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Field Excursion Guide

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REDUCED GRANITES AND VOLCANICS OF THE CENTRAL VICTORIAN MAGMATIC PROVINCE

INTRODUCTION

GEOLOGICAL SETTING OF VICTORIA

The two main episodes in the geological history of Victoria were the Cambrian to Carboniferous evolution of the eastern Australian continental margin, and the Jurassic to present day opening of the Southern Ocean by the rifting of Australia from Antarctica. The Palaeozoic units are exposed in the Great Dividing Range extending east-west centrally across the state; the Mesozoic-Cainozoic component forms an east-west coastal strip.

The Palaeozoic basement of the Lachlan Fold Belt (LFB) is subdivided into numerous tectonic zones of north-south strike; the zones of central Victoria which are pertinent to the excursion can be taken as typical (Fig. 1). From west to east these zones are:

(a) Bendigo-Ballarat zone

Early to mid-Ordovician turbidites – quartz-rich sandstone, shale and mudstone. The boundary with the Melbourne zone is the eastern side of the fault-emplaced Cambrian Heathcote Greenstone Belt consisting of tholeiitic rocks with lesser boninite, andesite and volcanogenic sediment.

(b) Melbourne zone

Late Ordovician to Middle Devonian turbidites, sandstone to mudstone, tending locally to shallow water limestone in the youngest parts. The interface with the Tabberabbera zone contains the Mount Wellington Greenstone Belt with similar lithologies to the Heathcote Greenstone Belt. Unconformable on these rocks are fluviatile sedimentary rocks of Late Devonian to Carboniferous age.

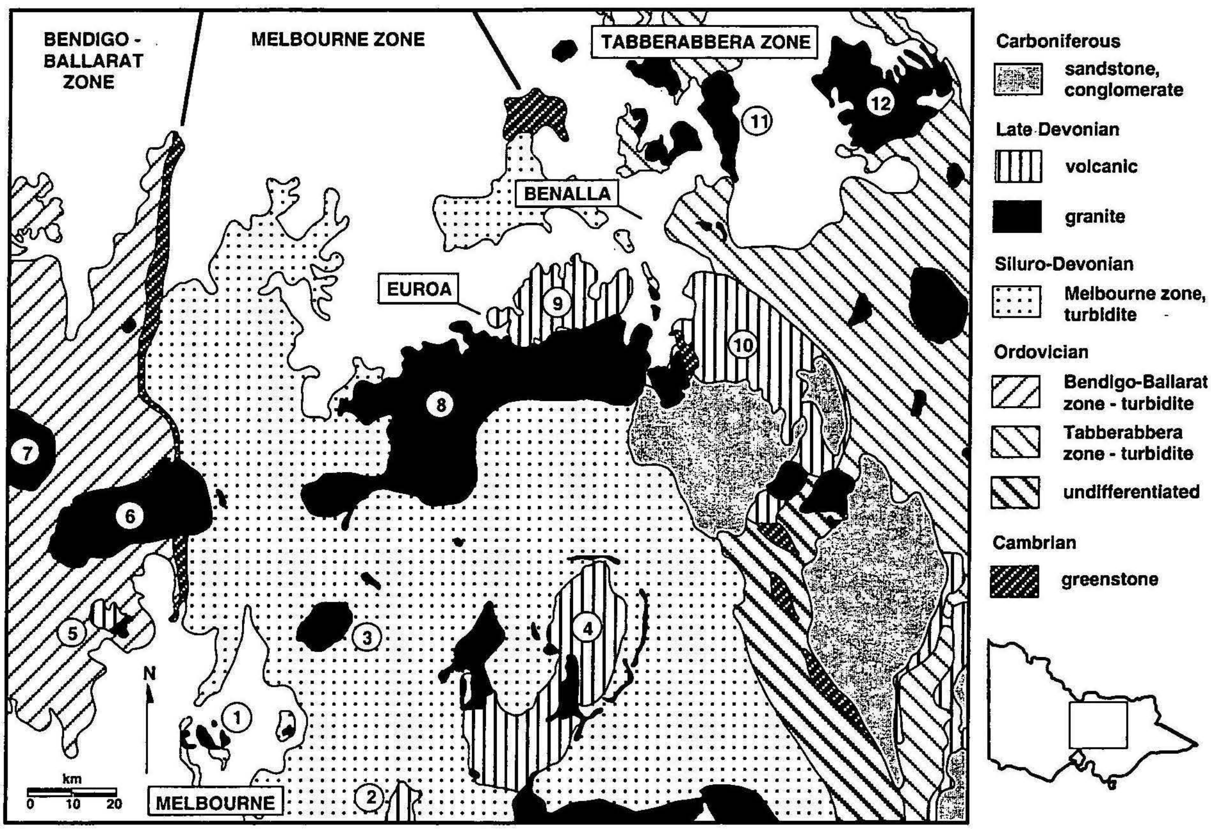
(c) Tabberabbera zone

Ordovician turbidites are quartz-rich sandstone, shale (commonly black) and mudstone. Fossils are mainly Late Ordovician.

All three zones are intruded by Late Devonian granitic rocks, and some localities also have equivalent volcanics, of the Central Victorian Magmatic Province.

The Palaeozoic tectonic environment in central Victoria is much argued, but in its broadest terms is part of the orogenic continental margin of Gondwana beginning as a Cambrian marginal sea, converting to a massive turbidite fan in the Ordovician. Turbidites also dominated the Silurian and Devonian of central Victoria. Deformation due to a predominantly east vergent thrust system terminated by the mid-Devonian. Post-tectonic conditions prevailed by the Late Devonian when there was extensive acidic magmatism producing the granites and associated volcanics of the Central Victorian Magmatic Province. Carboniferous fluviatile sedimentation adjacent to the boundary between the Melbourne and Tabberabbera zones was the last phase.

During the Mesozoic, an extensional tectonic setting developed across southern Victoria leading to the breakup of eastern Gondwana and the initiation of sea-floor spreading between Australia and Antarctica. The initial rift valley phase in the Early Cretaceous produced a thick sequence of fluviatile sandstone, and was followed by a period of limited sea-floor spreading from about 90 Ma allowing the establishment of marginal and intermittently marine conditions during the Late Cretaceous. Subsequent rapid sea-floor spreading from the Eocene led to marine sedimentation to the present day.



1 - Bulla granite; 2 - Dandenongs Igneous Complex; 3 - Mount Disappointment granite; 4 - Marysville Igneous Complex; 5 - Mount Macedon Complex; 6 - Cobaw Batholith; 7 - Harcourt Batholith; 8 - Strathbogie Batholith; 9 - Violet Town Volcanics; 10 - Tolmie Igneous Complex; 11 - Warby Range Batholith; 12 - Pilot Range Batholith

Figure 1: Central Victorian tectonic zones and geological units.

THE CENTRAL VICTORIAN MAGMATIC PROVINCE

The Central Victorian Magmatic Province encompasses the majority of granitic and equivalent volcanic rocks arrayed along regional strike from the Ballarat district in the west to the Wangaratta area in the east.

The province is of Late Devonian age and includes cordierite granites, garnet granites, rare andalusite granites, as well as hornblende granites. Cordierite granites have been known at least since 1925 (Tattam, 1925). Andalusite was described in a granite from the northwest part of the province by Hills (1941).

Almost all of the granites of the province crystallised in near surface, subvolcanic environments. Evidence for this is the common association of related volcanics, the presence of miarolitic cavities in many of the granites, the quartz-feldspar intergrowth textures (granophyric texture) and/or porphyritic texture of some granites. The following examples illustrate the style of occurrence as a function of level of exposure.

(a) purely volcanic – the Tolmie Igneous Complex, three major ignimbrite sheets (described below).
(b) volcanic-plutonic areas – e.g. Marysville Igneous Complex, Dandenongs Igneous Complex, Mt Macedon Complex, Strathbogie Batholith and related Violet Town Volcanics. The Marysville Igneous Complex comprises two impinging cauldron subsidence structures containing rhyolitic ignimbrite sheets with thicknesses up to 1000m. The northern cauldron is substantially surrounded by a ring dyke of porphyritic garnet granite. Part is intruded by granitic plutons.
(c) granitic batholiths – e.g. Cobaw and Harcourt Batholiths (the first visited on the excursion); large areas of granite with several, and sometimes many, internal phases.
(d) individual plutons – e.g. Bulla (described below), Mt Disappointment, South Morang, all of which appear to be emplaced at random across central Victoria independent of regional tectonic strike.

