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# Excursion Guide B-2

## Silurian Volcanics and Geological Time-scale, Canberra region

26 September, 1990

by

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Bureau of Mineral Resources, Geology and Geophysics
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## SILURIAN VOLCANICS and the GEOLOGICAL TIMESCALE, CANBERRA REGION

Wednesday 26 September

Leader:

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# SILURIAN VOLCANICS AND THE GEOLOGICAL TIME SCALE - CANBERRA REGION

The volcanics of the Canberra region are part of an extensive belt of Early Palaeozoic rocks covering most of SE Australia and known as the Lachlan Fold Belt (LFB). 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. A model of evolution (the oceanic model) is generally thought of as a plate tectonic one formed at the margin of the Palaeo-Pacific Plate. For a recent review see Scheibner (1989). An Ordovician Island Arc and deep marine sequence was fragmented and folded during the Silurian, and covered by a terrestrial sequence in the Late Devonian. 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 oceanic model, as the felsic rocks seem to have come from a crystalline lower crust of Late Precambrian age. 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, 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. An alternative model for the Lachlan Fold Belt could be that it represents a cover sequence for an earlier (Late Precambrian) period of continental growth (the basement-cover model).

The Silurian felsic volcanics have provided valuable evidence to support the basement-cover model, 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 composition of the magma, and the mineralogy commonly retains equilibria approximating the original temperature, pressure and volatile fugacities at the source of the magma. In particular P-T conditions of the source have been determined for some volcanic units (Wyborn et al., 1981; Wyborn & Chappell, 1986) and a geothermal gradient thought to have operated at the time of magma generation can be obtained.

