22 | 0.71 | 2.77 | 1.00 |
| CaO | 2.46 | 4.44 | 6.71 | 8.43 | 6.05 | 2.26 | 1.70 | 5.30 | 2.31 |
| $Na_2O$ | 2.22 | 3.08 | 2.66 | 2.48 | 2.60 | 1.92 | 2.63 | 1.86 | 2.56 |
| $K_2O$ | 3.53 | 2.09 | 1.55 | 1.31 | 2.01 | 3.60 | 4.63 | 2.55 | 3.96 |
| $P_2O_5$ | 0.13 | 0.10 | 0.11 | 0.09 | 0.11 | 0.15 | 0.08 | 0.09 | 0.09 |
| $H_2O+$ | 1.20 | 1.29 | 1.24 | 1.75 | 1.20 | 1.51 | 0.74 | 1.81 | 1.39 |
| $H_2O-$ | 0.31 | 0.17 | 0.10 | 0.13 | 0.20 | 0.22 | 0.14 | 0.15 | 0.15 |
| $CO_2$ | 0.14 | 0.06 | 0.06 | 0.09 | 0.10 | 0.12 | 0.11 | 0.07 | 0.29 |
| total | 99.74 | 99.82 | 99.78 | 100.04 | 99.77 | 99.80 | 99.80 | 99.72 | 99.95 |
| Trace elements (ppm) | | | | | | | | | |
| Rb | 170 | 90 | 62 | 48 | 89 | 183 | 236 | 132 | 178 |
| Sr | 128 | 190 | 254 | 215 | 254 | 139 | 97 | 135 | 198 |
| Ba | 460 | 325 | 275 | 170 | 355 | 475 | 350 | 385 | 625 |
| Zr | 194 | 107 | 85 | 52 | 112 | 187 | 100 | 109 | 136 |
| Nb | 10.5 | 6.5 | 5.0 | 5.5 | 6.5 | 13.0 | 10.0 | 7.5 | 10.5 |
| Y | 31 | 22 | 20 | 55 | 21 | 27 | 33 | 21 | 40 |
| Ce | 68 | 44 | 38 | 57 | 47 | 69 | 49 | 46 | 70 |
| Sc | 15 | 14 | 25 | 62 | 23 | 15 | 7 | 28 | 12 |
| V | 81 | 74 | 154 | 203 | 131 | 87 | 25 | 129 | 42 |
| Cr | 47 | 9 | 28 | 219 | 25 | 61 | 10 | 60 | 13 |
| Ni | 15 | 4 | 9 | 55 | 7 | 20 | 4 | 12 | 6 |
| Zn | 64 | 51 | 61 | 91 | 62 | 82 | 28 | 66 | 47 |
| Ga | 16.8 | 15.2 | 15.2 | 16.0 | 16.4 | 18.2 | 13.8 | 15.8 | 15.2 |
| Pb | 26 | 13 | 7 | 7 | 9 | 27 | 37 | 13 | 33 |
| Th | 19.2 | 11.6 | 7.6 | 6.4 | 9.2 | 19.2 | 19.2 | 14.0 | 18.0 |
| U | 3.8 | 2.0 | 1.4 | 1.6 | 1.4 | 4.0 | 6.4 | 1.8 | 4.2 |
| Modes | | | | | | | | | |
| Quartz | 35.1 | 28.7 | 22.3 | | 25.2 | 34.5 | 34.4 | 33.1 | 37.5 |
| K-feldspar | 9.7 | 4.6 | 0.4 | | 3.0 | 7.7 | 29.5 | 4.1 | 24.5 |
| Plagioclase | 33.8 | 51.3 | 52.3 | | 49.9 | 27.7 | 27.1 | 41.7 | 27.1 |
| Biotite | 19.0 | 14.6 | 16.0 | | 14.7 | 26.7 | 8.7 | 14.8 | 10.7 |
| Hornblende | | 0.5 | 8.2 | | 6.7 | | | 6.3 | |
| Muscovite | 1.9 | | | | | 3.4 | 0.2 | | |
| Opaques | 0.4 | 0.3 | 0.7 | | 0.4 | | 0.1 | | 0.1 |
| Titanite | | | | | | | | | |
| Apatite | 0.1 | | 0.1 | | 0.1 | | | | 0.1 |
| Allanite | | | | | | | | | |

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

### Stop 2-2: Hornblende-poor Round Flat Tonalite (Berridale 495872) sample KB2

There are good exposures of Kalkite Adamellite on the left hand side of the road where the rock is seen as a coarse-grained felsic granite dominated by quartz with lesser plagioclase and K-feldspar. Red-brown biotite is the main mafic mineral but there are some cordierite pseudomorphs and small amounts of secondary? muscovite can be seen in hand sample. There is a pronounced foliation trending about 30°. The foliation results from the orientation both of biotites and of the elliptically shaped metasedimentary inclusions. Walk northwards through the field on the east side of the road, parallel to the road as it descends into the broad valley to the north. Note the foliation in the granite until the contact with the Round Flat Tonalite is crossed. The foliation persists across the contact but is weaker in the tonalite.

The Round Flat Tonalite is a small I-type granite (6.6 $km^2$) completely enclosed by older S-type Kalkite Adamellite. It lies in a valley and this is typical of the tonalites of the Jindabyne Suite that intrude the S-type granites of the eastern part of the Kosciusko Batholith. Hornblende is rare in the rocks at the southern side of this body.

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

### Stop 2-3: Hornblende-rich Round Flat Tonalite (Berridale 499887) sample KB4

This is one of the most mafic samples of tonalite in the Kosciusko Batholith. 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 other tonalites of the LFB to be seen later in the excursion; an analysis of one inclusion (KB65) is given in Table 8.

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

Return south to the Alpine Way and follow west towards Jindabyne. After 10.5 km pull into the parking area just past the Jindabyne Dam spillway.

### Stop 2-4: 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.

## Stop 2-5: Lake Jindabyne

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 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 2-6: 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 hornblendes 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 (Day 5) 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 $\varepsilon_{Nd}$ = -5.0, $^{87}Sr/^{86}Sr(I)$ = 0.70769 and $T^{Nd}$ = 1480 Ma for this rock. Unpublished Pb data for feldspars are $^{206}Pb/^{204}Pb$ = 18.226, $^{207}Pb/^{204}Pb$ = 15.633 and $^{208}Pb/^{204}Pb$ = 38.253,

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 ($\alpha$ = straw yellow; $\beta = \gamma$ = 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 ( $\alpha$ = brownish yellow, $\beta$= dark olive green, $\gamma$ = 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 2-7: 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 $\varepsilon_{Nd}$ = -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 ($\alpha$ = 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. 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 Stops 2-8 and 2-9, or else continue 500 m across the Snowy River to Dalgety and then 2.1 km further on the Berridale road to Stop 2-10.

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 2-8: 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 $\varepsilon_{Nd}$ = -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 ($\alpha$ = 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. Continue to boulders of that body next to the road 5.7 km south of Stop 2-8.

### Stop 2-9: Finister Tonalite (Numbla 653368) sample BB100

This I-type pluton (33 km$^2$) is a light-grey even-grained hornblende-biotite granodiorite trasitional to tonalite.

Isotopic ages: The Finister Tonalite is somewhat of an enigma isotopically and even more work needs to be done to understand it. Geologically the pluton is one of the earliest in the Berridale Batholith, predating as it does the Numbla Vale and Buckleys Lake Adamellites. The mica ages measured on BB100 are 417 ± 2 Ma (Rb-Sr) and 415 ± 3 Ma (K-Ar). Mica ages measured on five other samples from the pluton are similar to these, with the exception of the Ar-Ar result of 428 ± 2 Ma measured on BB163. Once again, however, this result is suspected to be an overestimate of age because the Ar release pattern shows an anomalous peak for the steps between 750 and 950°C. The K-Ar and Ar-Ar ages measured on hornblende from BB163 are 411 ± 4 Ma and 415 ± 2 Ma, respectively.

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

Conventional analyses of zircons from the Finister show inheritance is present, but in lesser amounts than in the Tara Granodiorite, which shows no inheritance in its whole rock Rb-Sr and a much lower initial $^{87}Sr/^{86}Sr$, 0.706. The zircon analyses define a discordance array with an apparent 'mean' upper intersection age of a little over 1000 Ma.

It remains for ion probe analyses of the zircons to be made to see whether there is anything unusual about the age makeup of the Finister source rocks that might indicate the reason the inheritance in the whole rock Rb-Sr is so pronounced.

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

The road south from Stop 2-9 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 2-8 and this point. Return north to Dalgety and then 2.1 km further on Berridale road to Stop 2-10. Note that Dalgety was on the short list for selection as Australia's Capital!

## Stop 2-10: Dalgety Granodiorite (Berridale 645600) sample BB11

This rock is similar to BB9 at Stop 1-9 except that the K-feldspars are larger and up to 40 mm long, and there is a small amount of cordierite. As in the earlier locality there are dark fine-grained pseudomorphs, presumably after orthopyroxene. Inclusions at this locality include large (400 mm) more mafic Dalgety Granodiorite which themselves contain relatively coarsely crystalline inclusions; 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 $\varepsilon_{Nd} = -6.5$, $^{87}Sr/^{86}Sr(I) = 0.70991$, $T^{Nd} = 1510$ Ma.