All granites of the province are reduced with Fe^{3+}/Fe^{2+} extremely low. Ilmenite is the dominant, or only, opaque oxide phase. As a result of the low oxidation state there is no difference in colour between K-feldspar and plagioclase in unweathered samples – both are colourless or white in hand sample and commonly difficult to distinguish. Because of this we use the general term granite throughout this guide. Reduced granites always have red-brown biotites easily distinguished from the chocolate-brown biotites of granites crystallised from oxidised magmas. The colour of the biotites is more readily determined if flakes are prized off biotite crystals. Calculated oxygen fugacities of pristine granites are lower than in any other province within the Lachlan Fold Belt.

Another chemical feature of the province is the high Ba in all granites except for those which have been produced by crystal fractionation involving K-feldspar. When K-feldspar crystals are sufficiently large for the crystal to be examined for oscillatory zoning, high Ba granites (around 1000 ppm Ba) can be determined in hand specimen: Ba substituting for K in K-feldspar forms prominent zones.

Isotopic ages from numerous rocks in the province are constrained within the 360-370 Ma interval making them some of the youngest granites of the Lachlan Fold Belt. Maximum initial $^{87}Sr/^{86}Sr$ ratios are decidedly lower than in other parts of the fold belt. Considering the most peraluminous rocks, maximum initial ratios in central Victoria are 0.712, whereas to the east of the Tabberabbera zone initial ratios are as high as 0.720. This is interpreted to indicate a distinctive, isotopically relatively primitive component in the metasedimentary source (Gray, 1990).

The route of the excursion and the locations of STOPS are indicated on Figure 2. Notes for the first day of the excursion are largely taken from the second Hutton Symposium excursion guide (Chappell et al., 1991).

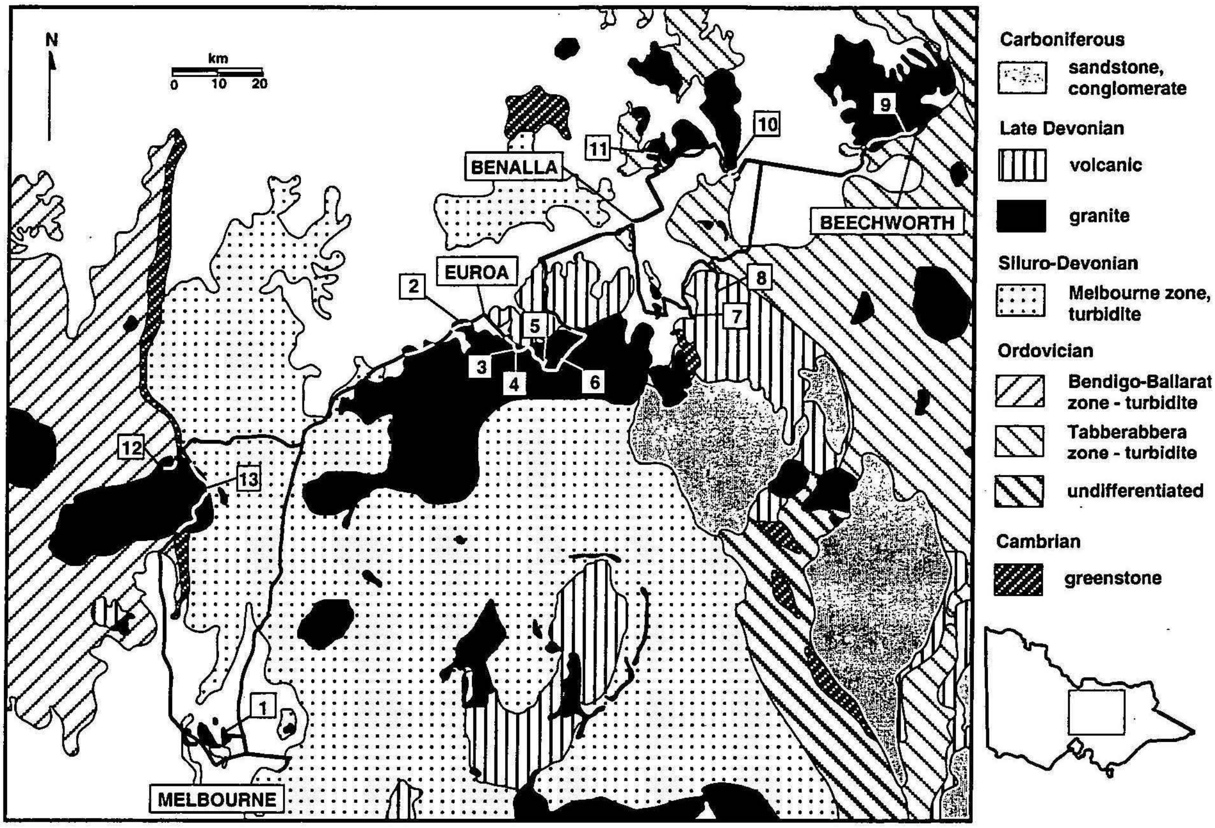


Figure 2: Route of the excursion.

EXCURSION ITINERARY

FIRST DAY: MELBOURNE TO BEECHWORTH

LA TROBE UNIVERSITY TO BROADMEADOWS

The route traverses the northern suburbs of Melbourne across ~1 Ma-old tholeiitic basalts of the Plains Subprovince of the Newer Volcanics Province. The route is Plenty Road to the northeast, then left into the Western Ring Road continuing to the Hume Highway exit. Take the Hume Highway 5km northward to Somerton Road. Travel westward along Somerton Road to a road cutting 1km west of the intersection with Pascoe Vale Road. See the detailed location information for STOP 1.

BULLA CORDIERITE GRANITE

The Bulla granite may be seen from the air on approach or departure from Tullamarine airport. The airport is on a low dissected plateau covered by thin Cainozoic basalts. The granite is exposed in part in the stream channels cut through the basalt. By projection of the boundary beneath the basalt cover, the pluton is estimated to have an area of 51km^2. Three zones have been mapped within the pluton. The outer zone, to be examined on the excursion, is rich in cordierite, whereas the inner zone granite is so poor in cordierite that this mineral is rarely seen in thin sections. The inner phase is also porphyritic. A contact, not exposed, is said to occur between the inner and intermediate zones suggesting that there has been movement of the central magma relative to the outer. Exposures closest to the route along the Hume Highway are on the northern outskirts of Melbourne where they are being rapidly eroded by new housing developments.

Cordierite was first recorded in this granite by Tattam (1925), who also described cordierite in the adjacent hornfels. He considered that the cordierite in the granite resulted from contamination with these contact metamorphosed sediments. He suggested that cordierite was not stable in granite whereas its micaceous alteration products were, thus explaining the intense alteration seen in the cordierite.

Country rock contamination was also argued by Bryndzia (1976), who did not recognise the widely scattered cordierite in the central part of the pluton, and therefore considered it to be the uncontaminated part. The outer unit of the pluton that we shall examine, he considered the most contaminated because it contains cordierite and its enclaves commonly contain garnet. Bryndzia thought that the well-shaped cordierites resulted from recrystallisation of metamorphic cordierite.

STOP 1: BULLA CORDIERITE GRANITE
(Melbourne CU160320. Road cutting on Somerton Road 1km west of the intersection with Pascoe Vale Road and immediately before the intersection with McPherson Boulevard which enters from the northern side. In addition, good examples of altered cordierite may be seen in blocks used to construct a nearby homestead (now Homestead Community Centre – CU160326). To reach the building, travel along McPherson Boulevard to the roundabout at which Whiltshire Drive and Douglas Mawson Drive (very appropriate) are met. Turn into Whiltshire Drive and the Community Centre is on the left. Sample collection would be unwise.