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

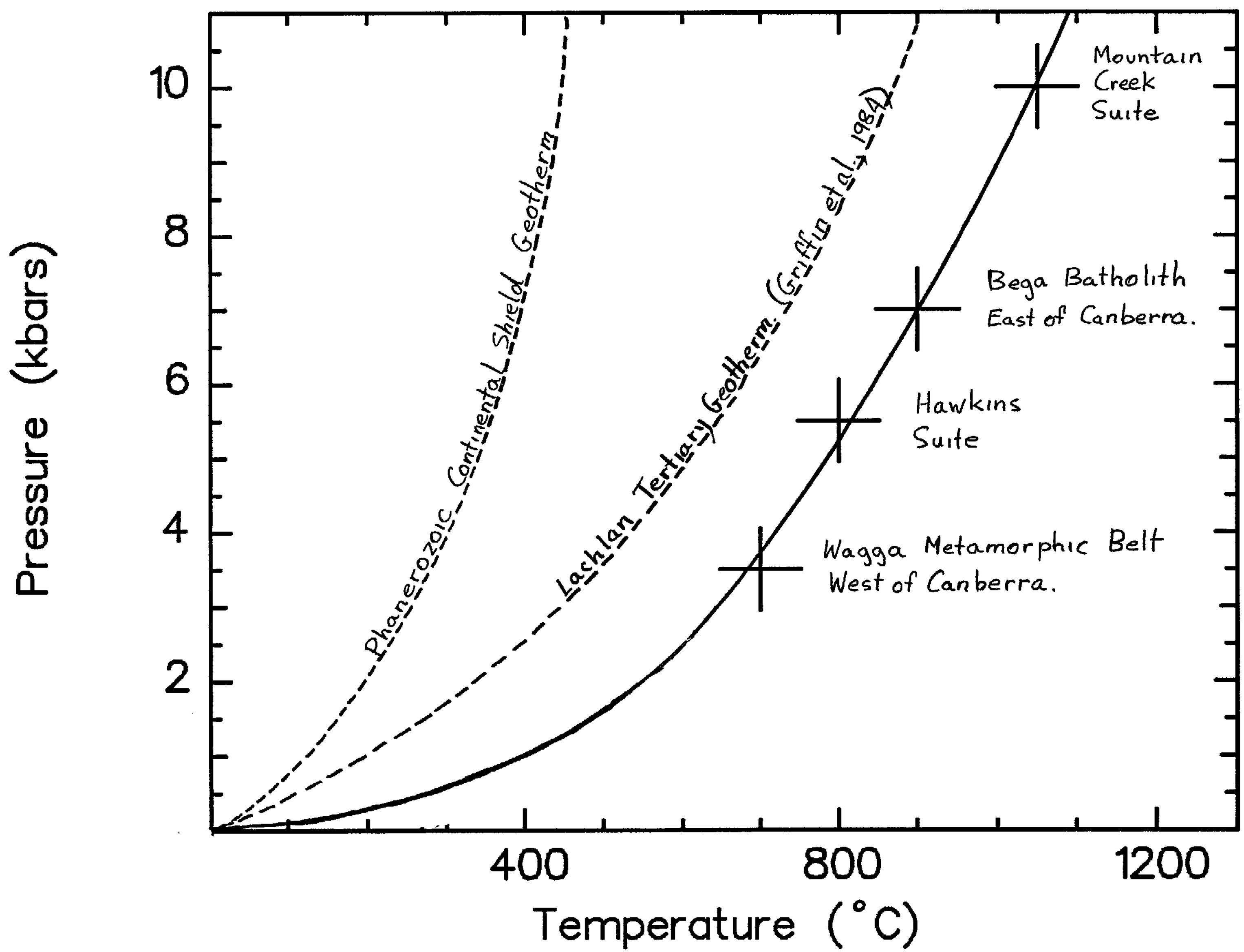
(i) Hawkins Suite

(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 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.

# Figure 1: Lachlan geotherm.



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 porpyritic 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 by BMR in the late 1970's and the three volcanic suites were recognized that a unified understanding of the stratigraphy emerged (figure 2 and stratigraphic column).

(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 do occur in the Lachlan Fold Belt that were derived from the Ordovician. 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 (Sn) **(STOP 3)**, which is interbedded in the fossiliferous

## CANBERRA REGION STRATIGRAPHIC COLUMN

EARLY DEVONIAN — MURRUMBIDGEE GROUP — limestone, shale, fossiliferous

MOUNTAIN CREEK SUITE — * MOUNTAIN CREEK VOLCANICS (Dmv) rhyolite lava, ignimbrite, airfall tuff, breccia

UNCONFORMITY uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu

LATE SILURIAN — YASS BASIN shale, limestone and siltstone, abundant fossils

LAIDLAW SUITE
- * LAIDLAW VOLCANICS (Slv) composed mainly of a single dacitic ignimbrite, and possibly laterally equivalent to the URIARRA VOLCANICS (Suv)
- * URIARRA VOLCANICS (Suv) including TARPAULIN CREEK ASHSTONE MEMBER at base mainly dacitic ignimbrite and airfall deposits
- * DEAKIN VOLCANICS (Sdv) including MUGGA MUGGA PORPHYRY MEMBER (Smv) at base interbedded dacitic lavas, ignimbrite and reworked sediments

EROSIONAL UNCONFORMITY uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu

LATE SILURIAN — YASS GROUP — YARRALUMLA FORMATION shale, sandstone, limestone, fossils

HAWKINS SUITE
- * MOUNT PAINTER VOLCANICS (Spv) composed mainly of a single dacitic ignimbrite with the LYONS ASHSTONE at top
- unnamed shale, sandstone and limestone near Fairlight, fossiliferous
- * MOUNT AINSLIE VOLCANICS (Sav) WALKER VOLCANICS (Swv) PADDYS RIVER VOLCANICS (Srv) dacitic lava, ignimbrite, interbedded sediments

* CANBERRA FORMATION (Smc) including NARRABUNDAH ASHSTONE (Sn) near top siltstone, shale, limestone, sandstone, fossiliferous