Continue north on road to Berridale, traversing the axis of the northern part of the Dalgety Granodiorite.

## DAY 3. BERRIDALE TO EDEN
## PARTS OF THE BERRIDALE AND BEGA BATHOLITHS

On the third day of the excursion, two localities of felsic granite in the Berridale Batholith, east of the IS-line, are examined. After crossing an extensive area covered by basalts of the Monaro Province, the excursion looks at I-type granites from the western parts of the Bega Batholith. Those are followed by a visit to an A-type granite locality. Finally, an examination is made of a cutting in Ordovician sediments, from which isotopic samples have been obtained. Chemical and modal analyses of rocks from these localities are given in Table 9.

Travel south from Berridale on the Dalgety road and after 2.3 km take the road on the left to Bobundara. This road crosses Dalgety Granodiorite and after 2.5 km it is close (~ 1 km) to the faulted contact of that pluton along the Berridale Fault, with that contact being mainly covered by Cainozoic basalt. The screen between the Dalgety and Buckleys Lake plutons is crossed about 700 m after Wullwye Creek; the screen is less than 500 m wide at this point. Further to the south, basalt flows on the left lap onto the Buckleys Lake Adamellite, with the latter having very large tors. Fresh boulders of that unit occur on the northern side of the road south of Buckleys Lake.

### Stop 3-1: Buckleys Lake Adamellite (Berridale 746634) sample BB10

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

Isotopic ages: Biotite ages have been measured on seven samples from the large Buckleys Lake Adamellite. All give ages very close to 417 Ma. The results obtained from BB10 are Rb-Sr 417 $\pm$ 1 Ma, K-Ar 413 $\pm$ 2 Ma and Ar-Ar 421 $\pm$ 1 Ma. The Ar-Ar age is greater than any Rb-Sr or K-Ar age measured on the other samples, and the Ar release spectrum is anomalous, so the Ar-Ar age is presently not considered to be geologically significant.

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

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

TABLE 9. CHEMICAL ANALYSES: BERRIDALE AND BEGA BATHOLITHS

| | BB10 | BB21 | AB6 | AB5 | AB149 | AB195 | AB206 | GI1 | IWS2 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 71.15 | 76.56 | 67.39 | 71.26 | 65.36 | 65.27 | 76.53 | 73.60 | 74.19 |
| $TiO_2$ | 0.37 | 0.19 | 0.53 | 0.40 | 0.51 | 0.58 | 0.06 | 0.34 | 0.64 |
| $Al_2O_3$ | 13.90 | 12.60 | 14.48 | 13.75 | 14.73 | 15.22 | 12.39 | 12.44 | 12.07 |
| $Fe_2O_3$ | 1.18 | 0.43 | 1.58 | 0.94 | 1.56 | 1.76 | 0.19 | 1.42 | 0.73 |
| FeO | 1.40 | 0.43 | 3.02 | 1.97 | 3.44 | 2.83 | 0.65 | 1.49 | 2.89 |
| MnO | 0.05 | 0.02 | 0.09 | 0.06 | 0.10 | 0.09 | 0.04 | 0.08 | 0.03 |
| MgO | 0.86 | 0.21 | 1.72 | 0.97 | 2.49 | 2.01 | 0.25 | 0.27 | 1.92 |
| CaO | 2.61 | 0.97 | 4.32 | 2.93 | 5.21 | 4.40 | 0.35 | 1.24 | 0.22 |
| $Na_2O$ | 3.04 | 3.52 | 2.63 | 2.82 | 2.48 | 2.74 | 3.57 | 3.53 | 1.69 |
| $K_2O$ | 3.98 | 4.16 | 2.99 | 3.37 | 2.15 | 3.43 | 4.67 | 4.23 | 2.52 |
| $P_2O_5$ | 0.08 | 0.03 | 0.11 | 0.09 | 0.12 | 0.19 | 0.01 | 0.07 | 0.17 |
| $H_2O+$ | 0.67 | 0.47 | 0.95 | 0.90 | 1.53 | 1.26 | 0.60 | 0.56 | |
| $H_2O-$ | 0.19 | 0.15 | 0.13 | 0.14 | 0.15 | 0.09 | 0.13 | 0.34 | |
| $CO_2$ | 0.24 | 0.11 | 0.08 | 0.23 | 0.28 | 0.20 | 0.14 | 0.14 | |
| total | 99.72 | 99.85 | 100.02 | 99.83 | 100.11 | 100.07 | 99.58 | 99.75 | |
| Trace elements (ppm) | | | | | | | | | |
| Rb | 190 | 214 | 135 | 151 | 108 | 133 | 304 | 201 | |
| Sr | 191 | 99 | 148 | 153 | 258 | 410 | 17.5 | 142 | |
| Ba | 590 | 545 | 415 | 635 | 400 | 805 | 65 | 710 | |
| Zr | 152 | 115 | 145 | 173 | 121 | 184 | 64 | 472 | |
| Nb | 12.0 | 16.5 | 9.0 | 8.0 | 8.0 | 9.0 | 13.0 | 28.0 | |
| Y | 32 | 26 | 32 | 29 | 19 | 21 | 60 | 83 | |
| Ce | 88 | 66 | 64 | 78 | 60 | 70 | 46 | 147 | |
| Sc | 11 | 5 | 17 | 11 | 19 | 14 | 5 | 17 | |
| V | 45 | 7 | 101 | 47 | 116 | 97 | 1 | 5 | |
| Cr | 4 | <1 | 11 | 7 | 33 | 17 | 1 | 2 | |
| Ni | 2 | <1 | 4 | 3 | 7 | 7 | <1 | 2 | |
| Zn | 32 | 17 | 55 | 37 | 50 | 61 | 15 | 121 | |
| Ga | 14.8 | 12.0 | 15.8 | 15.0 | 15.6 | 15.8 | 15.0 | 21.2 | |
| Pb | 19 | 17 | 15 | 15 | 7 | 15 | 30 | 31 | |
| Th | 21.5 | 19.8 | 16.4 | 17.6 | 12.0 | 13.8 | 23.5 | 23.5 | |
| U | 4.8 | 3.6 | 3.3 | 3.2 | 1.4 | 4.2 | 8.9 | 6.4 | |
| Modes | | | | | | | | | |
| Quartz | 36.1 | 34.3 | 30.1 | 36.4 | 27.4 | 27.1 | 36.0 | 31.3 | |
| K-feldspar | 19.6 | 35.0 | 13.8 | 22.6 | 8.5 | 15.3 | 37.5 | 44.7 | |
| Plagioclase | 38.3 | 28.3 | 36.1 | 31.6 | 41.2 | 40.2 | 26.1 | 21.3 | |
| Biotite | 5.5 | 1.9 | 13.4 | 9.2 | 12.3 | 11.0 | 2.5 | 1.5 | |
| Hornblende | | | 6.6 | | 10.2 | 4.4 | | 0.7 | |
| Muscovite | | 0.2 | | | | | 0.7 | | |
| Opaques | 0.5 | 0.3 | | 0.2 | 0.2 | 0.7 | 0.1 | 0.2 | |
| Titanite | | | | | <0.1 | 1.2 | | | |
| Apatite | | | | | 0.1 | 0.1 | | | |
| Allanite | | | | | 0.1 | | | | |

Continue on the road for 500 m and then take the Dalgety road to the right past large boulders of Buckleys Lake Adamellite to the south. This road crosses the Wullwye Screen which here is about 1200 m wide. There are extensive scree deposits from the metasedimentary rocks of the screen covering the western contact of the Buckleys Lake Adamellite. Beyond the thickly wooded southern flank of Wullwye Hill there is a good panorama of the central part of the Berridale Batholith.

### Stop 3-2: Wullwye Screen (Berridale 708594)

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

Continue to the Dalgety-Bombala road and then turn left through the easternmost part of the Dalgety pluton. This is followed in turn by basalt, Ordovician metasedimentary rocks, and then the edge of the Buckleys Lake body 1.1 km from the road junction. Bobundara Hill to the right is comprised of a thick series of basalt flows. The wooded area seen to the south after Bobundara Creek is the Maffra Adamellite, whose contact is crossed 6.0 km after joining the Bombala road. Stop at the junction with the road to Cooma after a further 1.7 km and walk150 m down that road to fresh boulders of the Maffra Adamellite.

### Stop 3-3: Maffra Adamellite (Numbla 769549) sample BB21

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

Isotopic ages: The Maffra Adamellite is one of the few I-type granites in the Berridale Batholith that is felsic enough to contain muscovite. The mica ages measured on BB21 are biotite Rb-Sr 410 ± 1 Ma, K-Ar 413 ± 2 Ma, Ar-Ar 414 ± 1 Ma, and muscovite Rb-Sr 414 ± 2 Ma. The great similarity between these results gives confidence that the emplacement age of the Maffra Adamellite is about 413 Ma.