In the road cutting, several unweathered surfaces are present in predominantly weathered material. Quartz occurs as large aggregates, 6-7 mm across, consisting of several individuals with weak undulose extinction and triple junctions. Plagioclase cross sections are crudely rectangular with good crystal shapes when in contact with K-feldspar. There are no well-defined cores, but compositions range from near An_{60} down to outer zones near An_{20}. Superimposed oscillatory zones are as abundant as any seen in the Lachlan Belt: at least 25 oscillations were found in one crystal. K-feldspar is microperthitic and appears as large crystals up to 10mm across that include other minerals. Biotite (α=pale straw, β=γ=red-brown) is mostly 1-2mm, rarely shows any crystal shape, and is rarely altered. Crystals that are altered are almost completely replaced by pale green chlorite that may contain rods and needles of rutile. Large, crudely rectangular cross sections of cordierite (10mm long) are widely scattered and altered to sericitic aggregates with cores of pale yellow pinite. There are some sheaves of muscovite in which individual well-defined crystals are up to 0.5mm: they are considered secondary. Apatite is seen as stumpy prisms averaging 0.1mm across and opaque minerals are seen to be common, particularly as inclusions in biotites: there are many hexagonal shaped cross sections and a few rod-shaped sections, suggesting that ilmenite predominates. Zircons are prominent. Enclaves containing cordierite, and more rarely garnet, are present.

The inner granite contains almost identical iron (FeO* = 3.70 %) and aluminium (Al_2O_3 = 14.91) to the outer more cordierite-rich type (FeO* = 3.66%, Al_2O_3 = 14.81). The higher CaO (2.93%), Na_2O (2.98 %) and K_2O (3.79 %) in the inner part limit the amount of cordierite that crystallises.

<u>Chemical analysis of an outer zone Bulla granite</u> (CV108; Chappell et al., 1991).

Major Elements (wt %)		Trace Elements (ppm)		Modal Minerals	
SiO_2	68.48	Ba	1050		
TiO_2	0.65	Rb	167		
Al_2O_3	14.81	Sr	154		
Fe_2O_3	0.06	Pb	24		
FeO	3.61	Th	16	quartz	35.7
MnO	0.05	U	4	plagioclase	34.1
MgO	1.33	Zr	228	K-feldspar	16.2
CaO	2.45	Nb	13	biotite	9.5
Na_2O	2.66	Y	30	cordierite	2.9
K_2O	3.57	Ce	67	muscovite	1.1
P_2O_5	0.20	Sc	12	opaques	0.2
H_2O^+	1.13	V	61	apatite	0.2
H_2O^-	0.13	Cr	29	zircon	tce
CO_2	0.37	Ni	13		
		Zn	79		
Total	99.50	Ga	19.6		

fO_2 calculated using the method of Kilinc et al. (1983): Δ NNO = - 3.0 (850° C and 1kb).

BULLA TO EUROA

Return eastward along Somerton Road to the Hume Highway. The highway trends northward across the young basaltic field to the vicinity of Wallan. Two prominent extinct volcanoes are located to the east of the highway superimposed on the tholeiitic plain. Bald Hill is basanite and Mt Fraser at Beveridge is hawaiite. Beyond Wallan, the Palaeozoic basement comprises Silurian and Devonian turbidites. At Tallarook, granite boulders of the Strathbogie Batholith are visible on the range to the east. Road cuttings immediately south of Seymour, before the Goulburn River is crossed, are in prominently bedded Devonian turbidites. Beyond Seymour, 9.3km north of the Goulburn River, the highway crosses the contact of the southwestern lobe of the Strathbogie Batholith, which then dominates the view to the east of the highway. STOP 2 is located on the northwestern side of the highway near the culmination of a gentle rise between the 143 and 144km markers; the site is at a vehicle layoff ~150m before the road sign 'C312 Euroa Exit 1km' and the granite boulders are near the rubbish bin(!).

STRATHBOGIE BATHOLITH

The Strathbogie granite is a large (1510 km^2) body, or batholith, of cordierite granites. The batholith (Phillips et al., 1981) has not been completely subdivided into separate intrusive units (plutons) although two separately mapped units are examined on the excursion. Overall, the batholith has an irregular shape essentially composed of rectilinear segments with north-south and east-west contacts and an east-west extent of 100km, cross-cutting the regional strike. The majority of the contact imposes a metamorphic aureole on the regional turbidites (described in the Bonnie Doon area by Phillips and Wall, 1980), excepting a northern segment intrusive into the Violet Town Volcanics. K-Ar ages are in the 357-354 Ma range (Richards and Singleton, 1981).

STOP 2: STRATHBOGIE GRANITE
(Euroa CV682294. Broken boulders on the northwestern side of the Hume Highway at a layoff on a gentle crest between the 143 and 144km markers where the highway enters granite exposures 5km southwest of Euroa)

This outcrop is typical of the more mafic parts of the Strathbogie Complex. It is a coarse-grained granite with some grey to white K-feldspar crystals up to 20mm long, and buff coloured quartz up to 5mm across. Biotite crystals, some with good shapes, have the characteristic red-brown colour of a reduced granite. Cordierites are prominent, but are almost entirely altered to a dark grey material, which is dull in contrast to the biotites. Rare garnets, surrounded by altered cordierite, are present. There are some patches of biotite + quartz thought to be altered orthopyroxene crystals. Sheaves of black tourmaline may be found.

<u>Chemical analysis of Strathbogie granite</u> (CV142; Chappell et al., 1991).

Major Elements (wt %)		Trace Elements (ppm)			
SiO_2	70.13	Ba	860		
TiO_2	0.52	Rb	185		
Al_2O_3	14.23	Sr	126	Modal Minerals	
Fe_2O_3	0.18	Pb	23		
FeO	3.09	Th	14.6	quartz	30.9
MnO	0.05	U	3.4	plagioclase	26.3
MgO	1.04	Zr	184	K-feldspar	24.5
CaO	1.96	Nb	12.0	biotite	11.2
Na_2O	2.53	Y	36	cordierite	2.5
K_2O	4.11	La	25	garnet	tce
P_2O_5	0.16	Ce	59	muscovite	4.0
H_2O^+	1.03	Nd	22	opaques	0.3
H_2O^-	0.13	Sc	11	apatite	0.3
CO_2	0.02	V	42	zircon	tce
rest	0.21	Cr	22		
		Co	9		
Total	99.39	Ni	10		
		Cu	8		
		Zn	65		
		Ga	18.8		
		As	3.0		
		Sn	8		

fO_2 calculated using the method of Kilinc et al. (1983): Δ NNO = - 2.6 (850° C and 1kb).

The Hume Highway is left via the Euroa exit. After crossing Seven Creeks in the town a right turn is taken signposted Strathbogie, ~100m beyond the bridge. Kilometre values for this stage are from the intersection. On leaving Euroa outcrops on the hills to the east seen for the next few kilometres are Violet Town Volcanics. These are intruded by the Strathbogie Batholith with the contact 8 km from the highway. At ~7.5km the climb into the range begins and prominent granite outcrops and cuttings commence. Proceed past the sign 'Kelvin View Fire Station 5km' and at 10.5km stop at the large road cutting with a prominent vertical face situated on the southern side of the road.

STOP 3: FELSIC STRATHBOGIE GRANITE OF KELVIN VIEW

(Euroa CV792252. Prominent road cutting 10.5km along the Euroa-Strathbogie Road from its commencement in Euroa)

The view northwest is along the valley of Seven Creeks which divides the Strathbogie Batholith on the southwest, from the Violet Town volcanics to the northeast.

Chemical analysis of felsic granite (CV114; Grid Ref. CV787247; Chappell et al., 1991).

Major Elements (wt %)		Trace Elements (ppm)	
SiO_2	76.35	Ba	64
TiO_2	0.08	Rb	326
Al_2O_3	12.88	Sr	17.5
Fe_2O_3	0.02	Pb	24
FeO	1.01	Th	5.6
MnO	0.05	U	9.4
MgO	0.16	Zr	54
CaO	0.54	Nb	7.0
Na_2O	3.02	Y	20
K_2O	4.82	La	5
P_2O_5	0.13	Ce	14
H_2O^+	0.54	Nd	5
H_2O^-	0.11	Sc	4
CO_2	0.01	V	3
rest	0.08	Cr	2
		Co	3
Total	99.80	Ni	1
		Cu	<1
		Zn	41
		Ga	16.2
		As	10.0
		Sn	15

Modal Minerals	
quartz	29.2
plagioclase	19.8
K-feldspar	44.3
biotite	2.4
cordierite	1.2
muscovite	3.1
opaques	tce
apatite	tce
zircon	tce
tourmaline	tce

fO_2 calculated using the method of Kilinc et al. (1983): Δ NNO = - 4.8 (850° C and 1kb). Because of the low total Fe, there is probably a large error in this value.

