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EXCURSION GUIDE

PALAEOZOIC FELSIC VOLCANISM IN THE CANBERRA DISTRICT

Doone Wyborn - Australian Geological Survey Organisation

GENERAL ASSEMBLY
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ANCIENT VOLCANISM & MODERN ANALOGUES

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INTRODUCTION

The volcanics of the Canberra district are part of an extensive belt of Early Palaeozoic rocks covering most of SE Australia and known as the Lachlan Fold Belt (LFB). A plate tectonic, continental margin model of evolution is generally described, where the LFB formed at the contact of Gondwana and the Palaeo-Pacific Plate. For recent reviews see Scheibner (1989) and Coney (1992). In this model, an Ordovician Island Arc and deep marine quartz-rich turbidite sequence was fragmented and folded during the Silurian and Devonian, covered by a terrestrial sequence in the Late Devonian, and folded again in the Carboniferous. Thus the LFB evolved from an essentially oceanic domain to a continental one over a period of around 150 million years, from the Ordovician to the Carboniferous. In Silurian to Early Devonian times most of the LFB was subjected to a high geothermal gradient, which resulted in an intense period of felsic magmatism, both plutonic and volcanic. Evidence from the resulting felsic igneous rocks is at variance with the continental margin model, as the felsic rocks seem to have come from a crystalline lower crust of Late Precambrian to Cambrian age, and new components added to the crust during continental margin subduction seem to be lacking. Continental collision to bring the oceanic rocks over the crystalline rocks in the early Silurian is not a viable explanation since such collision would result in a low geothermal gradient, and extensive uplift and erosion. In fact, in Late Silurian - Early Devonian times the geothermal gradient was very high, volcanic products were extruded close to sea-level, and have remained at that level (± about a kilometre) to the present day. Much of the uplift that *has* taken place occurred in the Cretaceous-Tertiary and appears to be associated with (i) rifting associated with the formation of the Tasman Sea, and (ii) crustal underplating of basaltic material during an extensive Tertiary basalt flare-up.

The tectonics of the Lachlan Fold Belt still remains an enigma. One possible model (Wyborn, 1992) involves the foundering of subcontinental lithosphere into the mantle, commencing in the Ordovician. Lithosphere-derived magmatism resulted during Ordovician times where the lithosphere was fertile enough to melt. The foundering commenced in the west and propagated eastwards, and resulted in asthenospheric upwelling such that hot asthenosphere came in contact with the thin overlying continental crust. Conductive heating of that crust resulted in melting on a massive scale producing the broad belt of Silurian-Devonian granites and volcanics that dominate the Lachlan Fold Belt geology we see today. In this scenario the effects of subcontinental lithosphere foundering reached the margin of Gondwana in the early Devonian, and foundering continued on into true oceanic subduction of the palaeo-Pacific plate at that time. The Late Palaeozoic New England Fold Belt grew as a result of this subduction. Models for the development of the Late Precambrian-Cambrian crust that sourced most of the granites in the LFB are not at all clear. This period in earths history is not well represented in the rock record, and yet isotopic evidence indicates that it is a period of marked continental crustal addition in Gondwana.

The felsic volcanics have provided valuable evidence to support the "reworking by melting" model of Late Precambrian to Cambrian crust, though the coeval granites have been studied in greater detail and were instrumental in the development of the model (see Chappell et al., 1988). Compared to the granites, the felsic volcanics contain a more anhydrous phenocryst mineralogy more indicative of the original mineralogical composition of the magma, and the mineralogy commonly retains equilibria approximating the original temperature, pressure and volatile fugacities at the source of the magma.

VOLCANIC SUITES

Three suites of felsic volcanics can be distinguished in the Canberra region, based on the mineralogy of the units. These are