UNCONFORMITY uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu

EARLY SILURIAN — BLACK MOUNTAIN SANDSTONE (Sls) quartz sandstone

* STATE CIRCLE SHALE (Sls) siltstone, shale, sandstone, rare fossils

UNCONFORMITY uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu

ORDOVICIAN — PITTMAN FORMATION (Op) including graptolitic ACTON SHALE MEMBER quartz-rich greywacke, shale

* to be examined on excursion
symbols refer to units shown in geological sketch

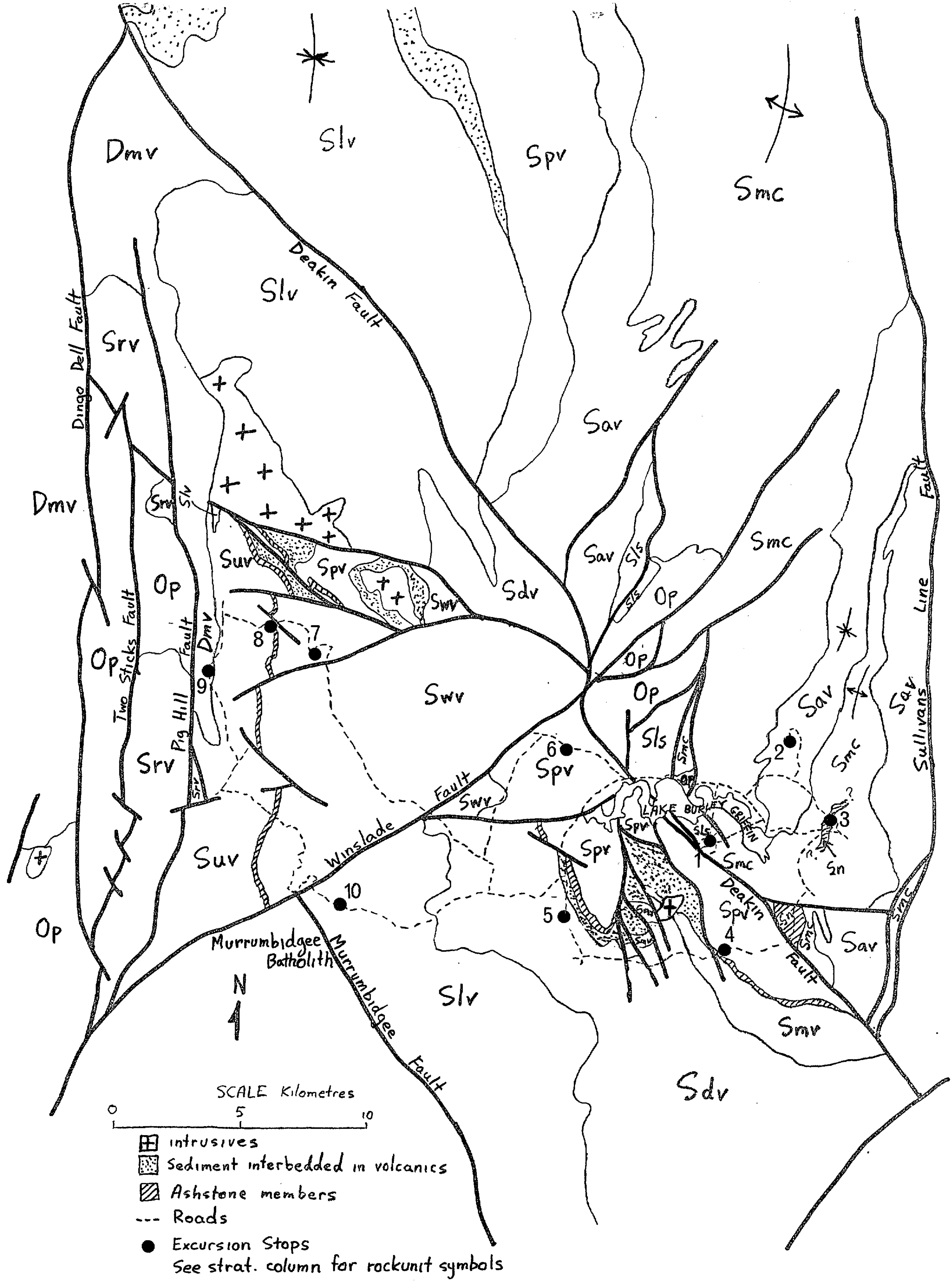



FIGURE 2. GEOLOGICAL SKETCH.