Kelvin View is a small felsic intrusion on the northern margin of the batholith. This, and sample CV142 of STOP 2, encompass almost all of the compositional variation within the batholith. Quartz and feldspar have an aplitic texture. Notice the grey colour of the feldspars and the red-brown colour of the biotites, again indicating that the rock is reduced. Cordierite crystals are locally apparent, particularly in outcrop and blocks across the road from the cutting wall. There are irregular patches of tourmaline up to 20mm across with prominent leucocratic haloes.

Continue along the Euroa-Strathbogie Road for ~1km from STOP 3 to Quaile's Road. On the northern sector of the intersection there are abundant broken boulders of Violet Town Volcanics. Abundant vehicle parking space can be had a short distance down Quaile's Road.

VIOLET TOWN VOLCANICS

Like many of the granites of the Lachlan Fold Belt, the Strathbogie granite is associated in space and time with volcanics. The cordierite garnet rhyolites of the Violet Town Volcanics were erupted as pyroclastic flows and occur as large sheets. Their composition is aligned with the variation trends of the granites: they belong to the same supersuite as the Strathbogie granites.

The Violet Town Volcanics (White, 1954; Clemens and Wall, 1984) extend along the northern contact of the Strathbogie Batholith for ~30km eastward from Euroa with an outcrop width of ~10km. The single cooling unit of rhyodacite and rhyolite is a sheet 430m thick predominantly with a shallow northerly dip of 5-15° steepening to as much as 80° toward the intrusive contact of the Strathbogie Batholith. Hornfels xenoliths are common. Felsic schlieren are discrete bodies mineralogically similar to the host, but coarser grained than, and with clear contacts against it. Chemically identical to the host, the schlieren are considered fragments of early-crystallised rock from the same magma.

STOP 4: VIOLET TOWN VOLCANICS

(Euroa CV799251. Boulders at the intersection of Euroa-Strathbogie Road and Quaile's Road)

The site is in an heterogeneous and contact metamorphosed form of the Violet Town Volcanics with abundant schlieren and some xenoliths. Rocks from this region adjacent to the contact with the Strathbogie granite have phenocrysts of quartz, plagioclase and biotite in a fine felsic groundmass of quartz, K-feldspar and plagioclase. Cordierite is mainly as clusters of small, equidimensional grains often as coronas to garnet. Orthopyroxene is absent. Contact metamorphism by the Strathbogie granite is very apparent in the clean polygonal groundmass and the cuspate margins of many phenocrysts engendered by recrystallisation of the adjacent groundmass.

The following is a description of the widespread, more homogeneous form of the Violet Town Volcanics away from the contact. In hand-sample, the rocks are generally dark grey and even-grained. Crystals of garnet, some as large as 5-10mm across, may be found in unweathered hand-samples. Study of a weathered surface can help in the recognition of some of the features seen under the microscope. In thin section there are large crystals, mostly 0.5-2mm across, of quartz, plagioclase, biotite, orthopyroxene, cordierite and garnet, set in a fine-grained matrix consisting dominantly of small, but more-or-less equigranular grains of quartz and alkali feldspar about 0.03mm in diameter. Scattered small crystals of biotite are easily recognised in the matrix, but it is impossible to identify cordierite and there appears to be no matrix orthopyroxene. The large plagioclase crystals may be surrounded by alkali feldspar sieved with matrix-sized quartz grains, and large quartz grains may be surrounded by a rim of quartz sieved with matrix-sized alkali feldspar. Quartz, which dominates the phenocryst assemblage, may be in crystals 5mm across; it is mostly irregular or angular in shape, although rarely there are crude hexagonal shapes. Embayments indicative of resorption are present on some quartz crystals.

Plagioclase crystals display many faces, but many crystals have clearly been broken, as indicated by irregular boundaries on part of a perfect crystal, or by the abrupt termination of zones present within some crystals. Although oscillatory zoning is seen on some sections of plagioclase, that mineral appears to be mostly uniform in composition near An_{50}-An_{55}. Biotite (α=pale yellow, β=γ=red-brown) is irregular in shape. Most of the larger biotite crystals have a paler coloured outer zone that is crowded with tiny grains of opaque mineral. The orthopyroxene crystals are irregular in shape and commonly show evidence of partial replacement by biotite. Cordierite is remarkably unaltered and hence it is very difficult to distinguish from quartz, except for the presence of tiny veinlets or cracks, particularly around the grain boundaries, in which the normal colourless cordierite shows a slight greenish discolouration; rare cordierite crystals contain tufts of sillimanite needles. The garnets seen in thin-section are small (about 1mm) and irregularly-shaped; they are always surrounded by unaltered cordierite in which there is an intergrowth of wormy orthopyroxenes. Some accessory apatites, zircons, and opaque minerals are distinctly larger (up to 0.3mm) than the matrix grains. At least some of the opaque mineral grains have the hexagonal shape of ilmenite. Monazite is an accessory mineral.

<u>Chemical analysis of Violet Town Volcanics</u> (LTU7457; Lim, 1984).

Major Elements (wt %)		Trace Elements (ppm)		
SiO_2	67.86	Ba	1021	
TiO_2	0.64	Rb	158	
Al_2O_3	15.38	Sr	184	Modal Minerals
Fe_2O_3	0.48	La	34	
FeO	3.34	Ce	57	quartz
MnO	0.07	V	72	plagioclase
MgO	1.46	Cr	35	K-feldspar
CaO	2.80			biotite
Na_2O	2.56			cordierite
K_2O	3.78			garnet
P_2O_5	0.19			
H_2O^+	0.47			
H_2O^-	0.10			
CO_2	0.00			
Total	99.13			

Broken crystals are the only petrographic evidence for this rock having an ash-flow origin. There are no relict shards and the matrix appears to have been recrystallised, perhaps as a result of contact metamorphism by the Strathbogie granite. The mineral assemblage except for orthopyroxene, is like that of the Strathbogie granites in which the orthopyroxene would have reacted to biotite on cooling. These data suggest that petrographically and chemically the Violet Town Volcanic rocks are co-magmatic with the Strathbogie granites. However, there are differences in initial Sr isotopic composition (Gray, 1990 gives values for initial $^{87}Sr/^{86}Sr$ of 0.712 for a granite and 0.708 for a volcanic rock). These isotopic differences are one of the reasons why we regard the volcanics as the same supersuite as the Strathbogie granites.

Continue along the Euroa-Strathbogie Road into the outskirts of Strahbogie. Just before the main street the road crosses Spring Creek, which can be identified by the Spring Creek Road sign. Turn into Spring Creek Road and proceed for 2.5km to a prominent slab-like exposure on the western side of the roadside.

STOP 5: PORPHYRITIC STRATHBOGIE GRANITE
(Euroa CV881224. Granite pavement on the western side of Spring Creek Road, 2.5 km from the junction with Euroa-Strathbogie Road in Strathbogie)

Good crystals of unaltered cordierite may be found at this locality. The porphyritic fabric of this rock is considered to have been produced by pressure quenching due to H_2O loss (Phillips et al. 1981). Loss of H_2O prevented the reaction of the cordierite to micas as the granite cooled.

<u>Chemical analysis of porphyritic Strathbogie granite</u> (CV125; Chappell et al., 1991).

Major Elements (wt %)		Trace Elements (ppm)			
SiO_2	75.32	Ba	115		
TiO_2	0.12	Rb	299		
Al_2O_3	13.01	Sr	31.0	Modal Minerals	
Fe_2O_3	0.08	Pb	24		
FeO	1.11	Th	6.8	quartz	33.4
MnO	0.05	U	10.2	plagioclase	16.6
MgO	0.25	Zr	69	K-feldspar	46.3
CaO	0.78	Nb	7.5	biotite	1.4
Na_2O	2.92	Y	21	cordierite	1.0
K_2O	4.58	La	7	muscovite	1.2
P_2O_5	0.13	Ce	18	opaques	0.1
H_2O^+	0.66	Nd	6	apatite	tce
H_2O^-	0.23	Sc	5	zircon	tce
CO_2	0.01	V	7		
rest	0.08	Cr	5		
		Co	4		
Total	99.33	Ni	2		
		Cu	2		
		Zn	42		
		Ga	16.0		
		As	4.5		
		Sn	19		

CV125 has a very low (0.08% Fe_2O_3) Fe^{3+} content; fO_2 is about 2 log units below QFM according to Phillips et al. (1981). This is equivalent to Δ NNO = - 3.

fO_2 calculated using the method of Kilinc et al. (1983): Δ NNO = - 2.2 (850° C and 1kb).