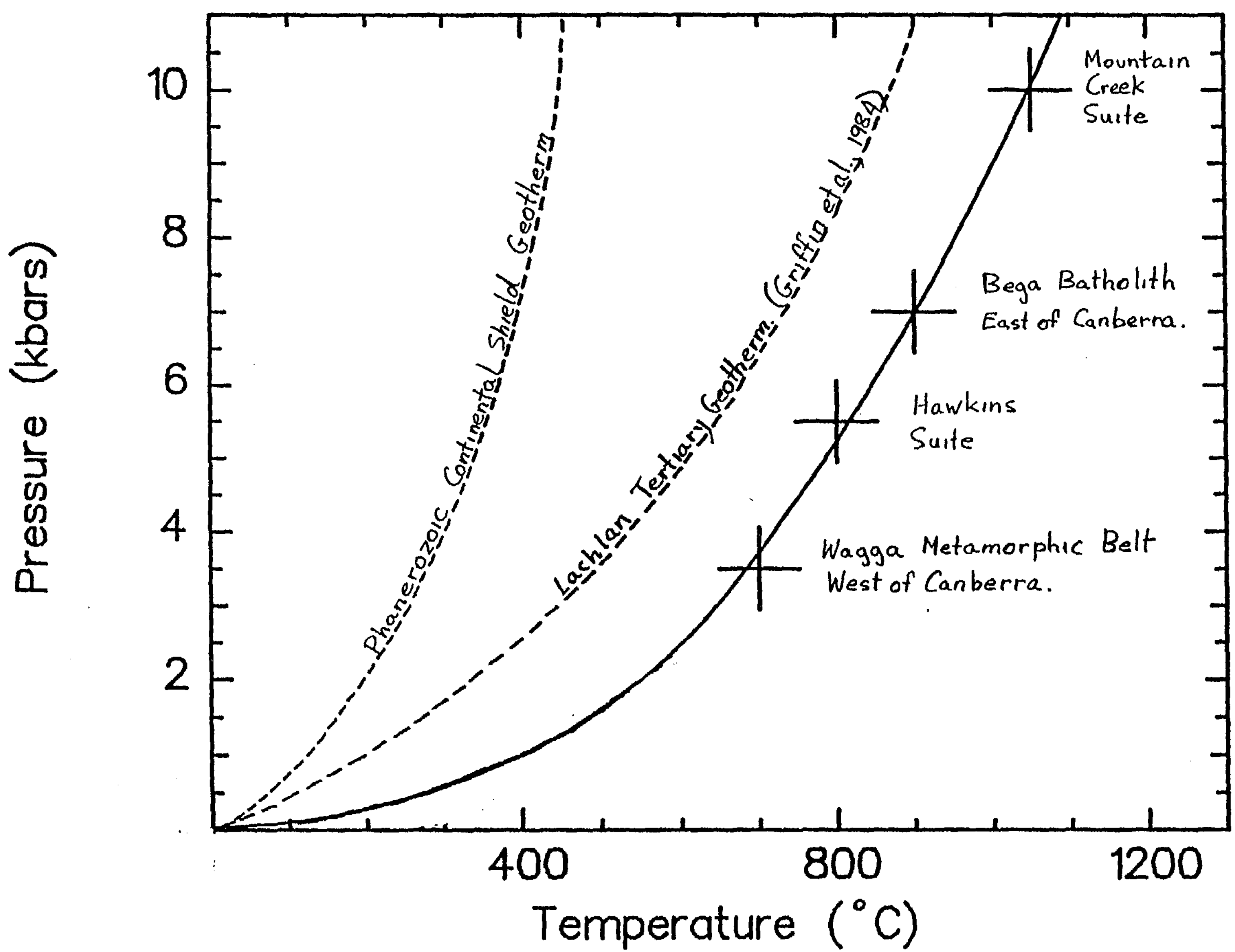
(i) Hawkins Suite

(ii) Laidlaw Suite

(iii) Mountain Creek Suite

Each suite is derived from a different source-rock of different chemical composition, and derived from a different level in the crust at different temperatures. The Hawkins Suite is the oldest and comes from the shallowest levels in the crust at the lowest temperatures. The Mountain Creek Suite is the youngest and comes from the deepest levels in the crust at the highest temperatures. The Laidlaw Suite is intermediate between the other two. A well-constrained geothermal gradient (figure 1) can be constructed through the crust using P-T estimates determined for these suites and combining them with evidence from elsewhere in the LFB (Wyborn & Chappell, 1986; Morand, 1990). This temperature profile combines P-T estimates from areas well east and west of Canberra, including the Wagga Metamorphic Belt and suggests that the maximum geothermal gradient was

Figure 1: Lachlan geotherm.



rather uniform over a large area. It was, however somewhat diachronous according to the age determinations on associated granitic rocks, being older to the west and younger to the east. Timing of felsic magmatism ranges from Early Silurian (425-430Ma) in the west to Early Devonian (385-400Ma) on the east coast. Thus the locus of crustal melting shifted eastwards over a distance of 300km during a 30-40Ma time period, that is about 1km per million years. The shift is in keeping with the Ordovician delamination model, coupled with a conductive heating time factor of about 30Ma.

The stratigraphy of the Canberra region has long been a difficult problem to decipher because of the lack of outcrop, extensive faulting, abundance of similar-looking highly porphyritic igneous units of either intrusive or extrusive origin, and apparent interbedding of sediments containing endemic Silurian fossils of little biostratigraphic use. Given these problems, stratigraphic names proliferated and correlations were tenuous. It was only after the petrology of the volcanic units was studied and the three volcanic suites were recognised that a unified understanding of the stratigraphy emerged (figures 2 and 3).

(i) **HAWKINS SUITE**

The Hawkins Suite of volcanics are part of the most extensive group of magmatic rocks in SE Australia. The intrusive rocks of the suite are known as the Bullenbalong Suite. The extrusive and intrusive rocks are comagmatic and chemically equivalent. The volcanics extend over a meridional strike length of over 250 kilometres, from Dubbo in the north to Kiandra in the south. The Bullenbalong Suite of granites is even more extensive, extending over 350 kilometres from Cowra in the north, almost to Bass Strait in the south. The most important characteristic of these chemically equivalent S-type suites is that they are strongly peraluminous, and thought to be derived from a mature pelite-rich sedimentary source. This source, however, is chemically less mature than the Ordovician greywackes that are widespread in the LFB. The source must have contained more feldspar to give it a higher Na_2O and CaO content than any granitic rocks that could be derived from the Ordovician sediments. S-type granites that **were** derived from the Ordovician quartz-rich greywackes do occur in the Lachlan Fold Belt . The most well known example is the Cooma Granodiorite, which is distinctly lower in Na_2O and CaO than the Bullenbalong Suite.