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

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

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

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

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

### Stop 3-4: Glenbog Granodiorite (Bombala 105460) sample AB6

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

The most conspicuous textural feature is the occurrence of quartz as large equidimensional grains (10-20 mm), commonly surrounded by a rim of small hornblende grains and generally with embayed margins. Larger lumps of quartz, 40 mm across, are occasionally present. Hornblende is present as prismatic crystals more than 10 mm in length. This rock is typical of those occurring near the western edge of the Bega Batholith. The most distinctive features are the low $Na_2O$ and Sr contents.

Inclusions are fairly abundant at this locality. They have been discussed in detail by Chen *et al.* (1990).

Isotopic ages: The Glenbog Tonalite has not been dated by Rb-Sr or K-Ar. J.R. Richards (*pers comm.*) has measured a biotite K-Ar age on Brown Mountain of 370 Ma that could be of Glenbog, but is more likely of Bemboka Granodiorite.

Zircon from Glenbog Tonalite AB6 has been analyzed by ion microprobe as part of our study of inheritance in the I-type granites of the Bega Batholith. Most of the zircon analyzed, as in all the I-type granites, is new zircon precipitated from the melt during magmatism. It gives an age close to 400 Ma. A small number of the zircons contain cores that have ages from early to late Proterozoic.

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

The most likely material to survive as enclaves is the more mafic parts of the source, implying thereby that the rocks from which the older inherited zircons are derived are the rocks in the source that are most easily melted. This is in direct contrast to the result obtained from the one studied enclave from an S-type granite. In that case the enclave showed the same pattern of inheritance as its host, and if anything the amount of inheritance in the enclave was the greater.

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

Petrographic description: Plagioclase occurs as complexly zoned rectangular crystals having prominent oscillatory zoning around mottled calcic cores near $An_{50}$ which often contain grains of quartz and fine apatite needles. The cores are extensively altered to epidote and sericite in many samples. The mafic minerals occur both as discrete grains and as clots. Hornblende ($\alpha$ = pale green, $\beta$ = olive green, $\gamma$ = dark brownish green with patches having a bluish tint) occurs both as well shaped prisms up to 10 mm across and as irregular grains in clots intergrown with biotite and magnetite. The biotite ($\alpha$ = straw yellow; $\beta = \gamma$ = dark sepia brown) is mostly ragged grains containing an abundance of tiny apatites and some small zircons as well large crystals of magnetite. K-feldspar is interstitial, enveloping all other minerals, including quartz crystals. Hornblende and biotite occur as discrete well-formed crystals when enclosed within K-feldspar or quartz. Accessory minerals include zircon and allanite. This rock shows signs of deformation with some bent biotite cleavages and undulose extinction in quartz grains.

Continue east and enter basalt1 km beyond Stop 3-4 and the cutting of the Brown Mountain Screen 2 km from stop. Beyond the screen the road enters the Bemboka Granodiorite. Stop 4.6 km from the Glenbog outcrop in a cutting on the south side of the road.

### Stop 3-5: Bemboka Granodiorite (Bombala 154442) sample AB5

The Bemboka Granodiorite has the largest area of exposure of any I-type granite in the LFB (970 km$^2$) with additional areas covered by Upper Devonian red-beds. It is probably the largest pluton in the belt, since the "larger" S-type bodies of the Kosciusko, Maragle and Wagga Batholiths are probably composite. This unit and the Wadbilliga Adamellite (75 km$^2$), a separate pluton further to the north, comprise the Bemboka Suite, the major component of the Bemboka Supersuite (1850 km$^2$), one of the three extensive supersuites in the central parts of the Bega Batholith. A medium- to coarse-grained rock with large prominent quartz crystals 20 mm across in places but mostly 10 mm.

Some large quartz crystals are surrounded by hornblende grains. This is a felsic rock and some of the K-feldspars are distinctly pinkish in colour, consistent with its more felsic composition. Inclusions are not common.

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

Return 1.6 km to the Brown Mountain Screen.

**Stop 3-6: Brown Mountain Screen (Bombala 132448)**

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

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

**Stop 3-7: Kelvin Granodiorite (Bombala 919118) sample AB149**

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

Isotopic ages: The zircon ion probe data from this locality are not yet reduced.

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

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

**Stop 3-8: Yurammie Granodiorite (Craigie 192867) sample AB195**

The Yurammie Granodiorite (245 $km^2$) makes up the central part of a zoned pluton in the Bega Batholith. It is gradational outwards into the more mafic Candelo Tonalite (45 $km^2$) from which Yurammie is distinguished by pink K-feldspar being noticeable in the field. Together these two units comprise the Candelo Suite, part of the Candelo Supersuite (1199 $km^2$) which is the "central" of the seven supersuites of the Bega Batholith. Yurammie is a moderately felsic member of the Candelo

Suite. It consists of large crystals (30 mm) of pink K-feldspar, white plagioclase crystals up to 10 mm and quartz 5 - 10 mm across. Large red-brown titanites can be seen in hand specimen and chalcopyrite is also relatively abundant. There are quite a few mafic inclusions, some containing large feldspar and quartz crystals.

Isotopic ages: The Yurammie Granodiorite contains a similar amount of inherited zircon to the Glenbog Tonalite, even though its $\varepsilon_{Nd}$ is not quite so negative (-4.6). About half the inheritance is latest Proterozoic, and half early Proterozoic. There is a marked lack of inherited zircons with intermediate ages.

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

Petrographic description: This rock is coarse grained with pink K-feldspar phenocrysts. Such pink coloured crystals are found only in I-type and A-type granites, although in those rocks the crystals may be white. In S-type granites K-feldspar crystals are always white in colour, provided the rock is fresh and not hydrothermally altered (Chappell & White, 1984). In thin section the K-feldspar is seen to have microcline twinning and there is further evidence of deformation normally seen when the the K-feldspar is microcline: the quartz has undulose extinction and some biotite cleavages are bent. Plagioclases up to 6 mm across are mostly in the range $An_{40}$ to $An_{45}$ with outermost zones down to $An_{25}$ and with rare cores near $An_{70}$. Ragged grains of biotite may be slightly chloritized. Hornblende ($\alpha$ = pale yellow-green, $\beta$ = olive green, $\gamma$ = dark green with bluish tint) is not common. Titanite is fairly abundant occurring as large crystals, sometimes 0.5 mm across. Accessory allanite magnetite, needles of apatite and zircon are conspicuous.

The bridge over Nungatta Creek is crossed 1.6 km beyond Stop 3-8. Boulders near the bridge contain abundant mafic inclusions, some of which have been analyzed. 26 km from the bridge and 600 m before Imlay Creek, stop at a roadside cutting of felsic Wallagaraugh Adamellite.

### Stop 3-9: Wallagaraugh Adamellite (Eden 379762) sample AB206

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

Examples of extensive feldspar fractionation in granites of the LFB are uncommon, particularly among the I-type granites, but such a process is well shown by the Wallagaraugh unit. It shows progressive changes among which the prominent decrease in Ba and Sr and increase in Rb are evidence for feldspar fractionation. Other elements vary in a concomitant way.

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

Petrographic description: This is a coarse-grained pink granite consisting almost entirely of strongly perthitic K-feldspar, quartz with undulose extinction and plagioclase forming tabular normally-zoned crystals with outer zones near $An_{15}$. The small amounts of biotite are generally chloritized commonly with strips of fluorite, titanite and white mica along the relict cleavage traces. A few patches of fluorite occur elsewhere in the rock.

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

### Stop 3-10: Devonian unconformity (Eden 398761)

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

Continue to Highway 1 (which extends around Australia), 12 km east of Stop 3-10. Turn south on the highway and then follow the Ireland Timms Forest Road east of the road 2.8 km south of the Imlay Road. At a distance of 3.8 km from Highway 1, take the Cockatoo Road to left, stopping at a cutting in granite1.4 km from that junction.

## Stop 3-11: Watergums Granite (Eden 513684) sample GI1

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

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

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

Petrographic description: Collins *et al.* (1982) have described this rock as even, medium to fine grained with K-feldspar ($Or_{60}$-$Ab_{40}$) being the most abundant mineral, forming tabular microperthitic crystals or granophyric intergrowths with quartz. It is accompanied by normally zoned plagioclase ($An_{30}$-$An_5$) with a composition mostly in the oligoclase range. Quartz also appears as clusters of small grains between K-feldspar or as large embayed crystals having the β-quartz form. Biotite (α = pale yellow, β = γ = dark brown) is mostly interstitial to K-feldspar but may form subhedral grains within the granophyric parts of the rock. Microprobe analysis shows that it is annite. Fluorite sometimes occurs as small lenses interleaved in biotite. Hastingsite (α = colourless, β = light brown, γ = khaki) is subordinate to biotite but crystallized before it and forms long prisms. In places it is interstitial to K-feldspar. It typically has inclusions of zircon, apatite and opaque minerals. A distinctly blue amphibole (α = aqua-blue, β = pale to inky-blue) occurs as small irregular grains around the hastingsites; microprobe analysis indicates that these are riebeckite-arfvedsonite solid solutions. Zircon (including some large zoned crystals), fluorite, and magnetite (with exsolved ilmenite) are constant accessory minerals whereas apatite and allanite are less common. Relicts of fayalite are rare.