All common granite minerals have large crystals, quartz as buff coloured individuals commonly 10mm across, K-feldspars up to 20mm and plagioclases up to 10mm, as well as large cordierites and biotites in a matrix of the same minerals having a much smaller grain size (averaging about 0.4mm). The K-feldspar is perthitic orthoclase which is more than twice as abundant as plagioclase. Plagioclase mostly shows normal zoning with a range in composition from An_{45} to An_{20}; that in the matrix is in the composition range An_{25} to An_{20}. Cordierite is variously altered. Some is replaced completely by an aggregate of greenish biotite and muscovite, and some is pseudomorphed by both micas and pinite. Both the large cordierites and those in the matrix, may occur as perfectly shaped crystals. A few isolated muscovite flakes also occur throughout the matrix and are considered secondary. Biotite (α=pale yellow; β=γ=red brown) appears as ragged crystals commonly including tiny zircons and monazites around which are prominent pleochroic haloes. Apatites are relatively large stumpy prisms up to 0.5mm long whereas rare opaque minerals, pyrrhotite and ilmenite are tiny and are also commonly included in biotite.

Return to Strathbogie and the intersection of Spring Creek Road and Euroa-Strathbogie Road. Follow the main road southward through Strathbogie (it now becomes Strathbogie-Merton Road), crossing Smith's Bridge, and travel for 2.5km to the intersection with Tame's Road. Proceed into Tame's Road, the direct continuation of this road segment, leaving the Strathbogie-Merton Road, which curves to the right. Continue for 1.7km to an intersection. Turn left into the road signposted 'Violet Town 31km' (actually Benalla Road) and travel for 2.9km along this road until ~30m past the side road, Brookleigh Road. Granite boulders are on the left hand side of Benalla Road.

STOP 6: GARNET-BEARING STRATHBOGIE GRANITE
(Euroa CV913210. Boulders on the left hand side of Benalla Road near the intersection with Brookleigh Road)

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

<u>Chemical analysis of garnet-bearing Strathbogie granite</u> (CV126; Chappell et al., 1991).

Major Elements (wt %)		Trace Elements (ppm)		
SiO_2	70.54	Ba	700	
TiO_2	0.49	Rb	237	
Al_2O_3	13.90	Sr	102	Modal Minerals
Fe_2O_3	0.21	Pb	23	
FeO	2.93	Th	15.0	quartz
MnO	0.06	U	3.8	plagioclase
MgO	1.01	Zr	182	K-feldspar
CaO	1.66	Nb	11.5	biotite
Na_2O	2.43	Y	34	cordierite
K_2O	4.27	La	25	garnet
P_2O_5	0.18	Ce	59	muscovite
H_2O^+	1.01	Nd	21	opaques
H_2O^-	0.16	Sc	11	apatite
CO_2	0.01	V	41	zircon
rest	0.23	Cr	25	
		Co	9	
Total	99.09	Ni	11	
		Cu	4	
		Zn	67	
		Ga	18.6	
		As	6.5	
		Sn	10	

fO_2 calculated using the method of Kilinc et al. (1983): Δ NNO = - 1.7 (850°C and 1kb).

STRATHBOGIE AREA TO TATONG

Continue northeastward from STOP 6 along the road towards Violet Town, turning left at Watkins Road (signposted Euroa 27km). Turn right into Boundary Hill Road (Violet Town 25 km). Turn left at Boho Hall and go 7km to Harrys Creek Road and continue to Violet Town. Between Boho Hall and Harrys Creek Road junction, the granite contact is crossed and outcrops of Violet Town Volcanics are encountered. The description of an unmetamorphosed sample of Violet Town Volcanics is from the road cutting 1.2 km along Harrys Creek Road. Watch for koalas in this area. The route continues northeastward on the Hume Freeway to the Midland Highway exit on the outskirts of Benalla (Mansfield B300). The stages that follow are: B300 southward to Swanpool; left turn at Swanpool signposted Tatong continuing to a T-junction and left turn at Moorngag cemetery; after 3.6km (near a Catholic Church) veer right to Tatong. At Tatong turn right at the cross-roads and proceed 3km southeast on the Tatong-Tolmie Road. The site is a road cutting on the eastern side of the road ~40m south of the 3km road marker.

TOLMIE IGNEOUS COMPLEX

The Late Devonian Tolmie Igneous Complex (Brown, 1961; Gaul, 1982) is primarily exposed in the Tolmie Highlands as a triangular area 25km a side. The northeastern margin is faulted against Ordovician sedimentary rocks; the western margin is complex, partly fault-controlled by the Mount Wellington Greenstone Belt, and partly an artifact of the erosional limits of the volcanics on basement; the southern margin is concealed by Carboniferous conglomerate and sandstone of the Mansfield Basin with volcanics revealed in drainages which have incised the younger sequence. The complex was originally subdivided into three major acidic eruptives, the Hollands Creek Rhyodacite (chemically rhyolite), Ryans Creek Rhyolite and Toombullup Rhyodacite (Brown, 1961). Thicknesses are difficult to determine and Brown (1961) gives estimates of 1200, 600 and 1800m respectively, substantially greater than the ~200m values for exposed thicknesses of Gaul (1982).

The complex commenced with the formation of grabens on its western side, which partially filled with fluviatile conglomerate before eruption of the Hollands Creek Rhyolite. The Ryans Creek Rhyolite, which is unconformable on the folded Hollands Creek Rhyolite, was emplaced complex-wide and grades upwards into the Toombullup Rhyodacite, with a drastic increase in plagioclase content. The Toombullup Rhyodacite is not visited by the excursion and is a homogeneous, grey ignimbrite with garnet, cordierite, orthopyroxene and fayalite.

TOLMIE IGNEOUS COMPLEX – HOLLANDS CREEK RHYOLITE

The following description of the Hollands Creek Rhyolite (rhyodacite in previous literature) is derived from Douglas (1985). The volcanics developed in two grabens; STOP 7 is in the southern graben. Prior to eruption, the grabens accumulated a basal conglomerate, dominated by quartzite and vein quartz clasts, with lesser sandstone and mudstone, deposited in a fluviatile environment.

The Hollands Creek Rhyolite extends over an area in excess of 70km^2. There is a subtle vertical variation in the unit with three subdivisions recognised, though the complete sequence is only in the southern graben. The basal unit is <20m thick with abundant fragments of basement greenstone and chert up to 5cm across. The intermediate unit (~120m thick) is most significant, lacks the fragments and is intensely welded with a black matrix. The upper subdivision (~20m thick) has a lighter grey matrix and is less welded. The matrix/phenocryst proportion increases up-sequence and the most significant mineralogical change is from the intermediate to upper units as a decrease in plagioclase, and increase in K-feldspar phenocrysts; internal chemical variation is minor. Categorisation as an ignimbrite is based upon fragmental phenocrysts and flattened pumice.

Subsequent to eruption the rhyolite in the southern graben was deformed into a syncline, and the Ryans Creek Rhyolite follows unconformably.

STOP 7: HOLLANDS CREEK RHYOLITE

(Whitfield DV213316. Broken boulders in a road cutting on the eastern side of the Tatong-Tolmie road immediately south of the 3km marker located south of Tatong)

The Hollands Creek Rhyolite has a fragmental texture in hand specimen with white, angular feldspar phenocrysts of all sizes down from 6mm. Quartz phenocrysts are less obvious, but nonetheless abundant and equidimensional, mainly rounded, but grading to angular. The crystal fragments are unevenly distributed in a very fine, dark grey matrix. Dark, fine grained fragments (up to 2cm) are usually after pumice, but also basement sedimentary rock. Microscopically, quartz phenocrysts vary from euhedral β-quartz shapes, to equant and rounded with occasional resorption re-entrants, to angular; larger phenocrysts have pronounced cracking. Feldspars are rectangular to angular. Biotite has invariably been altered to chlorite and opaque. Cordierite and garnet form rare, angular grains (<1mm), the former replaced by pinite. Pumice fragments vary from elongate, lenticular to highly irregular in shape. The matrix is predominantly ultrafine grained and hardly resolved by the microscope, scattered with small angular fragments from the phenocryst minerals.

Chemical analysis of Hollands Creek Rhyolite (LTU7851; Douglas, 1985).