Early Silurian Canberra Formation (Smc). This is soon succeeded by a thick sequence of shallow marine to subaerial volcanics, the Ainslie Volcanics (Sav). Further west other names (Walker Volcanics-Swv **(STOP 7)**, and Paddys River Volcanics-Srv) 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 new. 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 An50. In the granitic equivalents, orthopyroxene is absent, but cordierite and infrequent garnet are present. In the granites the plagioclase grains have broad An50 cores and narrow strongly zoned rims down to An20. 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 mobilized, 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 (i.e. the composition of the lower to middle crust). Thus the granites map or image the compositional variations of the deep crust. This has provided a powerful argument in the dispute between the oceanic model and the basement-cover model for the 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% crystal of the same variety as in the lower units) and known as the Mount Painter Volcanics (Spv) **(STOPS 4 and 6)**. 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. 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 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 **(STOP 4)**, 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).

(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 (An70-An35) 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 crystallized from the melt during ascent and cooling. The Laidlaw Suite is thought to be derived from a feldspathic 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 (Smv) **(STOP 4)**. This is overlain by a sequence of lavas and ignimbrites known as the Deakin Volcanics (Sdv) **(STOP 5)**. 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 (Slv) **(STOP 9)**. This unit can be mapped north of Yass and has a total strike length of about 100km. It could 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.

West of the Murrumbidgee River the Hawkins Suite is overlain by a volcanic unit known as the Uriarra Volcanics (Suv). 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 oxidized. At the base is a bedded ashstone, the Tarpaulin Creek Ashstone Member **(STOP 8)**, 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.

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. 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 stronger to the west in a sequence of Silurian sediment known as the Tumut Trough. The Mountain Creek Volcanics (Dmv) **(STOP 9)** 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 is 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. 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 3).