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

## Stop 3-12: Ordovician sediments (Eden 398761) sample IWS2

Ordovician sediments are exposed in this cutting. A "dirty sandtone", standing out as a competent layer in the western face of this cutting has been collected for U-Pb zircon analysis. A partial major element analysis is given in Table 10. The extremely low Ca content of this rock is typical of the Ordovician sediments of the LFB.

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

Every sediment contains a major zircon population slightly older than 500 Ma, which tails upwards to ages not exceeding 600 Ma. All samples contain major age groupings at about 1000 Ma, and a further minor groupings upwards to middle Archaean ages. The proportions of the different components differ from sample to sample but the ages represented are consistent from one to the next. For the first time we are getting hard information on the provenance of the massive flysch deposits of south-eastern Australia. Clearly the source is not so distant that the sediments have had a chance to become well mixed. On the other hand, major igneous activity in Pan African (~600 Ma) and Grenville (~1000 Ma) times has yet to be recognized in southeastern Australia. One can always call on a lost source to the south, the predominant palaeocurrent direction, possibly in Antarctica or beyond, but a viable alternative, given the patterns of inheritance in the granites, is that we are reading a record of igneous activity in eastern and possibly central Australia now largely obscured by younger cover.

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

Continue north along Highway 1 to Eden.

## DAY 4. EDEN TO NAROOMA
## PARTS OF THE BEGA BATHOLITH AND THE MT DROMEDARY COMPLEX

The fourth day of the excursion examines rocks from the eastern side of the Bega Batholith, and also the very felsic Mumbulla A-type granite. Those localities are followed by a brief visit to the Cretaceous Dromedary Complex. Chemical and modal analyses of rocks from these localities are listed in Table 10.

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

### Stop 4-1: Eden Rhyolite at Rotary Park Lookout (Eden 590927)

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

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

### Stop 4-2: Brogo Granodiorite (Bega 523387) AB82

The Brogo Granodiorite is an elliptical pluton centred a few kilometres NNE of Bega. It has a distinctive composition and comprises the Brogo Suite, part of the Cobargo Supersuite (370 km$^2$). The rock is medium-grained with biotite and lesser hornblende. The K-feldspar crystals, up to 15 mm across, have a slightly pinkish shade. This is an "oxidized" rock containing brown biotite plus titanite, allanite and magnetite. Inclusions are dominantly of the mafic hornblende-bearing variety but a large metasedimentary block, 3 m across, occurs in the western side of the cutting. Such inclusions are very rare in granites of the LFB and in general only occur near to the contact.

Isotopic ages: One biotite K-Ar age has been measured on this unit, 380 Ma (J.R. Richards, *pers. comm.*). The zircons collected from this site have yet to be analysed by ion probe.

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

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

### Stop 4-3: Bega Valley Lookout (Bega 523408)

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

TABLE 10. CHEMICAL ANALYSES: BEGA BATHOLITH AND DROMEDARY COMPLEX

| | AB82 | AB40 | AB116 | AB118 | AB190 | AB128 | MD1 | MD8 | MD10 | MD12 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 67.18 | 68.77 | 77.51 | 77.00 | 67.59 | 64.47 | 52.06 | 59.60 | 64.82 | 67.16 |
| $TiO_2$ | 0.47 | 0.53 | 0.14 | 0.15 | 0.54 | 0.66 | 0.96 | 0.54 | 0.37 | 0.31 |
| $Al_2O_3$ | 15.05 | 14.75 | 11.76 | 11.83 | 15.22 | 15.54 | 15.67 | 17.98 | 16.26 | 16.13 |
| $Fe_2O_3$ | 1.44 | 0.99 | 0.27 | 0.40 | 0.97 | 1.29 | 3.21 | 1.21 | 1.60 | 1.55 |
| FeO | 2.05 | 2.46 | 1.04 | 1.05 | 2.65 | 2.98 | 5.73 | 3.32 | 2.09 | 1.07 |
| MnO | 0.08 | 0.07 | 0.03 | 0.04 | 0.07 | 0.08 | 0.18 | 0.13 | 0.11 | 0.09 |
| MgO | 1.96 | 1.29 | 0.05 | 0.04 | 1.59 | 2.52 | 4.52 | 1.16 | 1.03 | 0.64 |
| CaO | 3.82 | 3.12 | 0.34 | 0.61 | 3.77 | 4.96 | 8.43 | 3.50 | 2.45 | 2.41 |
| $Na_2O$ | 3.66 | 3.53 | 3.04 | 3.06 | 3.56 | 3.61 | 2.88 | 4.17 | 4.03 | 4.38 |
| $K_2O$ | 2.66 | 2.94 | 4.94 | 4.98 | 2.49 | 2.30 | 4.45 | 6.46 | 5.69 | 4.98 |
| $P_2O_5$ | 0.16 | 0.16 | 0.02 | 0.02 | 0.15 | 0.16 | 0.72 | 0.27 | 0.19 | 0.12 |
| $H_2O+$ | 1.10 | 0.96 | 0.59 | 0.47 | 0.99 | 0.93 | 0.62 | 0.66 | 0.61 | 0.50 |
| $H_2O-$ | 0.12 | 0.11 | 0.17 | 0.18 | 0.13 | 0.14 | 0.19 | 0.15 | 0.36 | 0.31 |
| $CO_2$ | 0.19 | 0.20 | 0.18 | 0.07 | 0.20 | 0.18 | 0.18 | 0.66 | 0.46 | 0.23 |
| total | 99.94 | 99.88 | 100.08 | 99.90 | 99.92 | 99.82 | 99.80 | 99.81 | 100.07 | 99.88 |
| Trace elements (ppm) | | | | | | | | | | |
| Rb | 92 | 123 | 232 | 230 | 103 | 87 | 133 | 272 | 321 | 224 |
| Sr | 406 | 256 | 43.5 | 50 | 339 | 390 | 1440 | 940 | 630 | 965 |
| Ba | 485 | 505 | 640 | 655 | 390 | 405 | 1225 | 715 | 490 | 895 |
| Zr | 117 | 191 | 173 | 187 | 146 | 159 | 86 | 161 | 284 | 189 |
| Nb | 9.0 | 9.5 | 20.0 | 18.0 | 8.5 | 9.0 | 6.0 | 17.0 | 26.0 | 19.5 |
| Y | 20 | 18 | 84 | 100 | 22 | 21 | 21 | 16 | 24 | 18 |
| Ce | 54 | 71 | 153 | 142 | 54 | 54 | 59 | 59 | 83 | 61 |
| Sc | 10 | 10 | 18 | 14 | 9 | 13 | 16 | 9 | 8 | 7 |
| V | 62 | 54 | 2 | 2 | 61 | 85 | 230 | 53 | 31 | 29 |
| Cr | 31 | 13 | <1 | <1 | 18 | 35 | 50 | 8 | 4 | 5 |
| Ni | 8 | 6 | <1 | <1 | 12 | 20 | 24 | 4 | 2 | 1 |
| Zn | 49 | 57 | 116 | 106 | 54 | 50 | 98 | 66 | 59 | 40 |
| Ga | 15.8 | 16.8 | 20.0 | 20.0 | 16.8 | 17.0 | | | | |
| Pb | 13 | 16 | 37 | 33 | 18 | 11 | 14 | 22 | 22 | 14 |
| Th | 10.8 | 12.4 | 27.0 | 22.0 | 14.4 | 12.6 | 7.4 | 15.0 | 35.8 | 38.2 |
| U | 3.3 | 2.3 | 6.8 | 5.8 | 3.8 | 2.5 | 2.4 | 3.4 | 10.6 | 9.4 |
| Modes | | | | | | | | | | |
| Quartz | 24.5 | 35.0 | 34.8 | 34.7 | 29.3 | 16.5 | 0.5 | 3.0 | 13.8 | 13.7 |
| K-feldspar | 12.2 | 9.3 | 45.0 | 46.4 | 9.5 | 15.7 | 32.6 | 55.7 | 50.2 | 41.7 |
| Plagioclase | 48.3 | 43.2 | 16.6 | 15.4 | 48.6 | 45.2 | 31.7 | 25.9 | 29.4 | 39.8 |
| Biotite | 10.2 | 12.1 | 3.3 | 3.0 | 8.4 | 12.7 | 7.9 | 3.7 | 2.4 | 0.1 |
| Hornblende | 3.8 | <0.1 | | | 3.7 | 8.9 | 1.1 | 10.5 | 3.2 | 3.1 |
| Opaques | 0.6 | 0.2 | 0.2 | 0.3 | 0.3 | 0.6 | 4.4 | 0.7 | 0.9 | 1.1 |
| Titanite | 0.1 | | | | 0.1 | <0.1 | | 0.2 | | 0.4 |
| Apatite | 0.2 | 0.2 | 0.1 | <0.1 | 0.1 | 0.1 | 1.8 | 0.3 | 0.1 | 0.1 |
| Allanite | 0.1 | | <0.1 | 0.2 | | | | | | |
| Pyroxene | | | | | | | 20.0 | | | |

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

### Stop 4-4: Kameruka Granodiorite (Bega 477416) sample AB40

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

Isotopic ages: A K-Ar biotite age of 360 Ma has been measured on the Kameruka Granodiorite by J.R. Richards (*pers. comm.*).

