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IAVCEI CANBERRA 1993

EXCURSION GUIDE

TUMUT REGION

P.G. Stuart-Smith and K. A. Dadd

GENERAL ASSEMBLY
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Record 1993/60
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Tumut Region

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by

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IAVCEI, CANBERRA 1993
INTRACONFERENCE FIELD TRIP B2: TUMUT REGION

EXCURSION GUIDE

by

P.G. Stuart-Smith[1] and K.A. Dadd[2]

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION
RECORD 1993/

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ITINERARY

Depart Canberra 8.30 a.m.

STOP 1 (30 minutes) Goobarragandra Volcanics, Hume Highway.
STOP 2 (30 minutes) Gatelee Ignimbrite, Tumut River bridge, Brungle.
STOP 3 (30 minutes) Wyangle/Blowering Formations, Brungle Creek.

LUNCH (1 hour) Brungle Creek.
STOP 4 Wyangle Formation, Brungle Creek.

STOP 5 (1 hour) Blowering Formation/Honeysuckle Beds contact.
STOP 6 (30 minutes) Mundongo formation, Lowthers Lane.
STOP 7 (30 minutes) Faulted Coolac Serpentinite/Young Granodiorite contact, Bumbolee Creek Road.
STOP 8 (optional if time permits) Frampton Volcanics, Gundagai Quarry.

DINNER 7.00 - 9.30 p.m. The Vineyard restaurant, Murrumbateman.

Return to Canberra 10.00 p.m.

INTRODUCTION

The Tumut region, about 100 km west of Canberra, was the site of shallow-marine deposition in one of a number of extensional basins which developed during the Silurian within the Lachlan Fold Belt on extensive Ordovician quartz-rich flysch deposits. The main objective of this excursion is to examine some of the excellent exposures of Silurian basinal S-type felsic volcanics and their relationship to intercalated sediments and pillow basalt. In addition other features to be examined include: Devonian I-type ignimbrite; Early Silurian rhyolite; and the Mooney Mooney Fault Zone, a major tectonic zone in the region containing the Coolac Serpentinite. The excursion route and stops are shown in Figure 1.

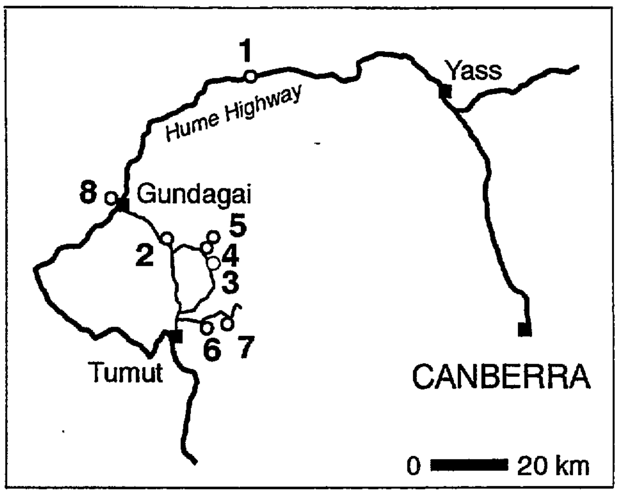


Fig. 1. *Excursion route and locality map.*

REGIONAL GEOLOGY

The geology of the eastern part of the Tumut region is given in Figure 2 and diagrammatic stratigraphic relations are shown in Figure 3.

The Tumut region covers the southern part of the Tumut Synclinorial Zone (Scheibner, 1985), an Early Palaeozoic tectono-stratigraphic province in the southeastern part of the Lachlan Fold Belt, southeastern New South Wales. The zone is bounded by the NW-trending Mooney Mooney and Gilmore Fault Zones, separating the Synclinorial Zone from, respectively, the Goobarragandra Block to the east and the Wagga Metamorphic Belt to the west. The Goobarragandra Block comprises mainly Silurian granitoids and their coeval waterlain to subaerial volcanics, mafic intrusions, and minor Silurian shallow-marine sediments. The Wagga Metamorphic Belt consists of Ordovician flyschoid metasediments and volcanics, and Silurian felsic and mafic intrusions (Basden, 1990).