Figure 3

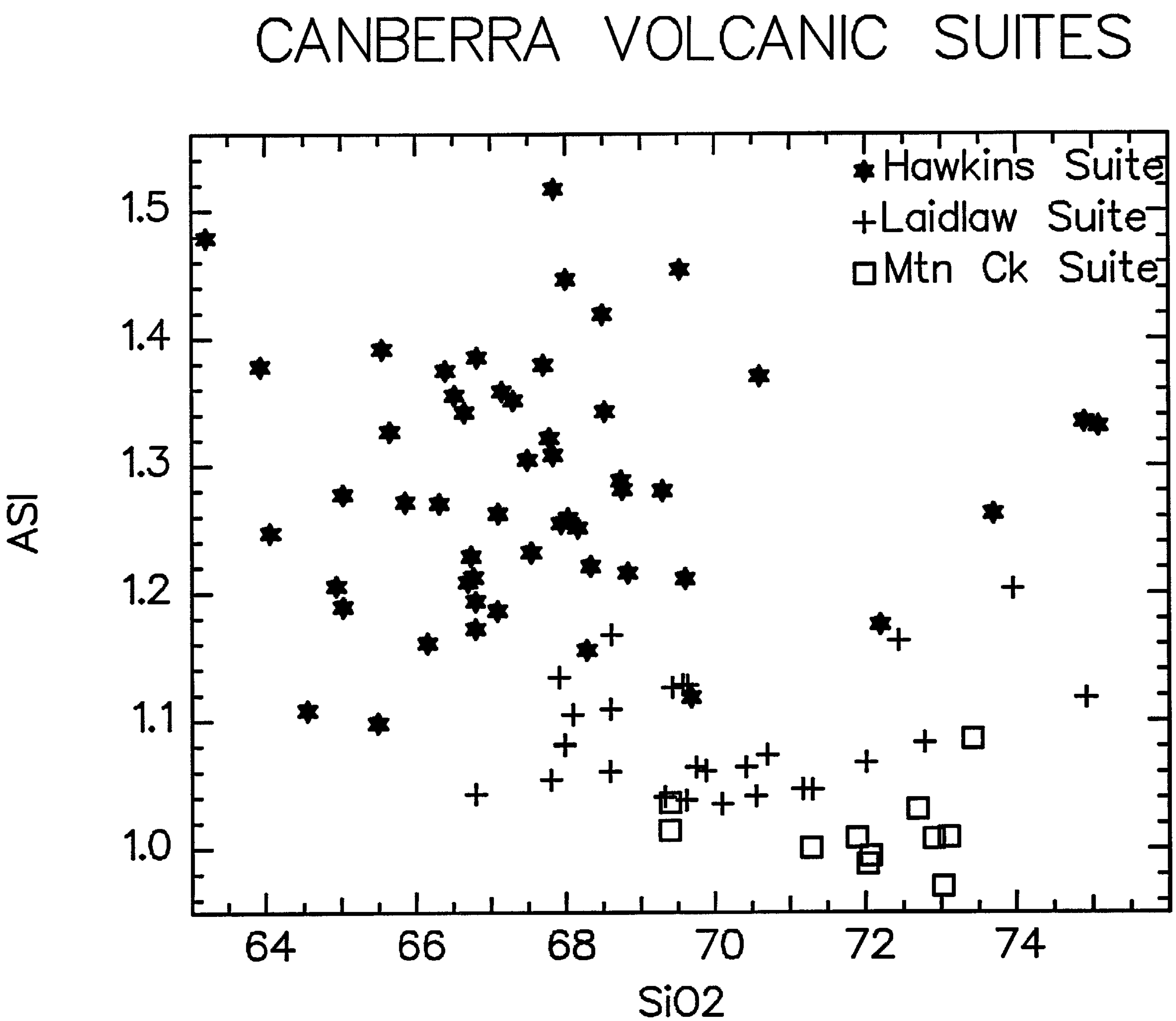

CANBERRA VOLCANIC SUITES
Hawkins Suite
Laidlaw Suite
Mtn Ck Suite
1.5
1.4
1.3
1.2
1.1
1.0
ASI
64
66
68
70
72
74
SiO2

TABLE 1: AVERAGE CHEMICAL COMPOSITIONS OF SOME VOLCANIC UNITS

| Volcanic Unit | Walker | Mt.Painter | Laidlaw | Mtn Ck |
|---|---|---|---|---|
| no. of analyses | 13 | 9 | 26 | 11 |
| $SiO_2$ | 67.82 | 66.30 | 70.00 | 71.89 |
| $TiO_2$ | .56 | .59 | .43 | .53 |
| $Al_2O_3$ | 13.99 | 13.93 | 14.17 | 13.93 |
| $Fe_2O_3$ | 1.85 | .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 |
| $Na_2O$ | 2.28 | 1.86 | 2.74 | 3.62 |
| $K_2O$ | 4.49 | 3.58 | 3.31 | 4.29 |
| $P_2O_5$ | .12 | .11 | .09 | .07 |
| $H_2O+$ | 2.18 | 2.47 | 1.23 | .53 |
| $H_2O-$ | .19 | .10 | .11 | .05 |
| $CO_2$ | .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 |

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 earliest part of the Devonian.

## EXCURSION STOPS

### STOP 1 State Circle Roadcut Unconformity

This cutting on State Circle, immediately north-east of the lawns of Parliament House, is a protected ACT geological monument and is also on the register of the National Estate. It exposes a tectonic break between the State Circle Shale and the overlying Camp Hill Sandstone Member of the Canberra Formation. Both formations are cut by block faults. Spectacular slump folding of the shales and sedimentary boudinage of a sandstone layer are seen below the unconformity.