Major Elements (wt %)		Trace Elements (ppm)		
SiO_2	74.12	Ba	845	
TiO_2	0.39	La	67	
Al_2O_3	12.86	Ce	50	Modal Minerals
Fe_2O_3	0.52	V	32	
FeO	2.24	Cr	20	quartz
MnO	0.06	Ni	12	plagioclase
MgO	0.69	Cu	8	K-feldspar
CaO	1.40	Zn	53	biotite
Na_2O	1.79			cordierite
K_2O	4.40			garnet
P_2O_5	0.13			
H_2O^+	1.12			
H_2O^-	0.11			
CO_2	0.22			
Total	100.02			

The label rhyolite clearly supplants rhyodacite given the high K_2O content.

TATONG TO MOLYULLAH

On returning to Tatong, the Benalla-Tatong Road is followed northward for 5.5km where the right branch of the Y-junction, the Molyullah-Tatong Road is taken. After 7km turn right into the road signposted Molyullah and take it to a T-junction. Turn left at the T-junction and proceed 0.8km to the cross-roads between O'Deas Road and Watchbox Road. Proceed directly on Watchbox Road. The next site is 7.4km from the cross-roads and visible to the east of the road as a small waterfall in Watchbox Creek. A T-junction with a bridge over Watchbox Creek is a short distance beyond the site.

TOLMIE IGNEOUS COMPLEX – RYANS CREEK RHYOLITE

The Ryans Creek Rhyolite has an estimated maximum thickness of 200m It is very distinctive in hand specimen with phenocrysts of pink, rectangular K-feldspar (2mm) and equidimensional quartz with rounded to β-quartz outlines (1mm) in a very fine grained pale cream to green matrix. Other occasional phenocrysts are rectangular, white plagioclase, variously altered to pale green, dark greenish alteration products after cordierite, and garnet. Rock fragments are limited to minor (<1cm) angular fragments of hornfels and quartzite.

Gaul (1982) gives a subdivision of the unit into: (a) basal zone characterised by minor plagioclase, tourmaline and a slightly higher phenocryst/groundmass ratio; (b) main zone with little or no plagioclase and the phenocryst/groundmass ratio increasing upward; and (c) a transition zone to the Toombullup Rhyodacite with plagioclase increasing upwards and the development of minor biotite.

STOP 8: RYANS CREEK RHYOLITE
(Outcrop in the bed of Watchbox Creek adjacent to a small waterfall)

Waterworn surfaces present the typical porphyritic texture with quartz and K-feldspar phenocrysts. Locally, euhedral cordierite and rare garnet phenocrysts, tourmaline patches and hornfels xenoliths are visible. The matrix at this site is more altered than usual.

Microscopically, quartz phenocrysts range from well-defined β-quartz shape, to rounded, to angular, and are commonly bevelled with deep indentations due to resorption. Garnet phenocrysts are euhedral, and pinite pseudomorphs equant, and often euhedral, cordierite. Basal rocks have a well-preserved ultrafine matrix and vitroclastic texture including glass shards (illustrated by Birch, 1978). Otherwise the matrix is very fine, equigranular, felsic material suggestive of incipient recrystallisation; occasionally, tourmaline occurs in dense clusters of matrix-sized grains. Inclusion-laden secondary muscovite frequently overgrows the matrix.

Chemical analysis of Ryans Creek Rhyolite (average of 39 analyses; Birch, 1978)

Major Elements (wt %)		Trace Elements (ppm)		
SiO_2	75.06	Ba	849	
TiO_2	0.19	Rb	329	
Al_2O_3	12.65	Sr	51	Modal Minerals
FeO	1.31	Zr	190	
MnO	0.05			quartz
MgO	0.27			plagioclase
CaO	0.30			K-feldspar
Na_2O	2.80			biotite
K_2O	5.06			cordierite
P_2O_5	0.14			garnet
Loss	1.72			
Total	100.25			

The average analysis is characterised by high SiO_2 (75%) and K_2O (5.1%) and very low MgO (0.3%), CaO (0.3%) and Sr (50 ppm). These data suggest fractional crystallisation involving plagioclase. However, Ba is very high for a fractionated rock and is possibly the result of K-feldspar accumulation.

MOLYULLAH TO BEECHWORTH

Returning to the cross-roads, O'Deas Road is followed to the right to a T-junction, with a further right turn into Kilfeera Road signposted to Wangaratta. At the next Y-junction again follow the signpost to Wangaratta. At the Greta South intersection take the right hand road signposted Wangaratta. Subsequently, the road curves northward as Wangaratta-Kilfeera Road through Greta to the intersection with Glenrowan-Myrtleford Road. A right turn is taken to Milawa and Markwood. At Markwood the route deviates along Everton-Markwood Road crossing the Ovens River to Everton. Turn right into Everton along the Ovens Highway and within the township turn left into the road signposted Beechworth. Take this road to intersect the Beechworth-Wangaratta Road, which is followed to Beechworth

SECOND DAY: BEECHWORTH TO MELBOURNE

Leave Beechworth retracing the inward journey along Beechworth-Wangaratta Road. From the 100km per hour road sign on the outskirts of Beechworth proceed 1.9km to the intersection with Flat Rock Road which is STOP 9.

PILOT RANGE BATHOLITH

The Pilot Range Batholith (Young, 1983) has an almost square outline with sides 25km long. Although subdivided into several phases, contacts appear to be gradational. The majority of rocks have high SiO_2 (75-77%) and K_2O (>4.5%). The Beechworth granite has variants due to varying degrees of fractional crystallisation as well as hydrothermal alteration producing sericite, tourmaline and topaz. Commonly, there is a quench texture of phenocrysts of quartz and feldspar in a fine quartzofeldspathic groundmass. The batholith is significantly older than the other rocks of the excursion at 377 Ma.

STOP 9: BEECHWORTH GRANITE
(Albury DV683746. Road cutting in the northeast sector of the intersection of Flat Rock Road with Beechworth-Wangaratta Road)

The rock is felsic and porphyritic. There are large (up to 20mm long) crystals of white K-feldspar seen to be perthitic in thin section, lesser partly altered plagioclases with a composition mostly in the range An_{25-20} (up to 20mm), smoky quartz (5-10mm), and a few ragged red-brown biotites, mostly chloritised, in a fine grained matrix of the same minerals with a grainsize mostly in the range 0.5mm to 0.1mm. There is a suggestion of graphic intergrowths of quartz and feldspar around some of the large crystals. Some patches of muscovite occur in sheaves or as isolated flakes. In thin section most of the biotite (α=pale brownish yellow, β=γ= red brown) is seen to be altered to a pale greyish green chlorite accompanied by chunks of fluorite. ilmenite and irregularly shaped patches of what appears to be secondary monazite. A few isolated tiny crystals have the shapes of monazite. Zircon and apatite are both very rare accessory minerals.

Chemical analysis of a more mafic Beechworth granite (CV224; Chappell et al., 1991)

Major Elements (wt %)		Trace Elements (ppm)		Modal Minerals
SiO_2	73.93	Ba	405	
TiO_2	0.21	Rb	267	
Al_2O_3	13.47	Sr	93	
Fe_2O_3	0.19	Pb	28	
FeO	1.31	Th	19	quartz
MnO	0.04	U	9.8	plagioclase
MgO	0.30	Zr	127	K-feldspar
CaO	0.98	Nb	11.5	biotite
Na_2O	3.22	Y	40	muscovite
K_2O	4.87	La	26	ilmenite
P_2O_5	0.10	Ce	61	
H_2O^+	0.70	V	12	
H_2O^-	0.17	Cr	3	
CO_2	0.23	Ni	<1	
		Cu	3	
Total	99.72	Zn	39	
		Ga	18.4	
		Sn	15	

fO_2 calculated using the method of Kilinc et al. (1983): Δ NNO = - 0.93 (850°C and 1kb).

BEECHWORTH TO GLENROWAN

Continue westward along Beechworth-Wangaratta Road to the Everton turnoff and recapitulate the route of the first day Everton-Markwood-Millawa continuing along Glenrowan-Myrtleford Road to the Hume Highway. A short leg southward on the highway and the Glenrowan exit, lead to the centre of the township. Follow the Glenrowan Wine Region direction sign to cross the railway bridge. A further right turn at the T-junction into Old Hume Highway (also known as Warby Range Road) leads to the outskirts of the town and the turnoff into Kays Lane. STOP 10 is the quarry on private property beyond the end of the lane. Ask for permission at Lot 18. There is an access track to the quarry.