Ion probe analyses of the zircons show many of the grains to contain inherited cores. The ages of the inheritance are very well defined: the melt-precipitated zircons are about 400 Ma old, there is one inherited component between 500 and 600 Ma old, a second inherited component 900 to 1200 Ma old, and a couple of grains which are late Archaean and early Proterozoic. This pattern epitomises the inheritance found in the Bega Batholith as a whole and defines very clearly the ages of the components which are contributing to the granite melts. Components of the same ages dominate the granites' host sediments, showing that both the granites and the sediments are derived from the products of the same episodes of igneous activity.

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

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

### Stop 4-5: Mumbulla Granite (Bega 566486) sample AB116

The Mumbulla Granite is medium-grained very felsic granite *sensu stricto*, with an area of 56 $km^2$, and comprising the prominent Mumbulla Mountain. This unit and the Ellery Granite (64 $km^2$), in the Kosciusko Basement Terrane, are the largest A-type plutons in the LFB. Together with the Dr George Mountain Granite (13 $km^2$), this granite comprises the Mumbulla Suite, occurring some 100 km north of the Watergums Granite of Stop 3-11. This is a very felsic granite. The K-feldspar is a dull pink whereas the plagioclase is white to greenish. Scattered flakes of biotite are mostly altered. This locality is at an altitude of 400 m. The Mumbulla Granite has many of the very distinctive trace element features of A-type granites, as did the less felsic A-type granites of the Gabo Suite, discussed above. Thus the REE and Ga contents are high but Zr and Nb are only a little higher than felsic I-type granites. Ba contents are high for such felsic rocks, from 500 to 655 ppm, and so the rocks do not seem to have undergone any significant feldspar fractionation. The compositions are probably very close to an unmodified primary A-type melt.

Isotopic composition: Sample AB119 from this unit gave values of $\varepsilon_{Nd}$ = -2.3, $^{87}Sr/^{86}Sr(I)$ =

0.70608 and $T^{Nd}$ = 1410 Ma.

Smaller vehicles can drive to the summit of Mumbulla Mountain although the track is sometimes in a poor condition. Take the road to the left a few hundred metres past Stop 4-5. There are several exposures of granite on this road including the "type" locality AB118 2 km from the road junction.

### Stop 4-6: Mumbulla Granite (Bega 571500) sample AB118

This is sample 4473 of Collins *et al.* (1982) at an altitude of 550 m. It is very similar in composition to sample AB116 at Stop 4-5.

Petrographic description: Collins *et al.* (1982) have described this rock as medium to coarse and even-grained, dominated by pink K-feldspar and quartz and with lesser amounts of plagioclase that is greenish because of alteration. Biotite ($\alpha$ = pale yellow, $\beta = \gamma$ = dark brown) is the sole primary mafic mineral forming irregular-shaped crystals which are commonly interstitial to quartz and K-feldspar. Chlorite is a common secondary alteration product whereas red-brown alteration products presumably after fayalite are rare. Accessory minerals include magnetite, fluorite, zircon, apatite and allanite.

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

### Stop 4-7: Quaama Granodiorite (Cobargo 566604) sample AB190

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

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

Approaching Cobargo, the hills on the right are a screen between the Cobargo and Quaama intrusions. Mt Dromedary is seen on the skyline to the north. At Cobargo, 11.5 km from Stop 4-7, take the Bermagui Road to the east through the Cobargo pluton. Hornfels ridges are seen to the south and later to the north around this intrusion. At 5.2 km from the highway the road enters the Coolagolite pluton at the point where where the Coolagolite Road leaves to the right. Stop at exposures on the north side of road near Green Tyrrells Road at 7.1 km.

### Stop 4-8: Coolagolite Granodiorite (Cobargo 650671) sample AB128

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

Isotopic ages: Despite the Coolagolite Granodiorite having only a slightly positive $\varepsilon_{Nd}$ (+0.2), it contains less inherited zircon than any other analyzed granite from the Bega Batholith; one grain of the 64 surveyed. The age of the zircon precipitated from the melt is well defined at close to 400 Ma, a result supported by conventional analyses by Fanning (*pers. comm.*) of some of the same crystals dated by ion probe.

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

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

### Stop 4-9: Mt Dromedary Monzonite at Tilba Quarry (Narooma 370776) MD7

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

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

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

Approximately 2 km to the south there is a track leading to the summit of the mountain. Samples MD8, MD10 and MD12 (Table 10) represent a sequence of compositions through to the centre of the zoned inner intrusion. The petrology of the Mt Dromedary pluton has been discussed in detail by Smith *et al.* (1988).

Continue on Highway 1 for 16 km to Narooma.

## DAY 5. NAROOMA TO CANBERRA
## PARTS OF THE MORUYA AND BEGA BATHOLITHS

The last day of the excursion examines localities in the small Moruya Batholith which are the most easterly of the Devonian I-type granites in the Lachlan belt. The northern parts of the Bega Batholith are crossed while returning to Canberra, and two granites are examined. Chemical and modal analyses of rocks from these localities are provided in Table 11.

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

### Stop 5-1: Bodalla Granodiorite (Narooma 381973) sample MG20

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

Isotopic ages: The K-Ar biotite age of the Bodalla Granodiorite is 370 Ma (J.R. Richards, *pers. comm.*).

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

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

### Stop 5-2: Tarandore Point, Tuross Head (Narooma 424062 to 423051) MG39

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

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

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

TABLE 11. CHEMICAL ANALYSES: MORUYA AND BEGA BATHOLITHS

| | MG20 | MG39 | MG42 | MG24 | MG14 | MG29 | MG3 | AB299 | AB368 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 74.91 | 66.32 | 60.13 | 53.39 | 67.18 | 62.88 | 71.50 | 64.44 | 68.69 |
| $TiO_2$ | 0.15 | 0.67 | 0.99 | 1.38 | 0.51 | 1.02 | 0.34 | 0.61 | 0.41 |
| $Al_2O_3$ | 13.37 | 15.08 | 16.42 | 14.77 | 15.50 | 15.90 | 14.18 | 14.97 | 14.09 |
| $Fe_2O_3$ | 0.38 | 1.37 | 2.04 | 2.26 | 0.88 | 1.55 | 0.39 | 2.18 | 1.37 |
| FeO | 1.16 | 2.62 | 3.73 | 6.42 | 2.76 | 4.19 | 1.89 | 3.02 | 1.98 |
| MnO | 0.07 | 0.08 | 0.11 | 0.14 | 0.08 | 0.09 | 0.06 | 0.09 | 0.06 |
| MgO | 0.24 | 1.95 | 3.27 | 6.19 | 1.80 | 2.42 | 0.70 | 2.45 | 1.70 |
| CaO | 1.10 | 4.05 | 5.91 | 9.68 | 4.08 | 3.95 | 2.08 | 5.23 | 2.73 |
| $Na_2O$ | 4.21 | 4.18 | 3.94 | 3.44 | 3.81 | 3.78 | 3.84 | 2.57 | 2.66 |
| $K_2O$ | 3.50 | 2.31 | 1.41 | 0.59 | 2.21 | 2.46 | 3.70 | 2.95 | 3.93 |
| $P_2O_5$ | 0.06 | 0.19 | 0.28 | 0.10 | 0.16 | 0.34 | 0.12 | 0.16 | 0.11 |
| $H_2O+$ | 0.58 | 0.79 | 1.03 | 1.08 | 0.76 | 1.11 | 0.72 | 1.07 | 1.65 |
| $H_2O-$ | 0.18 | 0.15 | 0.18 | 0.19 | 0.09 | 0.12 | 0.07 | 0.14 | 0.21 |
| $CO_2$ | 0.02 | 0.14 | 0.28 | 0.24 | 0.11 | 0.16 | 0.36 | 0.08 | 0.22 |
| total | 99.93 | 99.90 | 99.72 | 99.87 | 99.93 | 99.99 | 99.95 | 99.96 | 99.81 |
| Trace elements (ppm) | | | | | | | | | |
| Rb | 90 | 72 | 36.5 | 5.6 | 61 | 92 | 141 | 115 | 147 |
| Sr | 123 | 380 | 487 | 532 | 327 | 326 | 215 | 363 | 313 |
| Ba | 580 | 440 | 325 | 185 | 445 | 545 | 585 | 625 | 570 |
| Zr | 102 | 187 | 168 | 94 | 138 | 273 | 155 | 165 | 136 |
| Nb | 12.0 | 12.5 | 14.0 | 6.5 | 11.5 | 17.0 | 12.5 | 7.5 | 9.0 |
| Y | 25 | 20 | 23 | 15 | 18 | 14 | 25 | 27 | 26 |
| Ce | 42 | 47 | 51 | 30 | 50 | 52 | 61 | 62 | 81 |
| Sc | 3 | 13 | 15 | 31 | 9 | 10 | 5.4 | 21 | 12 |
| V | 6 | 79 | 113 | 240 | 63 | 97 | 26 | 109 | 67 |
| Cr | 1 | 16 | 37 | 184 | 23 | 33 | 2 | 31 | 12 |
| Ni | <1 | 11 | 26 | 56 | 10 | 16 | <1 | 10 | 7 |
| Zn | 37 | 52 | 68 | 77 | 54 | 83 | 38 | 62 | 34 |
| Ga | 15.0 | 15.6 | 17.4 | 14.8 | 15.8 | 17.6 | 14.0 | 16.0 | 14.2 |
| Pb | 15 | 9 | 6 | 4 | 9 | 9 | 19 | 14 | 11 |
| Th | 8.6 | 12.0 | 5.0 | 4.0 | 8.4 | 5.6 | 14.4 | 12.8 | 24.5 |
| U | 3.6 | 2.8 | 1.8 | 1.0 | 2.7 | 1.4 | 5.9 | 2.2 | 3.2 |
| Modes | | | | | | | | | |
| Quartz | 34.6 | | | 3.3 | 27.7 | | 32.7 | 26.2 | 36.6 |
| K-feldspar | 26.2 | | | 0.2 | 6.4 | | 22.0 | 13.6 | 19.8 |
| Plagioclase | 34.7 | | | 57.8 | 50.6 | | 39.7 | 40.8 | 34.2 |
| Biotite | 4.5 | | | 18.0 | 11.2 | | 5.6 | 8.7 | 6.7 |
| Hornblende | | | | 18.6 | 3.9 | | | 8.9 | 2.6 |
| Opaques | | | | 1.8 | | | | 1.3 | |
| Titanite | | | | 0.2 | | | | 0.3 | |
| Apatite | | | | 0.1 | 0.2 | | | 0.2 | |
| Allanite | | | | | | | | | 0.1 |