Around Canberra the first evidence of Hawkins Suite volcanism is a shallow marine bed of volcanic ash known as the Narrabundah Ashstone **(STOP 2)**, which is interbedded in the fossiliferous Early Silurian Canberra Formation. This is soon succeeded by a thick sequence of shallow marine to subaerial volcanics, the Ainslie Volcanics **(STOP 3)**. Further west other names (Walker Volcanics - **STOP 5**, and Paddys River Volcanics) are used for volcanics at about the same stratigraphic position. These units contain lavas and ignimbrites and some interbedded sediments. Sediments at one locality within the Walker Volcanics contain a rich assemblage of trilobites (Chatterton & Campbell, 1980) including 18 species, 8 of which are newly described. The volcanics are mostly highly porphyritic dacites with about 40-50% phenocrysts of quartz, plagioclase (mostly albitised by burial metamorphism), biotite, cordierite, orthopyroxene (mg 45-50) and xenocrysts of garnet. Where the plagioclase is unalbitised, it is relatively unzoned around An_{50}. In the granitic equivalents, orthopyroxene is absent, but cordierite and infrequent garnet are present. In the granites the plagioclase grains have broad An_{50} cores and narrow strongly zoned rims down to An_{20}. In the volcanics, commonly the garnets and the cores of the cordierites contain schistosely aligned inclusions of sillimanite. The high crystal content of the magmas and the presence of obvious high grade metamorphic xenocrystic garnet and inclusion-rich cordierite has lead to the citing of these rocks as supporting the **restite model** of granite genesis (Chappell et al., 1987). This model proposes that the source for a granite magma was partially melted (perhaps to about 40%) and the whole source region was mobilised, including the ≈60% of unmelted source (the restite). Thus a granite containing about 60% restite, or a volcanic containing about 60% restite phenocrysts would approximate the average composition of the source region. By using this model for many of the granites of the Lachlan Fold Belt it is possible to quite accurately determine the composition of the source rocks for the granites (ie. the composition of the lower to middle crust). Thus the granites map or image the compositional variations of the deep crust (Chappell, 1979). This has provided a powerful tool for constraining the tectonic development of the Lachlan Fold Belt.

The Mount Ainslie and Walker Volcanics are topped by a distinctive ignimbrite unit which is extremely crystal-rich (80% crystals of the same variety as in the lower units) and known as the Mount Painter Volcanics **(STOP 4)**. The centre of eruption for this ignimbrite was probably quite close to Canberra city as there it contains the largest and greatest abundance of lithic and flattened pumice fragments (well displayed at **STOP 4**). The ignimbrite extends north for over 60 kilometres to an extensive area of poorly mapped Hawkins Suite volcanics north east of Yass. Near Fairlight, west of Canberra, the Mount Painter Volcanics are separated from the underlying Walker Volcanics by a sequence of fossiliferous sediments, but no detailed work has been carried out on