### STOP 2 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 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 stepfaults 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 Mount Ainslie Volcanics which conformably overlie the sequence of shallow marine sediments of the Canberra Formation. 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 lower 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 lower 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. 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.

## STOP3 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 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.

**STOP 4 Mount Painter Volcanics and Mugga Mugga Porphyry on Hindmarsh Drive**

At this locality we will walk up section along Hindmarsh Drive through the Mount Painter ignimbrite and Lyons Ashstone, across a fault and into the base of the Mugga Mugga Porphyry Member of the Deakin Volcanics. Flattened pumice fragments, though difficult to see in the outcrops indicate the ignimbrite dips west at 20°. The fragments are better exposed in boulders removed from the side of the road at the start of the section. They are crystal-rich (50%) and coarser grained than the host ignimbrite which contains 80% crystals. Altered cordierite and orthopyroxene occur as prismatic crystal which are difficult to distinguish in most examples. Fragments of garnet can be found on close inspection. Lithic fragments include fine quartz sandstone, epidote-rich marly siltstone, quartz-feldspar porphyry, microgranite and vein quartz.

At the top of the hill the ignimbrite is intruded by a porphyry intrusion containing scattered K-feldspar phenocrysts to 3cm across. The intrusion has fine grained banded margins several metres wide and is about 70m thick. Above the porphyry, which probably belongs to the Laidlaw Suite, Mount Painter ignimbrite is again exposed and overlain by the Lyons Ashstone. There is then a break in outcrop which corresponds to the Yarralumla Formation. At the next roadcut weathered altered sediments and tuffaceous material contain pyritized pods of mineralization, which are in turn faulted against the coarse basal part of the Mugga Mugga Porphyry Member. The grainsize is suggestive of an intrusive origin at this locality.

**STOP 5 Deakin Volcanics on Tuggeranong Parkway**

At this locality some interesting relationships can be examined between ignimbrites of the Deakin Volcanics and interbedded volcanic sediments. Some coarse quartz sandstones are composed almost entirely of $\beta$-quartz grains reworked from the volcanics.

LUNCH ON LAKE BURLEY GRIFFIN aboard the SS Lady Clare

**STOP 6 Mount Painter Volcanics on William Hovell Drive**

This locality on the southern slopes of Mount Painter is similar to **Stop 4**, but it contains very prominent crystal-rich flattened pumice fragments, the largest up to 30*10cm. In places they occupy 50% of the rock. Several large garnets are conspicuous on the outcrop. The ignimbrite dips at <10° to the south-east. A similar lithic population is present to **Stop 4**, but fragments are bigger and more numerous. This locality is probably close to the centre of eruption.

**STOP 7 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.

**STOP 8 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 airfall? 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 8** there seems to be a facies change into the Laidlaw ignimbrite. The depositional differences between the Laidlaw and Uriarra ignimbrites are not understood.

### STOP 9 Mountain Creek Volcanics opposite Brookvale on Mountain Creek Road

This is the only easily accessible reasonable outcrop of the Mountain Creek Volcanics, but demonstrates the contrast between it and the Silurian volcanic units reasonably well. Much better outcrops are present in the mountains to the west, where crystal-poor lava domes, flow banded lavas and ignimbrites, airfall deposits and breccias are well-exposed. The weathered lava? at this outcrop is rather more crystal-rich than normal, but still contains only about 20% phenocrysts, almost entirely of plagioclase. Quartz is absent. The rhyolite lavas commonly have <10% phenocrysts of plagioclase (An60-70) and two pyroxenes, though fresh orthopyroxene has never been found. Unlike the Silurian volcanics, the Mountain Creek suite do not contain any restite phenocrysts.

### STOP 10 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 kilometers. The ignimbrite is thought to be an erupted pluton. It is thought to be S-type, and derived from a feldspathic source, rather than a pelitic source. The rock is crystal-rich, with about 65% phenocrysts of quartz, plagioclase (zoned An70-An35), sanidine (Or70-Or76), hypersthene (mg 50-60), biotite, ilmenite, allanite, and magnetite. 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.

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