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

At Boogumgoridgee Point, projecting from the beach between Tarandore Point and Tuross Head, the tonalite is typical of the main mass not associated with the gabbroic-diorite. This tonalite (9.6 $km^2$) is the most mafic unit in the Moruya Batholith and in the Moruya Suite (see also Stop 5-3). Sample MG39 from this locality is the most felsic sample of this body that has been analyzed.

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

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

### Stop 5-3: Tuross Head Tonalite at Bingie Bingie Point (Narooma 442107) MG42

The Tuross Head Tonalite is a heterogeneous body, varying from quartz-diorite to granodiorite in composition. A mafic variety, crowded with inclusions is well exposed on the point. Both the inclusions and the mafic minerals show a very strong preferred orientation with the foliation trending 330$^o$ and dipping steeply. MG42 is the most mafic granite collected from the Moruya Batholith, for which the compositions range continuously from 60 to 75% $SiO_2$. The composition of this rock is fairly similar to a typical andesite, and granites for which that comparison can be made are only found in the LFB in the Moruya Batholith and close by in the eastern side of the Bega Batholith. Relative to the bulk of I-type granites in the LFB these eastern granites are high in $Na_2O$ and Sr. As at Stop 5-2, the tonalite is intrusive into a body of gabbroic diorite (MG24) at this locality and a coarse-grained big-hornblende rock is often developed near contacts.

A large aplite dyke cuts the tonalite and several east-west trending mafic dykes cut the gabbroic diorite-tonalite-aplite complex. These are of two types and different ages although all are parallel. One set is dacitic in composition, whereas the others are alkali basalts or hawaiites, presumably closely related to the nearby Cainozoic basalt flows. These younger dykes are easily distinguished by an abundance of large (usually 10 - 30 mm long) oriented plagioclase crystals. All of the Cainozoic dykes contain inclusions but these have been concentrated in the central dyke. These inclusions include anorthosites, hornblende anorthosites and spinel pyroxenites, as well as xenocrysts of amphibole, garnet, labradorite, and rare biotite and olivine, with some inclusions of country rock. The pyroxenes are an aluminous variety similar to those found on the liquidus at 1 GPa (10 kb) by Green & Ringwood (1967). Halford (MSc thesis, 1970) has shown that the compositions of some of these minerals are consistent with a high-pressure origin and they are considered to be deep-seated crystallization products of the alkali basalt itself, rather than samples from the lower crust of the area.

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

Petrographic description: Plagioclase is the dominant mineral in this rock. It is seen in thin section to have squat mostly rectangular shapes up to 4 mm in longest dimension. All have complex oscillatory zoning around irregular calcic cores. The inner zones are mostly near $An_{35}$ and outermost zones being near $An_{20}$. The inner zones of the plagioclase crystals commonly outlined by strings of sericite, were interpreted as restite by White & Chappell (1977)

Hornblendes ($\alpha$ = pale yellow-green, $\beta$ = olive green, $\gamma$ = dark green with bluish tint) usually appears as ragged crystals that are crowded near their centres with small magnetites. The hornblendes may occur as isolated crystals or more commonly in clots or aggregates with equally ragged biotites ($\alpha$ = straw yellow; $\beta = \gamma$ = dark sepia brown to chocolate brown) and irregularly shaped magnetites. Biotite and to some extent hornblende is partly replaced by chlorite. Quartz grains have irregular shapes (up to 2 mm) and are mostly interstitial to the dominant plagioclase. Magnetite and tiny apatite prisms are common. Zircon crystals are conspicuous but when they occur in biotite there are no pleochroic haloes. Titanite is minor and occurs as poorly shaped interstitial crystals or as strings of irregularly shaped individuals mainly in close association with secondary chlorite: it is either late or secondary.

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

## Stop 5-4: Moruya Tonalite in Dorman Long Quarry (Batemans Bay 396227) MG14

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

Isotopic ages: A biotite K-Ar age measured by J.R. Richards (*pers. comm.*) on the Moruya Tonalite is 380 Ma. This is very close to the age obtained on melt-precipitated zircon by the ion probe. Even though the Moruya Tonalite has the highest $\varepsilon_{Nd}$ measured in the Bega Batholith, +3.0, it still contains an appreciable component of inherited zircon cores. Most of the inheritance is between 500 and 600 Ma old, one grain is about 1000 Ma old, and there is nothing older. It appears that the eastward progression towards more positive $\varepsilon_{Nd}$ is associated with a decrease both the age and abundance of the inherited components, although the Coolagolite result shows that even where the abundance of inheritance is very low, very old cores still survive.

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

Return to Highway 1 and then drive north for 28 km to the junction of the highway to Canberra. Travel along this road for 14.3 km to the Nelligen Quarry. This road is through typical coastal forest dominated by Spotted Gums (*Eucalyptus maculata*) with an underbrush of Wattles (*Acacias*) and She-oaks. The bright purple flowering creeper is a purple coral-pea (*Hardenbergia violacea*) sometimes called 'sarsparilla'. The bedrock comprises steeply dipping Palaeozoic slates and sandstones that are well exposed in the road cutting near the approaches to the Nelligen bridge over the Clyde River, 7.1 km west of Highway 1. Nelligen was the old port for the gold mining town of Braidwood situated on the plateau to the west. West of the Clyde River the road follows Nelligen Creek, along the banks of which are abundant River Oaks and exotic California Pines and European Willows. About 500 m west of the Nelligen Creek bridge (13.1 km from the Highway), cordierite hornfels forming a contact aureole around the Nelligen Granodiorite may be seen in the shallow road cutting. A small granite quarry is located about 100 m south of the road and 1200 m west of Nelligen Creek, set in a Spotted Gum Forest with Dwarf Palms covering the floor that are primitive Cycads (*Macrozamia communis*).

**Stop 5-5: Nelligen Granodiorite (Batemans Bay 359522) sample MG3**

The Nelligen Granodiorite is a relatively homogeneous circular-shaped body 69 $km^2$ in area at the northern end of the Moruya Batholith. This rock has similarities with more felsic members of the Moruya Suite, but in detail there are differences (see p. 22) and it is grouped with those other units in the Moruya Supersuite. It is a moderately felsic medium-grained granite in which the K-feldspars are pink, indicative of crystallization under oxidizing conditions and this is also indicated by the presence of magnetite. There is no hornblende in the granite but it is present in the inclusions which are more metaluminous. Biotite (chocolate-brown) is the only ferromagnesian mineral and since biotite is always peraluminous this indicates that the rock is slightly peraluminous. Consistent with this, titanite is absent although it is recorded in other members of the Moruya Supersuite.

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

**Stop 5-6: Braidwood Granodiorite (Braidwood 527703) sample AB299**

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

Isotopic ages: Ion probe analyses of zircons from the Braidwood Granodiorite show the same pattern that has now become familiar as a feature of the majority of the Bega Batholith granites; a cluster of results close 400 Ma representing the zircon newly formed during magmatism, a cluster of ages between 500 and 600 Ma representing the immediate source of the granites, a couple of analyses near 1000 Ma representing that source's possible precursor, and a couple of early Proterozoic grains probably derived from a small amount of sediment in the source.

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

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

**Stop 5-7: St Bede's Church, Braidwood (Braidwood 540738)**

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

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

**Stop 5-8: Boro Granodiorite (Braidwood 413963) sample AB280**

The Boro Granodiorite (135 $km^2$) is the most northerly pluton in the Glenbog Suite. The rock at this locality shows the distinctive features seen ealier in the Glenbog Granodiorite at Stop 3-4, such as the prominent large crystals of quartz.