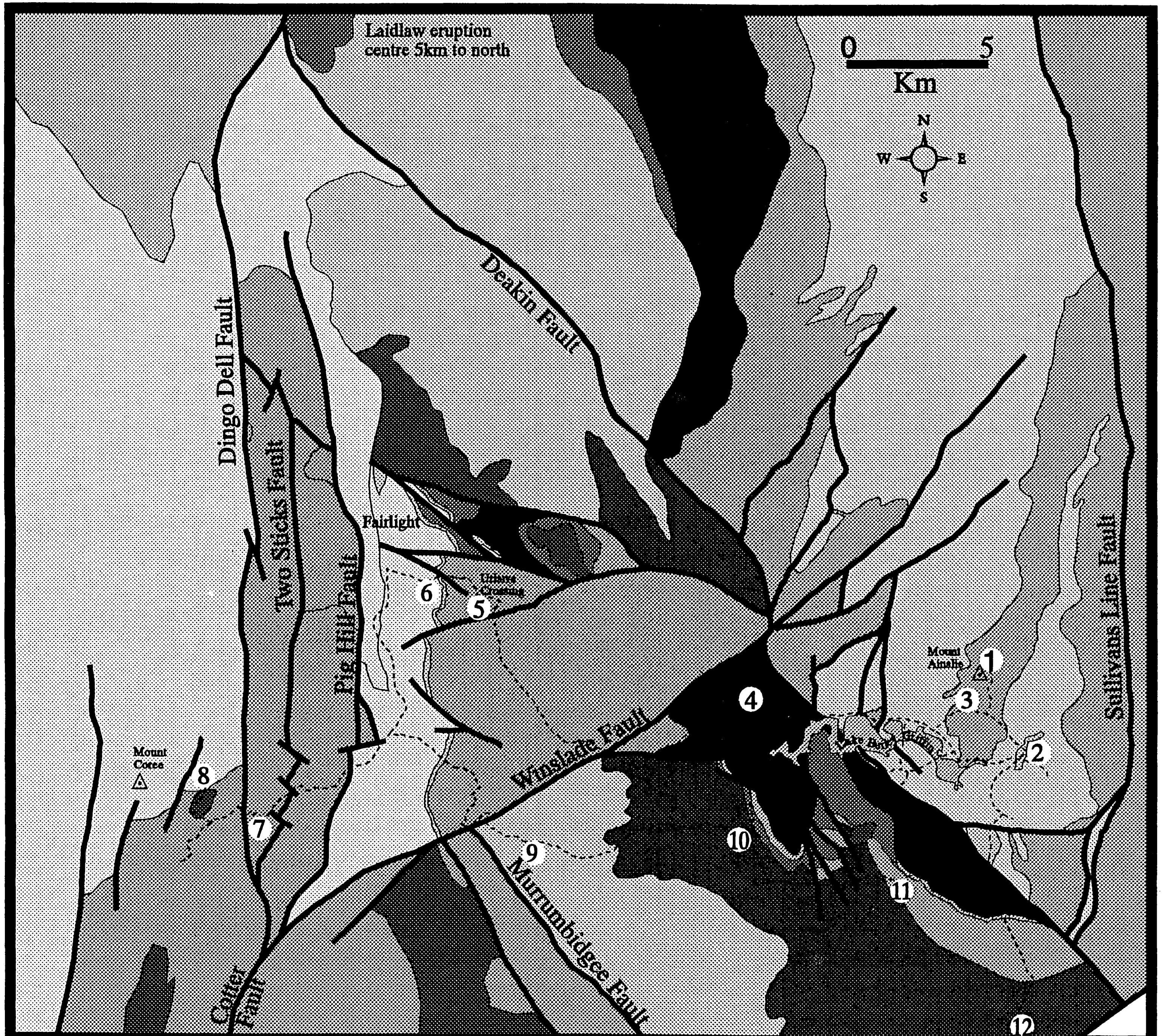
FIGURE 2

CANBERRA DISTRICT STRATIGRAPHIC COLUMN

EARLY DEVONIAN	MURRUMBIDGEE GROUP limestone, shale, fossils
MOUNTAIN CREEK SUITE	MOUNTAIN CREEK VOLCANICS rhyolite lava, ignimbrite, airfall tuff, breccia
UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu
LATE SILURIAN	YASS BASIN shale, limestone, siltstone, abundant fossils
LAIDLAW SUITE	LAIDLAW VOLCANICS composed mainly of a single dacitic ignimbrite, possibly the lateral equivalent of the URIARRA VOLCANICS URIARRA VOLCANICS including TARPAULIN CREEK ASHSTONE MEMBER at base, mainly altered dacitic ignimbrite and reworked volcaniclastics, airfall deposits DEAKIN VOLCANICS including MUGGA MUGGA PORPHYRY MEMBER at base, interbedded dacitic lavas,ignimbrite and reworked sediments
EROSIONAL UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu
LATE SILURIAN	YASS GROUP and YARRALUMLA FORMATION shale, sandstone, limestone, fossils
HAWKINS SUITE	MOUNT PAINTER VOLCANICS composed mainly of a single dacitic ignimbrite with the LYONS ASHSTONE at top unnammed shale, sandstone and limestone near Fairlight, fossils MOUNT AINSLIE VOLCANICS, WALKER VOLCANICS and PADDYS RIVER VOLCANICS; dacitic lava, ignimbrite, rhyolitic ignimbrite, interbedded sediments
EARLY SILURIAN	CANBERRA FORMATION including NARRABUNDAH ASHSTONE near top, siltstone, shale, limestone, sandstone, fossils
UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu
EARLY SILURIAN	BLACK MOUNTAIN SANDSTONE quartz sandstone, siltstone
UNCONFORMITY	uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu
ORDOVICIAN	Marine quartz-rich turbidite sequence, graptolitic shales

FIGURE 3

GEOLOGY OF THE CANBERRA DISTRICT



- Lake Burley Griffin
- Roads
- ① Excursion stop
- Early Devonian sediments overlying Mt Ck Volcs.
- Mountain Creek Volcanics (Mountain Creek Suite)
- Uriarra Volcanics (Laidlaw Suite)
- Laidlaw Volcanics (Laidlaw Suite)
- Deakin Volcanics (Laidlaw Suite)
- Mugga Mugga Porphyry (lava)
- Ashstones
- Intra-volcanic sediments mostly shallow marine
- Mount Painter Ignimbrite (Hawkins Suite)
- Hawkins Suite volcanics
- Early Silurian shallow marine sediments
- Ordovician quartz-rich turbiditic sediments
- Granitic and Porphyry intrusives

the fossils. Where the Mount Painter Volcanics crops out south of Lake Burley Griffin, it is topped by a bedded ashstone unit, the Lyons Ashstone, which probably represents part of the complementary fines that settled after the deposition of the ignimbrite unit. Above the ignimbrite, shallow marine sediments were again deposited in places including the Yass Group and the Yarralumla Formation. The Yass Group has been well dated by conodonts (Link & Druce, 1972) as early Ludlovian (the earliest part of the late Silurian). The onset of shallow marine conditions over a broad area implies regional subsidence took place after cessation of Hawkins Suite volcanism. Thus the style of volcanism was not that of a typical intra-caldera thick volcanic sequence with thin outflow sequence, but more like the filling of a broad regional subsidence feature with no obvious fault-controlled caldera centre. This style of eruption coupled with the high crystallinity of the magma (as restite phenocrysts) and equivalent composition to granitic bodies suggests that a large restite-rich granitic body has somehow erupted, producing a large volume, low power eruption that effectively evacuated a granite magma chamber. Smaller, commonly less porphyritic, eruptions (Mount Ainslie and Walker Volcanics) prior to the main eruption signify the approach of the magma body to the surface. The preservation of mineral equilibria at or near source depths provides some constraints on ascent rates.