The basement rocks in the area are **Cambrian-Ordovician** in age, comprising mainly greenschist facies mafic and ultramafic rocks. These rocks occur as interpreted metamorphic core complexes (Stuart-Smith, 1990a) and in fault-bounded allochthonous blocks. Extensive ultramafic belts within the Mooney Mooney and Gilmore Fault Zones, such as the Coolac Serpentinite, may also be part of this basement (Stuart-Smith, 1990b).

Ordovician to Late Silurian flyschoid metasediments and felsic and mafic volcanics form two tectonostratigraphic sequences either structurally emplaced over or unconformably overlying basement rocks. The older of these two sequences consists largely of undated **quartz-rich to quartz-intermediate flyschoid metasediments and mafic and minor felsic volcanics.** These rocks (eg. Frampton Volcanics), deposited in deep to shallow-water environments, were deformed and metamorphosed during the Early Silurian **Benambran Orogeny,** and are overlain by dated **Early/Late Silurian S-type felsic volcanics, mafic volcanics, and minor fossiliferous quartz-poor to quartz-intermediate flysch** (e.g. Wyangle Formation, Blowering Formation, Honeysuckle Beds). The latter volcanics and sediments form the *Tumut Basin*. Locally **tholeiitic dyke complexes** intruded during an extensional event which accompanied this later period of volcanism.

During the Siluro-Devonian **Bowning Orogeny** the Early/Late Silurian and older strata were meridionally folded and metamorphosed to lower greenschist facies following intrusion of **S- & I-type granitoids** (e.g. Young Granodiorite). These granitoids, forming only a minor constituent of the Tumut Synclinorial Zone, are the dominant rock types in the adjacent Wagga Metamorphic Belt to the west and the Goobarragandra Block to the east.

Early Devonian post-kinematic I-type granitoids (e.g. the Bogong and Killimicat Granites) intrude older units and are associated with coeval **shallow-water to subaerial ignimbrite and minor sediments** (e.g. Minjary Volcanics, Gatelee Ignimbrite). These volcanic sequences form remnant subhorizontal sheets unconformably overlying older strata and granitoids. Minor outliers of flat-lying **Tertiary basalt and minor sediments** also unconformably overlie older rocks, commonly forming hill-top cappings in the region.

Representative geochemical analyses of selected volcanic rocks from the Tumut region are given in Table 1.

EARLY TO LATE SILURIAN VOLCANIC ROCKS AND ASSOCIATED SEDIMENTARY ROCKS OF THE TUMUT REGION

The Silurian Blowering Formation and Goobarragandra Volcanics in southeastern N.S.W., Australia (Fig. 2), comprise predominantly crystal-rich dacitic volcaniclastic rocks and less abundant fine-grained, volcanogenic sedimentary rocks locally overlying basal quartz-poor flysch of the Wyangle Formation. The