WARBY RANGES BATHOLITH

The small Warby Ranges Batholith (Eaton, 1984) is elongate north-south for 25km and up to 5 km wide tapering to the south. It forms the ridge of the Warby Range which extends northward from Glenrowan on the Hume Highway. There are six significant plutons characterised by high K-feldspar (>35%), with cordierite and garnet minor phases in several; the majority exhibit red-brown, reduced biotite. Tourmaline nodules and tourmaline aggregates on joint surfaces occur in several bodies. The plutons share high silica (74-78%) and K_2O (4.7-5.6%), with CaO <1.2%, and often <0.6%. Quartz veins are widespread and variously may contain minor amounts of pyrite, chalcopyrite, galena, cassiterite or fluorite. The large working quarry immediately south of Glenrowan is in the felsic Glenrowan Granite which gives biotite K-Ar ages of 368±15 Ma (Richards and Singleton, 1981) and 375±6 Ma (McKenzie et al., 1984).

STOP 10: WARBY SPRINGS GRANITE
(Wangaratta DV308657. Abandoned quarry, now private property – permission required from owner)

The Warby Springs granite (Eaton, 1984) is the distinctive, more mafic, cordierite-bearing granite of the batholith, a small pluton 2.5 x 0.8 km, located towards southern end of batholith in the environs of Glenrowan township. The mildly porphyritic, medium grained rock has a distinctive speckled dark-white appearance with indistinct phenocrysts of K-feldspar (<30mm) and quartz (<15mm) in medium grained quartz, K-feldspar, plagioclase, biotite (α=pale yellow; β=γ=deep red brown), and minor cordierite and garnet; there are occasional biotite aggregates (~10mm). Pinite after cordierite is very irregular in shape; garnet is also irregular and often intergrown with biotite. The granite in the quarry face is host to a small pod pegmatite with cavities.

Chemical analysis of Warby Springs granite (LTU7184; Eaton, 1984)

Major Elements (wt %)		Trace Elements (ppm)		Modal Minerals	
SiO_2	73.81	Ba	692		
TiO_2	0.24	La	35		
Al_2O_3	13.91	Ce	57		
Fe_2O_3	0.59	V	11		
FeO	1.93	Cr	3	quartz	36.3
MnO	0.06			plagioclase	8.7
MgO	0.42			K-feldspar	36.7
CaO	1.21			biotite	15.2
Na_2O	3.01			cordierite	0.8
K_2O	4.82			garnet	0.9
P_2O_5	0.17			opaques	0.8
H_2O^+	0.60				
H_2O^-	0.28				
CO_2	0.10				
Total	101.15				

GLENROWAN TO LAKE MOKOAN GRANOPHYRE

Return to Glenrowan and continue westward leaving the town on Old Hume Highway without deviating at the T-junction that leads to the railway bridge. Continue on the northern side of the railway for 1.3km from the T-junction to turn right into Taminick Road and proceed northward to Baileys Vineyard ('steak and onions in a bottle') corner. Turn left, and after ~1.5km, turn right into Glenrowan-Boweya Road, and ~4km northward turn left into Lake Mokoan Road. Take the road along the northern shore of the lake to the weir and turn right into the unsealed road which heads northwestward for 1km to a T-junction identifiable by the property name 'Hill Park'. Seek permission to enter the granophyre quarry from Mr Farley at Hill Park. From the 'Hill Park T-intersection' proceed eastward and then northward for 2.3km to a gate (which may be locked). The entry gate to the quarry is another 300m beyond on the left. There are several quarries in the area; STOP 11 is in the largest.

Immediately to the west of the Warby Ranges Batholith and north of Lake Mokoan poorly exposed granitic rocks illustrate near-surface crystallisation features.

LAKE MOKOAN GRANOPHYRE
Lake Mokoan granophyre is a small intrusion only about 1km across emplaced in the hornfels surrounding an adjacent granite. Hornfels is exposed in a quarry separate from the main granophyre quarry.

STOP 11: LAKE MOKOAN GRANOPHYRE
(Wangaratta DV114678. Quarry adjacent to the Hill Park property)

Quartz, seen as grains 1-4mm across or aggregates of several crystals that are a little larger, is mostly surrounded by areas of granophyric texture. Plagioclase, seen to be up to 10mm in hand sample, is very dusty with clay alteration products and appears to be weakly zoned oligoclase, but some is albitised. The K-feldspar is very fine perthite and some grains appear rounded. Some biotite crystals (α=pale yellow; β=γ=red brown) are seen as perfect hexagonal shapes mostly about 1mm across and many are altered to pale green chlorite. Small (up to 1.5mm across) rectangular-shaped

Chemical analysis of granophyre (CG184; B.W. Chappell, unpublished).

Major Elements (wt %)		Trace Elements (ppm)	
SiO_2	77.06	Ba	300
TiO_2	0.13	Rb	316
Al_2O_3	12.31	Sr	22
Fe_2O_3	0.27	Pb	27
FeO	0.53	Th	40.5
MnO	0.02	U	8.0
MgO	0.09	Zr	104
CaO	0.46	Nb	7
Na_2O	3.18	Y	47
K_2O	5.49	La	29
P_2O_5	0.02	Ce	64
H_2O^+	0.43	Nd	21
H_2O^-	0.10	Sc	5
CO_2	0.21	V	4
rest	0.13	Cr	<1
		Co	2
Total	100.43	Ni	1
		Cu	2
		Zn	23
		Ga	15.2
		As	19.0
		Sn	13

sections are pseudomorphs of fine-grained phyllosilicates, probably after an aluminosilicate. Relicts of topaz in optical continuity occur within a partially sericitised crystal. Tourmaline and a few muscovite flakes both up to 2mm across are interstitial to other grains. Small miarolitic cavities are readily seen in more weathered samples.

The red brown biotite suggests that this is a reduced rock. In a felsic rock such as this the Fe^{3+}/Fe^{2+} can be an unreliable indicator of oxidation state. Granophyric texture is common in many near surface felsic intrusions: it probably results from pressure quenching. The composition of the rock indicates that it has been produced by fractional crystallisation involving feldspars as indicated by the high Rb and low Sr. The low P_2O_5 indicates that this fractional crystallisation occurred in a weakly peraluminous magma. Consistent with this, the high Th and high Y indicate that monazite was not a fractionating mineral.

LAKE MOKOAN AREA TO TOOBORAC

Return to the T-junction adjacent to the weir and turn right. After ~2km turn left into the main road to Benalla. Take it to a T-junction with Benalla-Winton Road to the northeast of Benalla. Turn right and travel along C313 into Benalla and use road signs to locate the approach to the Hume Highway. The southwestward journey (Melbourne direction) on the Hume Highway is a long stage retracing the outward journey to beyond Seymour. On the Melbourne side of the Goulburn River there is an exit to Tooborac. The Seymour-Tooborac Road passes the Puckapunyal army camp; open paddocks to the north of the road may contain kangaroos. At Tooborac take the Lancefield road C325 and proceed 5.1km southwestward to a Y-junction. Follow the Tooborac-Baynton Road for 4.2km to a point where the road commences to climb the hornfels ridge. STOP 12, boulders on the south side of the road, is located ~200m upslope from the point at which the bitumen road surface recommences.

COBAW BATHOLITH

The Cobaw Batholith (Stewart, 1966) is elongate approximately east-west with parallel sides and rounded ends (35 x 15km). It crosscuts the boundary of the Bendigo-Ballarat and Melbourne zones intruding out the Heathcote Greenstone Belt and imposing a contact metamorphic aureole up to 2km wide. It is primarily annular in form, with a dominant, central Baynton granite, and an almost complete ring of Pyalong granite. The Baynton granite is metaluminous or weakly peraluminous with small amounts of hornblende and abundant mafic microgranular enclaves. The Pyalong granite is strongly peraluminous with minor cordierite and occasional garnet and carries high grade regional metamorphic enclaves; it has a concentric flow foliation defined by tablet-shaped K-feldspar phenocrysts. The south-central part of the batholith is host to several other phases. K-Ar ages have a mean of 363 Ma (recalculated after Stewart, 1971).

STOP 12: PYALONG GRANITE

(Woodend BU980932. Roadside boulders on Tooborac-Baynton Road 9.3km by road from the Northern Highway in Tooborac)

Approaching STOP 12, the prominent hill with a trigonometric station located to the north of the road (Hayes Hill) elegantly displays the steeply dipping contact of the Pyalong Granite by its distribution of large boulders.