(ii) **LAIDLAW SUITE**

Volcanism again broke out soon after the deposition of the Yass Group and Yarralumla Formation, but this time the mineralogy of the volcanics was different to the underlying Hawkins Suite. Cordierite and garnet are absent and sanidine and allanite are present. The volcanics are crystal-rich like the Hawkins Suite, but only part of the phenocryst volume is thought to be restite material. Plagioclase crystals are more strongly zoned (An_{70}- An_{35}) and cores more calcic than those in the Hawkins Suite. Orthopyroxene is more magnesian (mg 50-60). Overall, although calcic plagioclase, orthopyroxene, allanite and some of the quartz and biotite phenocrysts are thought to be of restite origin, quartz, sanidine, sodic plagioclase and biotite have also crystallised from the melt during ascent and cooling. The Laidlaw Suite is thought to be derived from a felspathic greywacke source beneath the Hawkins Suite source. Several mappable volcanic units contain the mineralogy of the Laidlaw Suite. South of Lake Burley Griffin the earliest unit is a lava known as the Mugga Mugga Porphyry Member **(STOP 11)**. This is overlain by a sequence of lavas, ignimbrites and terrestrial sediments known as the Deakin Volcanics **(STOPS 10 and 12)**. These units have a distinctive purple-red oxidation colour which may have been imposed at the time of subaerial deposition. The Deakin Volcanics is overlain by a dark grey ignimbrite unit up to 500m thick known as the Laidlaw Volcanics **(STOP 9)**. This unit can be mapped north of Yass and has a total strike length of about 100km. It appears to represent a single ignimbrite eruption of nearly 1000 cubic kilometres of magma, and is rather like the Mount Painter Volcanics in representing a massive climactic eruption to bring to an end the extrusion of a distinctive magma type. The eruption centre for the ignimbrite is probably a circular area of disrupted and brecciated volcanics 5km across and about 12km south of Yass (5km north of the top of Figure 3).

West of the Murrumbidgee River the Hawkins Suite is overlain by a volcanic unit known as the Uriarra Volcanics. This has the mineralogy of the Laidlaw Suite and is in part probably laterally equivalent to the Laidlaw ignimbrite, but is more crystal-rich and oxidised. At the base is a bedded ashstone, the Tarpaulin Creek Ashstone Member **(STOP 6)**, which drapes over several units lower in the stratigraphy, including the Mount Painter Volcanics, the Walker Volcanics and the fossiliferous sediments between the two near Fairlight. This implies that there has been an erosional break before the eruption of the Laidlaw Suite. Between Canberra and Yass the Yass Group is also absent, with the Laidlaw ignimbrite directly overlying the Mount Painter Volcanics, again implying an erosional break. The Uriarra Volcanics at its base at **STOP 6** contains reworked volcaniclastic material producing diffuse bedding mixed with lava fragments, but higher up recognisable flattened lava fragments occur in a crystal rich (60% crystals) matrix. The matrix consists of angular poorly sorted crystal fragments. One possible origin for the distinctive texture and alteration of the Uriarra Volcanics is that they represent the lateral equivalent of the Laidlaw Volcanics, but the ignimbrite was fragmented as it passed over a shallow lake.

At Yass the Laidlaw Volcanics are overlain by a richly fossiliferous sequence that has been studied in great detail. The sediments range in age from Early Ludlovian to very early Devonian (Link & Druce, 1972). The lowest beds contain the same conodont zone fossil assemblage (the *Neoprioniodus excavatus* Zone) as the Yass Group, which underlies the Laidlaw Volcanics. Thus the Laidlaw Volcanics are restricted to a short interval in the Early Ludlovian.

(iii) **MOUNTAIN CREEK SUITE**

The sediments overlying the Laidlaw Volcanics at Yass are absent further south, and instead another volcanic suite the Early Devonian Mountain Creek Suite appears. The relationship is unconformable, and this break corresponds to the deformation known as the Bowning fold episode. Folding related to this event was much

TABLE 1 : AVERAGE CHEMICAL COMPOSITIONS OF SOME VOLCANIC UNITS

Volcanic Unit	Walker	Mt.Painter	Laidlaw	Mtn Ck
no. of analyses	13	9	26	11
SiO2	67.82	66.30	70.00	71.89
TiO2	0.56	0.59	0.43	0.53
Al2O3	13.99	13.93	14.17	13.93
Fe2O3	1.85	0.68	1.01	0.83
FeO	2.65	4.33	2.10	1.39
MnO	.06	.09	.05	.12
MgO	1.92	2.63	1.31	.60
CaO	1.17	2.28	2.86	1.86
Na2O	2.28	1.86	2.74	3.62
K2O	4.49	3.58	3.31	4.29
P2O5	.12	.11	.09	.07
H2O+	2.18	2.47	1.23	.53
H2O-	.19	.10	.11	.05
CO2	.37	.57	.14	-
Rest	.22	.20	.20	.20
Total	**99.88**	**99.73**	**99.74**	**99.31**
Trace	elements in	parts per	million	
Ba	783	562	655	940
Rb	204	156	137	170
Sr	84	111	180	315
Pb	111	20	47	22
Th	16	15	15	18
U	4.5	3.8	3.8	3.5
Zr	190	189	177	243
Nb	4	5	4	4
Y	30	25	28	30
La	46	53	58	39
Ce	75	86	100	86
V	117	135	87	41
Ni	18	29	12	8
Cu	15	34	17	12
Zn	73	89	60	68

stronger to the west in a sequence of Silurian sediments known as the Tumut Trough (IAVCEI Field Trip B2). The Mountain Creek Volcanics **(STOP 8)** occupy the mountainous area west of Canberra, and are distinctly different from the Silurian volcanics. They are crystal-poor rhyolitic lavas and ignimbrites with a phenocryst mineralogy of plagioclase, clinopyroxene and orthopyroxene. Quartz phenocrysts are absent in most units. These volcanics are I-type derived from lower crustal sources at high temperatures. Magnetite-ilmenite geothermometry gives temperatures over 1000°C (Wyborn & Chappell, 1986). The volcanics belong to a suite of intrusives and extrusives that extend in a meridional belt from NE Victoria for over 500km to Dubbo (Wyborn et al., 1987).