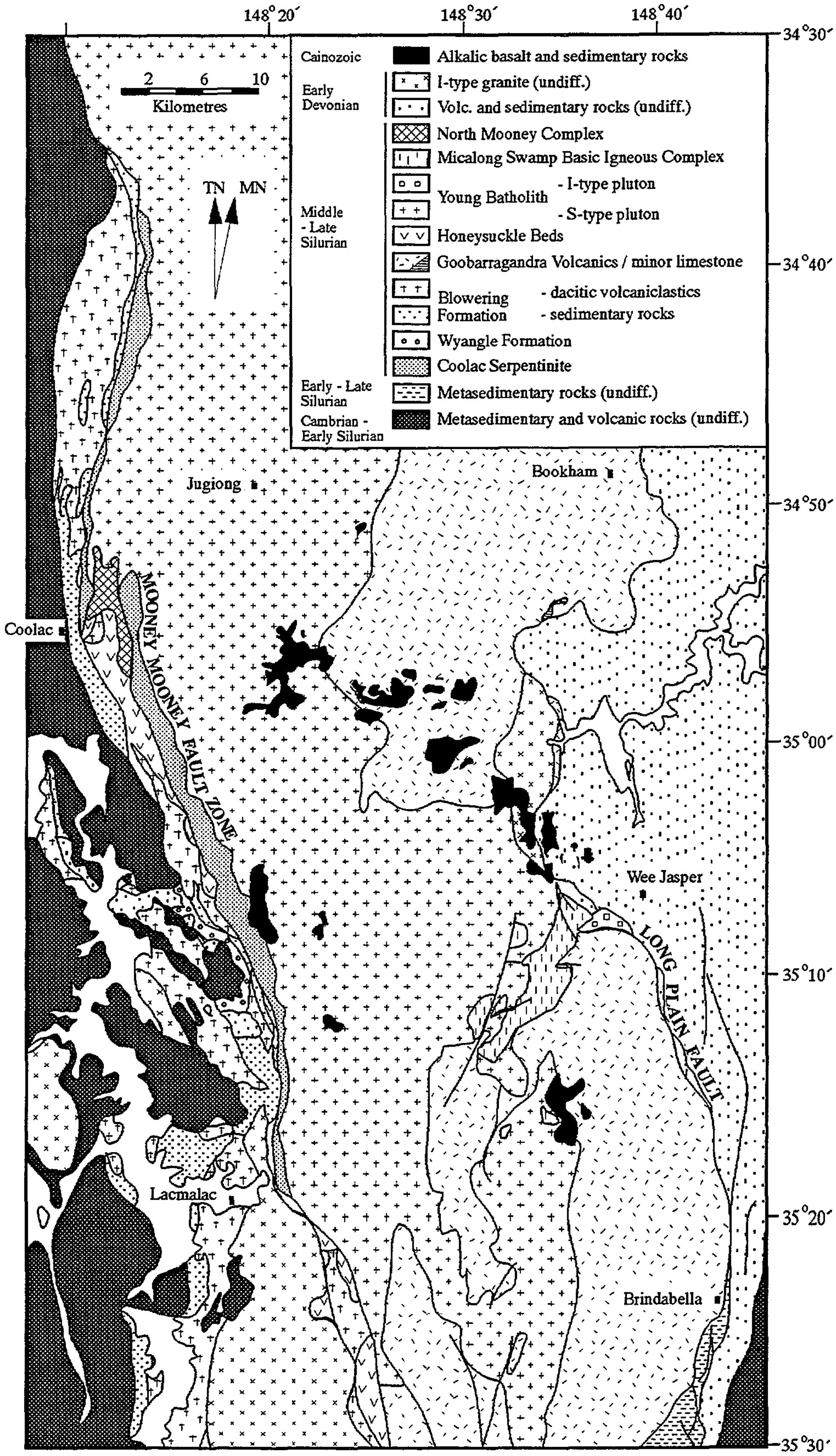


Fig. 2. *Location of the Blowering Formation (including Mundongo formation), Goobarragandra Volcanics and the Honeysuckle Beds. Simplified geology taken from Cramsie & others (1975), Fitzpatrick (1976), Owen & Wyborn (1979) and Basden (1990).*

dacitic rocks have been interpreted as ash flow and air fall tuffs (Owen & Wyborn, 1979; Basden, 1990). However parts of these sequences contain a significant proportion of intercalated sedimentary rocks, ranging in abundance from approximately 50% in the west within the Blowering Formation (informal name for sedimentary component: Mundongo formation) to almost 10% in the north and 1-2 % in the south within the Goobarragandra Volcanics. The Wyangle Formation, coarser parts of the Mundongo formation and sedimentary rocks in the northern Goobarragandra Volcanics contain fossil assemblages and a range of sedimentary structures indicating a marine depositional environment and that deposition was below wave base, dominantly by mass flow processes (Lightner, 1977). A similar depositional setting must have existed, at least in part, for the fine-grained sedimentary rocks of the Mundongo formation and for the intercalated coarse-grained, crystal-rich dacitic rocks of the Blowering Formation and Goobarragandra Volcanics, though most of the sediment-poor Goobarragandra Volcanics in the south is subaerial.