The exposure has the typical porphyritic texture of the Pyalong Granite and careful examination reveals the flow fabric defined by aligned K-feldspar phenocrysts. The enclave density is typical; they are widespread, but usually low in abundance. Those with metamorphic fabrics are represented at the site, though unremarkable.

Quartz aggregates up to 12 mm across and consisting of many subgrains are seen in thin section. The large K-feldspars, so prominent in hand sample, are seen in thin section to be microperthite, commonly twinned. The K-feldspars include all other minerals of the rock. Plagioclases commonly with rectangular cross sections are up to 10mm in longest dimension. Plagioclase is zoned from dominant An_{35-30} with outermost zones near An_{20} and rarely there is evidence for a more calcic core that has been altered: oscillatory zoning is common. Biotite (α=pale straw; β=γ=red brown) occurs as crystals commonly 2mm across with ragged boundaries. It is rarely altered to pale green chlorite. There are some crudely rectangular (3.5mm) or square aggregates of small (0.5mm) biotite crystals intergrown with quartz: these appear to be pseudomorphs after early orthopyroxene. Zircon crystals, some perfectly shaped and up to 0.25mm long, are mostly seen as inclusions in biotite along with lesser monazite. The tiny hexagonal and stumpy rod-shaped opaque mineral also mostly as inclusions in biotite, is ilmenite. Apatite mostly occurs as stumpy prisms (0.1 to 0.2mm), but some more irregular grains are up to 0.5mm. Interstitial secondary calcite is rare, as is muscovite. Cordierite and lesser garnet surrounded by cordierite, are seen to be widely scattered in the field, but were not seen in the thin section examined.

Chemical analysis of Pyalong granite close to Stop 12 locality (CG97; B.W. Chappell, unpublished).

Major Elements (wt %)		Trace Elements (ppm)		Modal minerals	
SiO_2	72.82	Ba	1360		
TiO_2	0.35	Rb	165		
Al_2O_3	13.42	Sr	112		
Fe_2O_3	0.11	Pb	31		
FeO	2.62	Th	21.5	quartz	36.9
MnO	0.04	U	3.8	plagioclase	29.5
MgO	0.53	Zr	221	K-feldspar	25.0
CaO	1.61	Nb	16.0	biotite	8.0
Na_2O	2.81	Y	45	muscovite	0.2
K_2O	4.17	La	34	cordierite	tce
P_2O_5	0.14	Ce	80	apatite	0.1
H_2O^+	0.80	Nd	27	ilmenite	tce
H_2O^-	0.11	Sc	10	zircon	tce
CO_2	0.27	V	20	calcite	0.2
rest	0.27	Cr	8		
		Co	6		
Total	100.07	Ni	4		
		Cu	7		
		Zn	82		
		Ga	19.8		
		As	4.5		
		Sn	5		

fO_2 calculated using the method of Kilinc et al. (1983): Δ NNO = - 3.3 (850°C and 1kb).

TOOBORAC TO PYALONG

Return to Tooborac and take the B75 south to Pyalong. The highway is located in a poorly-outcropping segment of the Pyalong granite annulus. The prominent ridge to the east is composed of hornfelsed Silurian turbidites of the Melbourne zone. Approaching Pyalong, the following markers give a guide to the next turnoff – firstly, a turn-off to Kyneton on the right; 100m beyond, Mollison Street. Continue another 100m to Sutherland Street, just before Mollison Creek. Turn right into Sutherland Street, but immediately divert into the un-named, unsealed road that trends westward (upstream) along the bank of the creek. Proceed along the road for 800m to the point at which the road commences to diverge from Mollison Creek. Walk upstream for ~200m to the abundant boulders of Baynton granite in the channel.

STOP 13: BAYNTON GRANITE

(Woodend CU090888. Boulders in the channel of Mollison Creek ~1km upstream from Pyalong)

The greater part of the exposure is typical of the Baynton granite and its array of enclaves, which are predominantly of the mafic microgranular type. One area is unusual in having a dense enclave cluster several metres across.

In the Baynton granite both feldspars are white to colourless as in any reduced rock, and hence difficult to distinguish from each other. However, multiple twinning can be seen on some of the plagioclases, whereas the K-feldspars are a little more pearly and some are much larger (up to 30mm) than the plagioclases. Rarely these larger K-feldspars display a weak zoning indicative of high Ba. Mafic minerals include both biotite and hornblende. Biotite is red-brown indicating that the rock is reduced, and this is confirmed by the absence of magnetite determined by using a hand magnet, and the lack of any pink colour in the K-feldspar. Hornblende is much less abundant than biotite, and not so easy to find in hand sample, although it is readily identified in the field, where it is occasionally seen as stout prisms up to 20mm long. No titanite is present, but there are a few elongate allanite prisms.

In thin section, plagioclase, the dominant mineral, appears as more or less rectangular cross sections up to 10mm. Plagioclase crystals have mottled inner parts with a composition near An_{50}, zoning outwards with many fine oscillations, to outermost rims near An_{15}. Included within some of the larger plagioclases are tiny well-shaped crystals of biotite. Quartz grains also vary in size up to about 5mm. K-feldspar is microperthite, and also varies in size up to about 30mm. Around, and within, the margins of many K-feldspars are tiny quartz grains, commonly appearing like coarse graphic intergrowths. Biotite (α=pale straw; β=γ=red-brown) is much more abundant than hornblende; it has irregular shapes, prominent pleochroic haloes around included zircon crystals, and is crowded with apatites. In many respects, the biotite resembles that in cordierite granites, presumably because like most cordierite granites, this is a 'reduced' rock. Rarely, some biotites are altered to green chlorite, commonly with associated secondary titanite granules. Hornblende (α=pale green; β=brownish green; γ=grass green with brown tint) is irregular in shape and has much the same grain size as biotite (up to about 3mm). Tiny, stumpy prisms of apatite varying in size, are common, and particularly conspicuous as inclusions in the biotite.

Opaque minerals are rare, there being only a few tiny grains that have hexagonal outlines suggestive of ilmenite. Primary titanite is absent.

Chemical analyses of the Baynton granite do not vary much over the whole unit. An analysis of a Baynton granite closest to the outcrop examined is given.

Chemical analysis of Baynton granite (CG96; B.W. Chappell, unpublished).

Major Elements (wt %)		Trace Elements (ppm)		Modal Minerals	
SiO_2	69.31	Ba	685		
TiO_2	0.52	Rb	196		
Al_2O_3	14.18	Sr	140		
Fe_2O_3	0.17	Pb	25		
FeO	2.99	Th	24.0	quartz	31.0
MnO	0.06	U	5.6	plagioclase	37.7
MgO	1.27	Zr	182	K-feldspar	20.2
CaO	2.70	Nb	13.0	biotite	9.3
Na_2O	3.60	Y	36	hornblende	0.4
K_2O	3.86	La	22	apatite	0.3
P_2O_5	0.13	Ce	53	opaques	0.8
H_2O^+	0.75	Sc	12	zircon	tce
H_2O^-	0.07	V	51	allanite	0.1
CO_2	0.08	Cr	22	calcite	0.1
rest	0.24	Co	8		
		Ni	11		
Total	99.49	Cu	42		
		Zn	55		
		Ga	18		
		Sn	6		

Notice the low Fe_2O_3 relative to FeO in the analysis, consistent with this being a reduced hornblende granite. The fO_2 calculated at 850°C and 1kb is Δ NNO = -2.8 using the method of Kilinc et al. (1983). This is close to four to five orders of magnitude less than the fO_2 calculated for the most oxidised granites of the LFB e.g. Braidwood granite.

PYALONG TO MELBOURNE

Return to the B75 in Pyalong. The journey to Melbourne can be accomplished using the Northern Highway via Kilmore to the Hume Highway, or by minor road Pyalong-Lancefield and the Melbourne-Lancefield Road. The following comments apply to the latter route. Travel southward from Pyalong for ~1km and turn into the Lancefield Road. The Cobaw Batholith is crossed for approximately half of the journey from Pyalong to Lancefield. Around the halfway point, the peak to the southwest of the road, Mt William, and the ridge extending to the south, mark the Cambrian Heathcote Greenstone Belt on the south side of the batholith. The greenstone belt defines the boundary between the Bendigo-Ballarat and Melbourne tectonic zones. Beyond Romsey, the massif to the west of the road is the Late Devonian Mt Macedon Complex of volcanics and minor granite. At Bulla the excursion completes its cycle with boulders of Bulla granite in the environs of Deep Creek.

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