CHEMISTRY, ISOTOPES & AGE DATES

The three volcanic suites, although similar in silica content (Table 1) are mineralogically distinct, and this is mainly reflected in the relative abundance of alumina and alkalis, which is in turn related to the composition of the source-rocks. The Hawkins Suite has an excess of alumina (peraluminous) reflecting its pelitic sedimentary source, the Laidlaw Suite has alumina and alkalis balanced, and the Mountain Creek Suite is metaluminous, reflecting its mafic igneous lower crustal source. This can best be represented in a plot of SiO_2 versus ASI, where ASI stands for aluminiun saturation index (molecular ($Al_2O_3/Na_2O+CaO+K_2O$)) (figure 4).

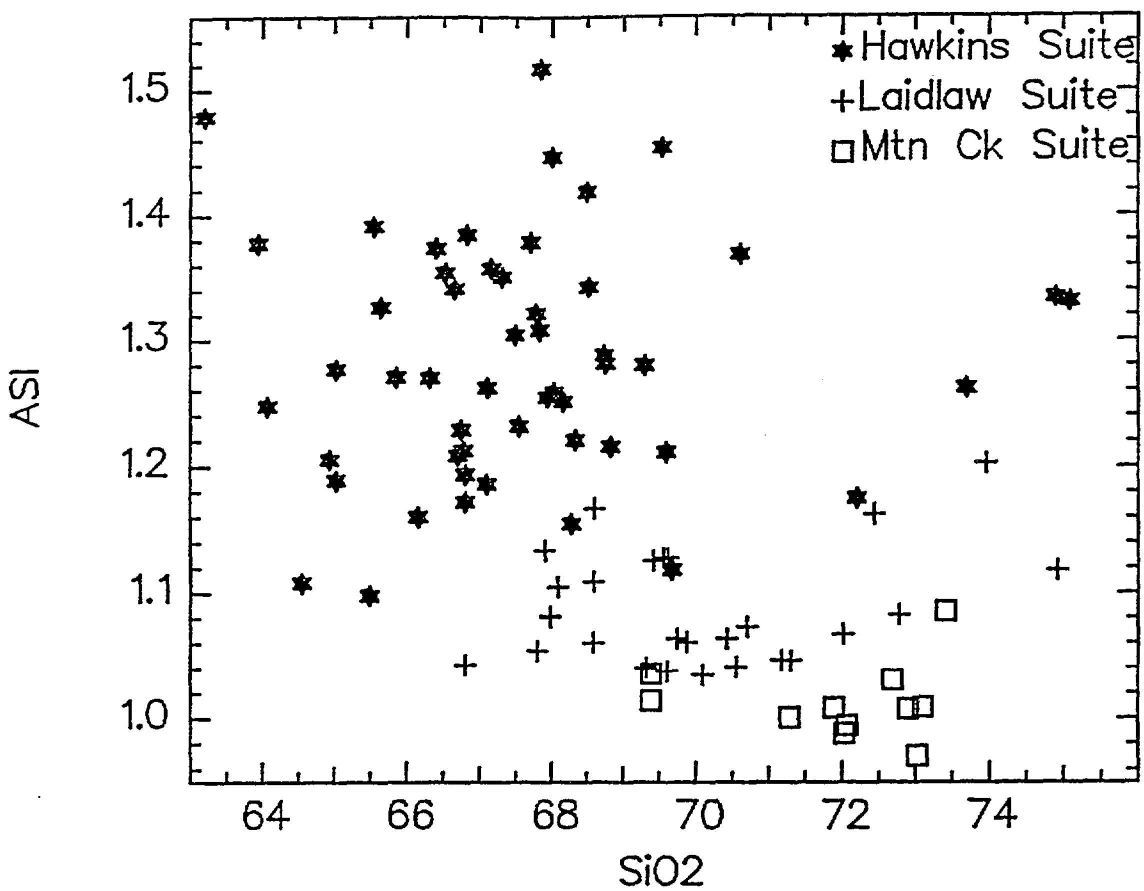


FIGURE 4- Plot of aluminium saturation index (ASI) versus SiO2 for Canberra volcanic suites. The large range of ASI in the Hawkins Suite is mainly caused by alteration during burial metamorphism.

The strontium isotopic initial ratios of the three suites further support the separate sources of the three suites. Only the Laidlaw Suite has been measured directly, but granites related to the other two suites have been measured. These give:

Hawkins Suite	0.715
Laidlaw Suite	0.7083
Mountain Creek Suite	0.7044

The Laidlaw Volcanics is an ideal unit to relate to the geological time scale. Its early Ludlovian age is constrained by fossils above and below and its mineralogy is suitable for both K/Ar and Rb/Sr dating. An age of 420.7±2.2 m.y. was obtained by Wyborn et al.(1982), which has considerably tightened control on the age of the Silurian Period. A granite which is comagmatic with the Mountain Creek Volcanics has been dated by the Rb/Sr method at 406±1 m.y. This age corresponds to the Early Devonian, as the Late Silurian to Early Devonian sediments at Yass lie below the unconformity that separates the Laidlaw Volcanics from the Mountain Creek Volcanics.