The Honeysuckle Beds (Fig. 2), a sequence of pillow basalt and fine-grained sedimentary rocks, occur to the east of the Blowering Formation. They were included by Ashley and others (1979) within a disrupted ophiolite sequence which included the Coolac Serpentinite to the east and the North Mooney Complex, and were thought by Ashley and others (1983) to represent the upper part of layer 2 and layer 1 of oceanic crust. Recent field mapping (Stuart-Smith, 1990b; Warner & others, 1992) within the Honeysuckle Beds and Blowering Formation, to the west, demonstrated that the Honeysuckle Beds are largely east-facing and dipping, and are interbedded with the uppermost Blowering Formation, thus placing them at the top of the Tumut Basin sequence, a position which is incompatible with them forming part of the disrupted ophiolite as previously interpreted.

Wyangle Formation

Quartz-poor flysch deposits of the Wyangle Formation unconformably overlie or are faulted against Cambrian-Ordovician basement and Ordovician-Early Silurian metabasalt. Where not faulted, the lower contact reflects an unconformable onlapping relationship. In places the overlying Blowering Formation oversteps the unit to rest directly on older rocks (Stuart-Smith, 1990a). The formation is conformably overlain, intruded by or intertongues with the Blowering Formation.

Allochthonous fossiliferous limestone clasts within diamictite contain conodonts of probable late Llandoverian - early Wenlockian age (Lightner, 1977), indicating a maximum age for the unit. However, the formation is probably considerably younger as other clasts contain ?Late Silurian *Tryplasma* and ?*Mazaphyllum* (Crook & Powell, 1976) and conformably overlying and intertonguing Blowering Formation strata contain early to middle Ludlovian allochthonous clasts (Lightner, 1977).

The formation comprises a sequence, up to 600 m thick, of interbedded fine to coarse grained quartz-poor and quartz-intermediate arenite, volcanilithic pebble and boulder conglomerate, diamictite, shale, mudstone and tuff. Although poorly exposed relative to the coarser clastics, weakly cleaved shale and mudstone probably account for over 50% of the unit. The conglomerate and diamictite are interpreted to represent debris-flow deposits (Kennard, 1974; Crook & Powell, 1976).