Isotopic composition: The isotopic composition of another sample of this pluton, AB281 gives $\varepsilon_{Nd} = -4.9$, $^{87}Sr/^{86}Sr(I) = 0.70827$, $T^{Nd} = 1470$ Ma. Compare with the data from sample AB6 at Stop 3-4.

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

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

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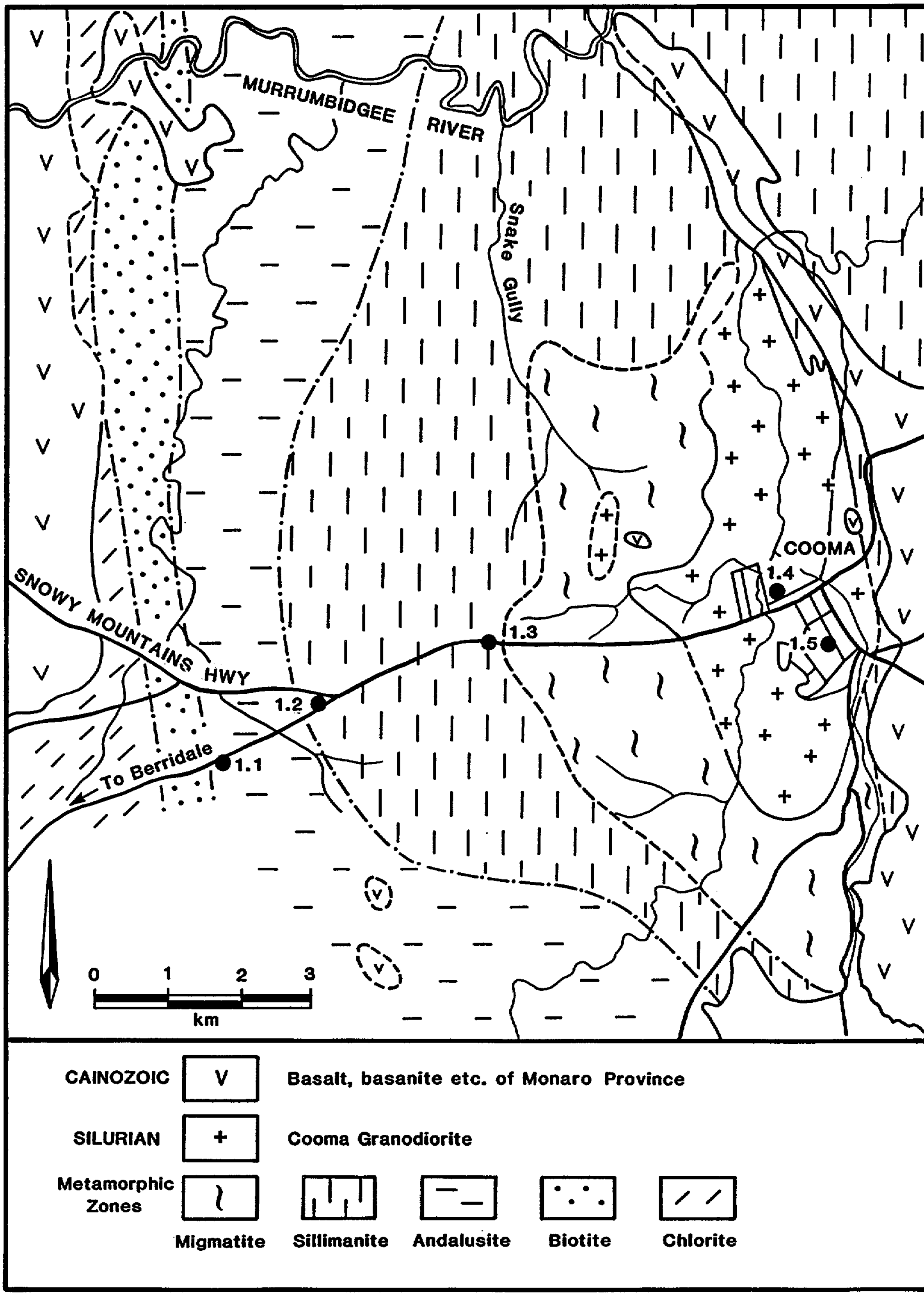


GEOLOGICAL SKETCH MAP OF THE COOMA COMPLEX

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.*

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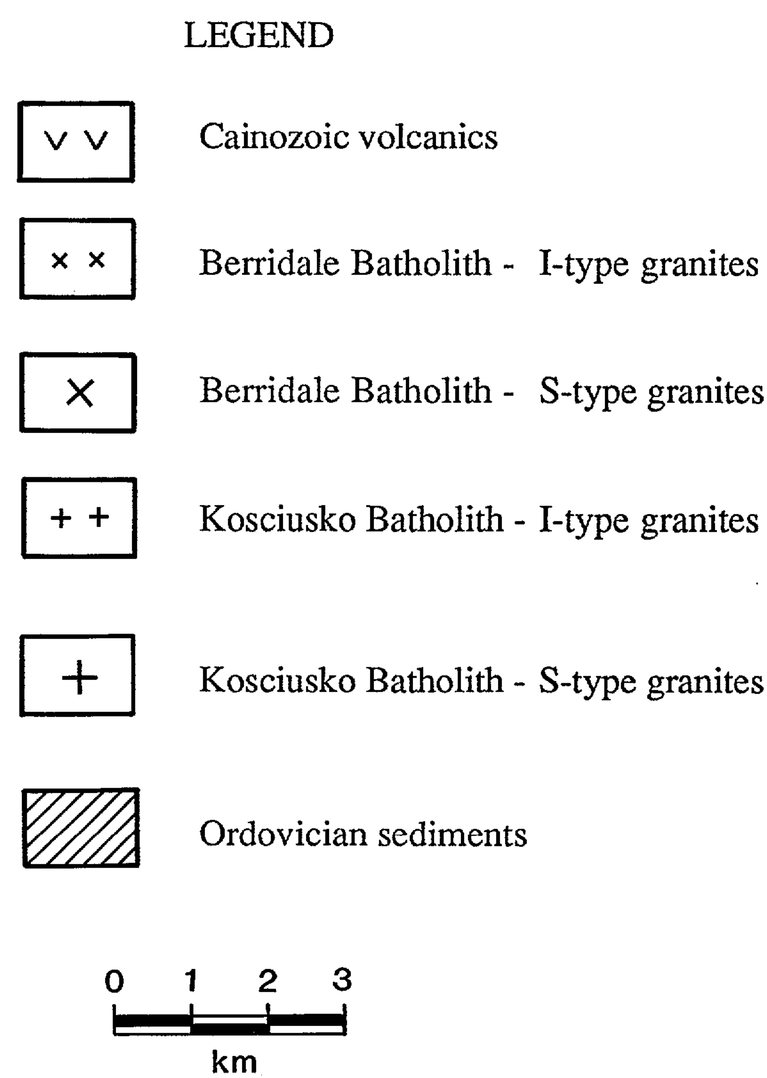