EXCURSION STOPS

STOP 1 Mount Ainslie Lookout

An overview of the geology of the Canberra region can be seen from this lookout. The Canberra Plain is an area bounded by faults to the east and west, and containing residual hills that represent the more resistant rock-types in the Palaeozoic sequences that underlie Canberra. The Plain is a remnant of a once widespread peneplain that stretched from Bass Strait to central NSW, and included the plateau surrounding Mount Kosciusko, the now highest mountain in Australia. The peneplain developed over the period from the Carboniferous to the Cretaceous, but was uplifted, mainly by block-faulting in the Tertiary. The Queanbeyan Fault to the east has had its most recent movements with west block down, which is the opposite sense to the step faults that occur between Canberra and the coast. The ridges to the west are bounded by more step faults, with sense west block up, so the Canberra Plain is situated in a local rift valley. Mount Ainslie is on a residual ridge of Silurian Mount Ainslie Volcanics

(STOP 3, note also the volcanic outcrops in road cuts as we drive down the mountain) which conformably overlie the sequence of shallow marine sediments of the Canberra Formation (**STOP 2**). The volcanics lie in a synclinal structure with the plains to the east and west being underlain by the less resistant shallow marine sequence. The hill to the west with Black Mountain Tower on top, is composed of early Silurian orthoquartzite, the Black Mountain Sandstone, which unconformably underlies the Canberra Formation. It is topographically higher than the younger rocks because it is located in a complexly faulted area astride a left-lateral strike-slip fault known as the Deakin Fault (see geological sketch). The fault jogs to the north to the west of Black Mountain, so that strike-slip movement along the fault possibly produced a pop-up structure of imbricate thrusts around Black Mountain. The early Silurian rocks are in turn underlain by an Ordovician quartz-rich greywacke sequence which is monotonous and widespread throughout Victoria and SE New South Wales (**STOP 7**). In the middle distance to the south west can be seen white outcrops of granite known as the Shannons Flat Adamellite, a pluton within the Murrumbidgee Batholith.

STOP 2 Narrabundah Ashstone and fossiliferous Canberra Formation on Fairbairn Avenue

In Woolshed Creek, fossiliferous mudstones from the Canberra Formation contain the first Silurian fossils found in Australia by Rev. W. B. Clarke in 1878. The dominant fossil is a brachyapod, the endemic species *Atrypa duntroonensis*. There are also trilobites, pelecypods, corals and bryozoans. The sediments dip west and are overlain by the Narrabundah Ashstone. This unit is the first indication of volcanism in the Canberra area. It is a single bed 50m thick with the bottom 15m composed of medium sand and the top 35m devitrified ash. The sand contains plagioclase, angular volcanic quartz fragments and aligned mica. At the top of the ashstone are well-bedded sediments consisting of reworked material from the ash bed.

STOP 3 Mount Ainslie Volcanics on Fairbairn Avenue

Above the Narrabundah Ashstone more shallow marine sediments were deposited before the onset of major volcanism, in this area known as the Mount Ainslie Volcanics. The fresh exposure is a crystal-rich ash consisting of crystals of quartz, albitised plagioclase, altered biotite, cordierite and orthopyroxene and rare broken fragments of almandine garnet, ie, the typical mineralogy of the Hawkins Suite. The weathered exposures display good bedding features (?airfall origin) which a dip to the east (opposite to that at **STOP 2**), and indicate this stop is to the west of the synclinal structure that Mount Ainslie occupies.

STOP 4 Mount Painter Volcanics on William Hovell Drive

This locality on the southern slopes of Mount Painter, contains very prominent crystal-rich flattened pumice fragments (perhaps more accurately called magma blobs), the largest up to 30*10cm. In places they occupy 50% of the rock. Several large garnets are conspicuous on the outcrop. Flattened pumice fragments indicate that the ignimbrite dips at $<10°$ to the south-east. The lithic population includes fine quartz sandstone, epidote-rich marly siltstone, quartz-feldspar porphyry, microgranite and vein quartz. This locality is probably close to the centre of eruption.

STOP 5 Walker Volcanics at Uriarra Crossing

On the east side of the bridge across the Murrumbidgee River a sequence of volcaniclastic sandstones dipping 20°WSW and overlain by shale is overlain by a crystal-rich volcanic unit. The volcanic has conspicuous euhedral cordierite phenocrysts and rare garnet. The phenocrysts in this rock are mostly subhedral to euhedral or, in the case of quartz, rounded and resorbed. There are no visible pumice fragments. The rock is probably a lava flow rather than an ignimbrite, and shows complex mixing at the contact with the underlying shale, indicating extrusion onto soft sediments. The sediment were probably deposited as local fluviatile-lacustrine deposits, though it is only a few kilometres from here that Chatterton & Campbell (1980) described to rich trilobite fauna in marine sediments also within the Walker Volcanics.

STOP 6 Tarpaulin Creek Ashstone Member and Uriarra Volcanics on south side of Fairlight Road

In a small quarry about 50m south of the road weathered Walker Volcanics is overlain by the basal unit of the Uriarra Volcanics, the Tarpaulin Creek Ashstone Member. This member is a distinctive marker bed and overlies several older units including the Mount Painter Volcanics a few kilometres to the north. At this locality the Mount Painter Volcanics were probably eroded away before deposition of the ashstone.

Above the ashstone there are outcrops of crystal-rich diffusely bedded deposits at the base of an electricity tower, and higher up the hill ignimbrite with aligned pumice fragments. The Uriarra Volcanics have the mineralogy of the Laidlaw Suite, and about 7 kilometres NW of **STOP 6** there seems to be a facies change into the Laidlaw ignimbrite. The depositional differences between the Laidlaw and Uriarra ignimbrites are not understood, but it is possible that the Laidlaw ignimbrite flowed over a shallow lake resulting in more alteration, crystal concentration, and winnowing of ash, thus producing the Uriarra Volcanics..

STOP 7 Ordovician Quartz-rich turbidite deposits on Brindabella Road near Condor Creek crossing.

This stop is to briefly inspect an example of the Ordovician mudpile (Coney, 1992) that is widespread in southeastern Australia. Here there is one quite strong deformation within this fault block, however in the next fault block to the east, the Ordovician is gently dipping and uncleaved. The age of deformation is probably late Devonian or Carboniferous, and thus is younger than the relatively undeformed Silurian volcanics we have been examining.

STOP 8 Base of Mountain Creek Volcanics above Condor Granite in Uriarra Pine Forest.

At this locality the Mountain Creek Volcanics probably disconformably overly the Condor Granite, a Silurian-aged I-type hornblende granodiorite that is of a different chemical suite to the volcanics. On the ridge to the east of the road, a dyke of Mountain Creek rhyolite several metres thick intrudes the granodiorite. The dyke displays well-developed steeply dipping flow banding, and contains a sparse (<10%) phenocryst assemblage of plagioclase (An_{60-70}) and two pyroxenes, though fresh orthopyroxene has never been found. Unlike the Silurian volcanics, the Mountain Creek suite does not contain any restite phenocrysts. Further along the road float of rhyolite lava can be sampled. Magnetite-ilmenite geothermometry on this lava indicates a temperature of extrusion of 1000°C at $f(O_2)$ of 10^{-10} bars (Wyborn & Chappell, 1986).

STOP 9 Laidlaw Volcanics on Cotter Road

The Late Silurian Laidlaw Volcanics consists mainly of a single welded ignimbrite sheet about 500m thick that once extended over an area of at least 1600 square kilometres. The ignimbrite is thought to be an erupted pluton. It is thought to be S-type, and derived from a felspathic source, rather than a pelitic source. The rock is crystal-rich, with about 60% phenocrysts of quartz, plagioclase (zoned An_{70}-An_{35}), sanidine (Or_{70}-Or_{76}), hypersthene (mg 50-60), biotite, allanite, ilmenite and magnetite. Oxide geothermometry yield temperatures between 715-740°C at $f(O_2)$ of 10^{-15}bars (Wyborn et al, 1981) The age of the ignimbrite is well-constrained as it is both underlain and overlain by richly fossiliferous sedimentary sequences. The fossils constrain the age of the volcanics to the early Ludlovian. The ignimbrite has been dated by K/Ar and Rb/Sr methods at 420.7 ± 2.2 m.y., and has been used as an important constraint on the age of the geological time scale.

This outcrop is typical and is one of the localities sampled in the dating work. Pumice fragments are absent, as the eruption centre is thought to be about 50 kilometres to the north, but a well-developed eutaxitic texture is prominent on thin section examination, thus testifying to its ignimbritic origin.

STOP 10 Deakin Volcanics on Tuggeranong Parkway - TAKE CARE, HEAVY TRAFFIC.

The Deakin Volcanics form a sequence of lavas, ignimbrites and volcanic sediments that underlie the Laidlaw Volcanics in the Canberra city area, but lens out towards the north from where the Laidlaw ignimbrite is thought to have erupted. Thus the bulk of the Deakin Volcanics would have been erupted from a different centre to the Laidlaw centre. At this locality some interesting relationships can be examined between weathered porphyritic ignimbrites of the Deakin Volcanics and interbedded volcanic sediments. Some coarse quartz sandstones are composed almost entirely of ß-quartz grains reworked from the volcanics. The sediments display soft sediment deformation where directly overlain by the volcanics.

STOP 11 Mugga Mugga Porphyry Member of Deakin Volcanics on Hindmarsh Drive - TAKE CARE, HEAVY TRAFFIC

The Mugga Mugga Porphyry Member is a distinctive lava unit up to 600m thick at the base of the Deakin Volcanics. It has a similar mineralogy to the Deakin and Laidlaw Volcanics. The lava has approximately 35% subhedral phenocrysts in a microgranitic groundmass. No eutaxitic texture is visible in thin section, but flow banding has been reported from other localities (Abell, 1991). A hornblende tonalite intrusion which crops out 2km from this locality, and is thought to underlie much of the area because of the extensive magnetic anomaly it produces, has probably slightly contact metamorphosed the lava.

As we continue along Hindmarsh Drive over the Red Hill saddle the bedded Lyons Ashstone can be seen on the right (south) side, followed by good exposures of the underlying Mount Painter ignimbrite.

STOP 12 (if time permits) Deakin Volcanics - fluviatile volcaniclastics on Monaro Highway - TAKE CARE, HEAVY TRAFFIC

Exposed in this road cutting are some fine examples of well bedded fluviatile volcaniclastic sediments, which in some beds include poorly sorted angular volcanic fragments up to 5cm across. There are also good accretionary lapilli at one particular stratigraphic level.

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