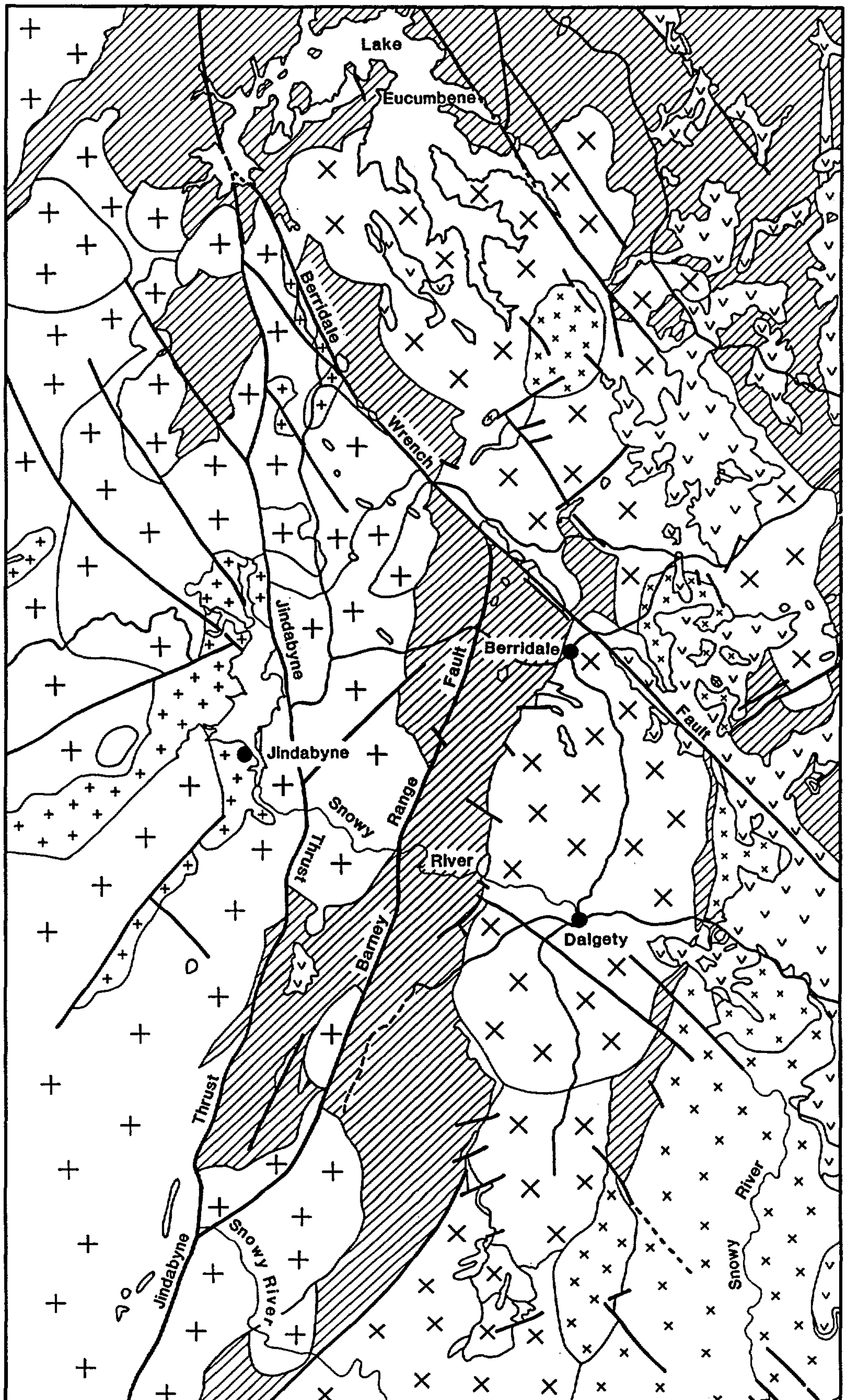
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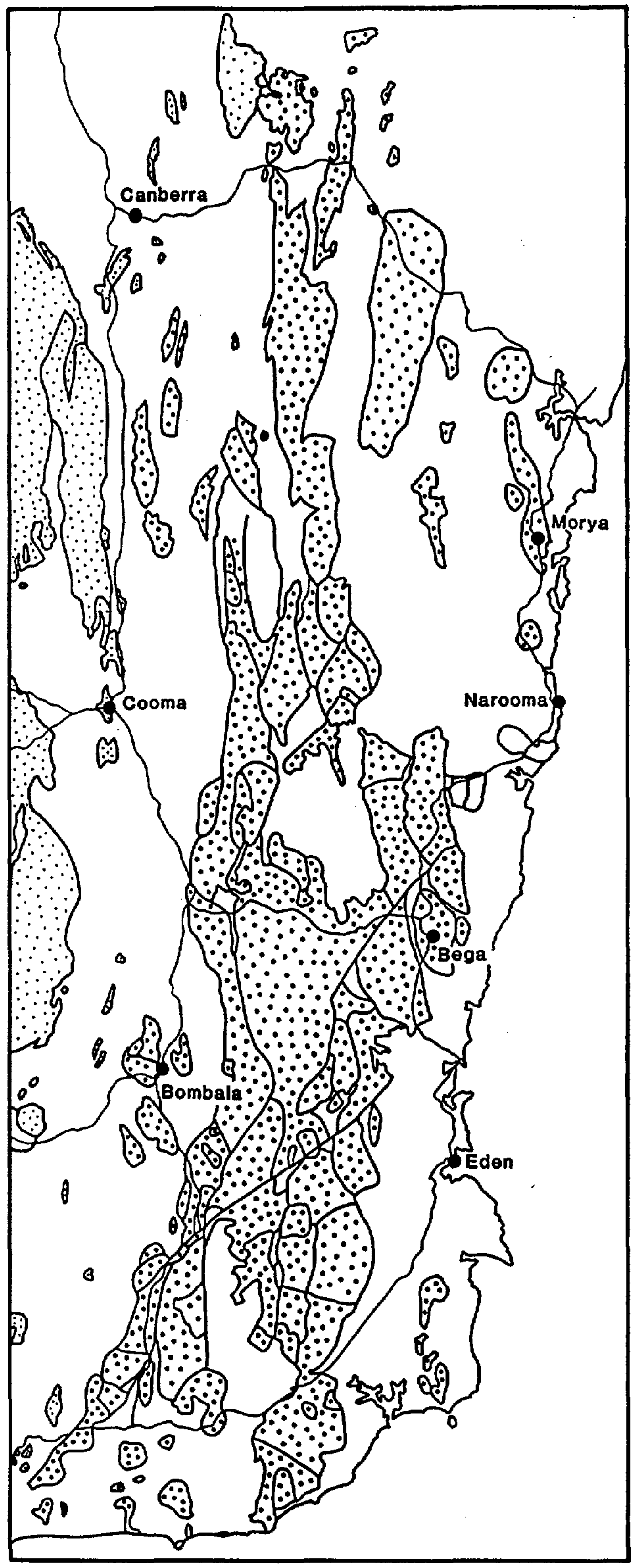



SKETCH MAP OF THE BEGA BATHOLITH

# 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."

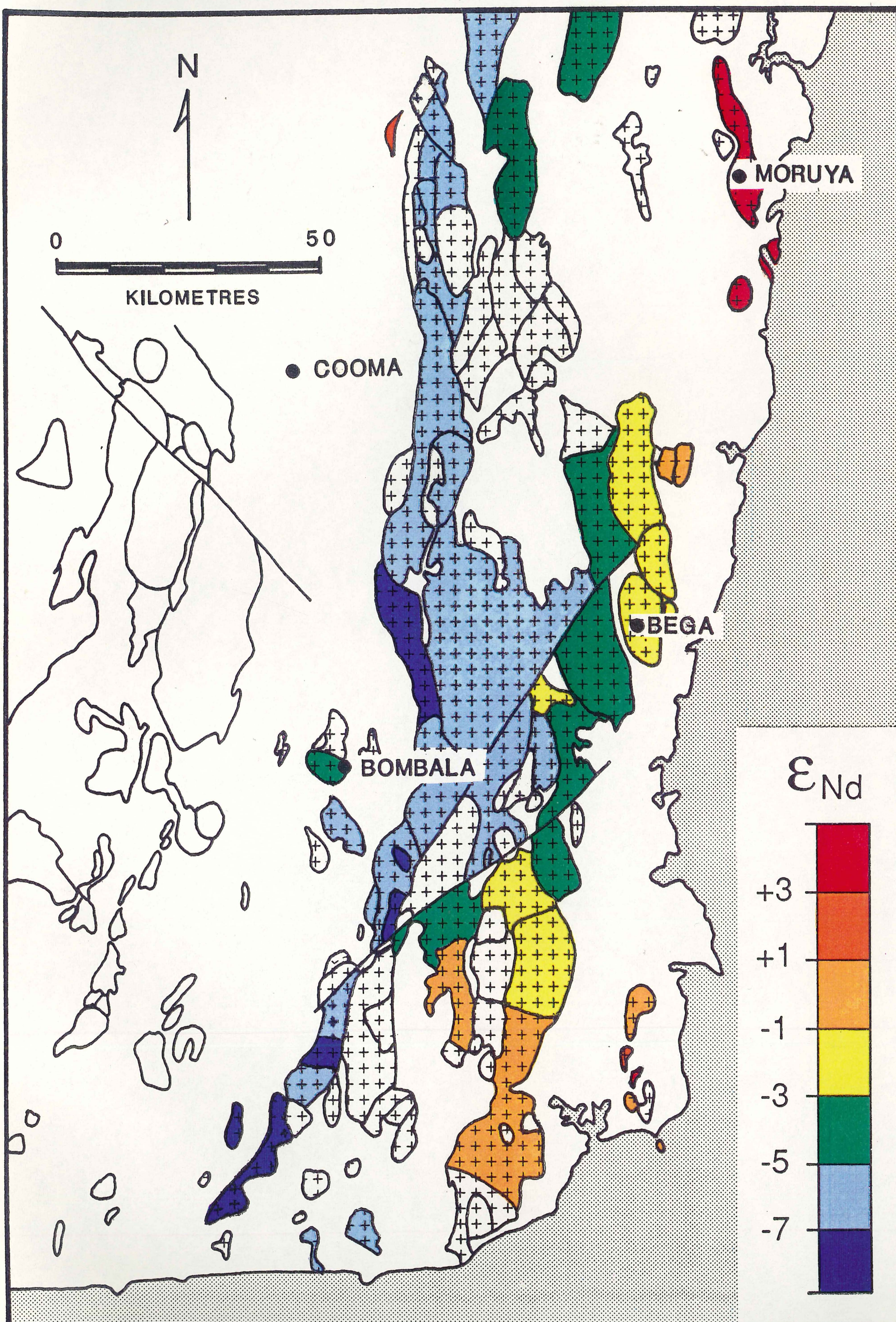
When they reached the mountain's summit, even Clancy took a pull—
    It well might make the boldest hold their breath;
The wild hop scrub grew thickly, and the hidden ground was full
    Of wombat holes, and any slip was death.
But the man from Snowy River let the pony have his head,
    And he swung 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.



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