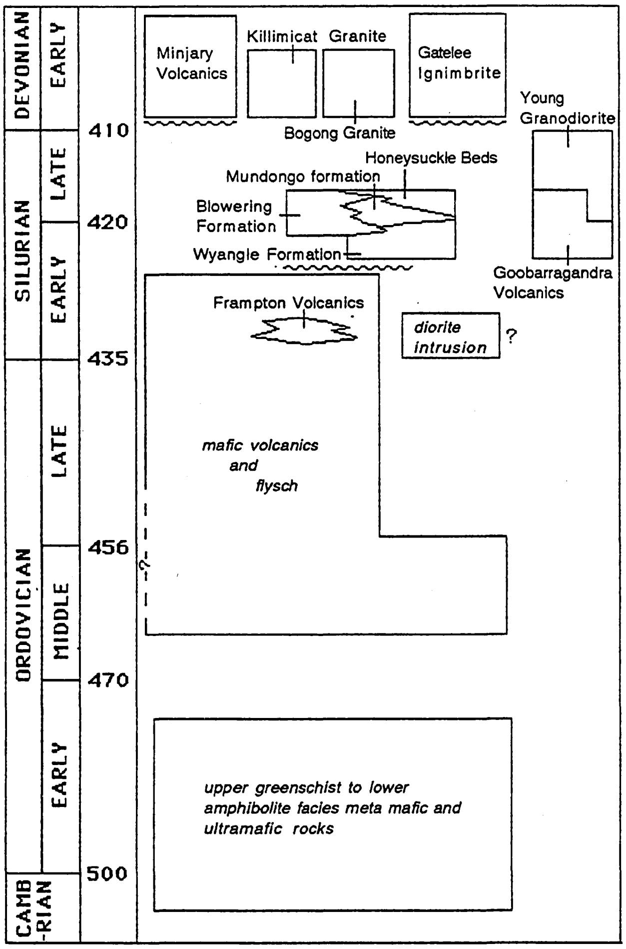


Fig. 3. *Diagrammatic Palaeozoic stratigraphy of the Tumut region.*

The quartz-poor arenites consist predominantly of plagioclase and mafic and dacitic volcanic rock fragments (Fig. 4). Detrital quartz grains constitute less than 2% with plagioclase 40-45%, amphibole up to 8%, and pyroxene less than 4% (Basden, 1990). The composition of the detrital clinopyroxene grains, and phenocrysts in mafic clasts, is similar to those in underlying Ordovician-Early Silurian mafic rocks (Stuart-Smith & others, 1992), indicating a probable local source for the flysch. Dacitic volcanics of the Blowering Formation also contributed, with dacitic

Table 1. Representative analyses from the Blowering Formation, Goobarragandra Volcanics, Honeysuckle Beds, Frampton Volcanics and Gatelee Ignimbrite. ANU#33320 from Kennard (1974).

Unit	Blowering Formation	Blowering Formation	Goobarrag. Volcanics	Goobarrag. Volcanics	Honeysuckle Beds	Honeysuckle Beds	Frampton Volcanics	Gatelee Ignimbrite
Grid Ref.	18649523	15841590	31942160	33722068	28268431	12962585	97882131	17800940
Sample No.	K90-66/5	K90-145	K91-393	K91-430	K90-49/1	K92-679	K91-350/1	ANU#33320
SiO2	67.67	68.64	70.45	69.44	53.47	50.65	73.48	73.09
TiO2	0.64	0.58	0.51	0.57	0.89	0.67	0.39	0.32
Al2O3	14.55	14.53	13.84	14.05	16.79	16.38	13.52	13.76
Fe2O3	0.86	1.13	0.62	1.74	3.4	2.32	0.87	1.16
FeO	3.66	3.17	2.88	3.14	4.38	4.61	1.76	0.46
MnO	0.07	0.07	0.06	0.09	0.15	0.11	0.04	0.04
MgO	1.93	1.85	1.46	1.3	6.61	8.96	0.6	0.12
CaO	1.93	1.85	0.97	1.69	6.38	9.59	1.46	1.58
Na2O	2.58	2.67	2.92	4.38	5.49	2.44	1.87	3.59
K2O	3.65	3.5	4.21	1.81	0.64	0.37	4.3	4.55
P2O5	0.13	0.1	0.09	0.14	0.1	0.14	0.17	0.06
L.O.I.	1.96	1.74	1.76	2.02	2.06	3.51	1.66	1.17
Total	99.62	99.83	99.78	100.38	100.36	99.75	100.12	100.13
Ba	498	568	573	397	67	201	874	705
Cr	62	50	34	3	295	378	15	
Cu	5	13	8	6	19	59	11	11
Ni	20	14	19	14	99	153	5	
V	90	88	11	11	208	182	36	16
Zn	61	64	11	1	68	52	56	40
Zr	188	183	223	8	108	66	191	241
Y	36	64	44	92	29	21	31	32
Nb	13	11	11	168	4	3	13	10
Pb	20	18	14	11	4	6	23	23
Rb	170	168	179	3	28	11	174	201
Sr	138	149	106	62	256	307	204	246
Th	17	15	23	31	3	5	17	
U	4	4	4	75		1	5	

clasts and mineral grains becoming more common in the upper parts of the unit.

Massive dacitic volcaniclastic rocks of the Blowering Formation and Goobarragandra Volcanics

A massive dacitic volcaniclastic rock is the most widespread facies within the Blowering Formation and northern Goobarragandra Volcanics, occurring as rounded tors or rubbly outcrop of massive and typically coarse crystal-rich dacite (MDV). Crystals are typically fragmented and include volcanic quartz up to 1.5 cm (10-20%), plagioclase up to 2 cm (15-20%), biotite up to 5 mm (2-10%) and minor altered hornblende (Fig. 5). Some samples contain rare garnet crystal fragments up to 1.5 cm and most samples have accessory zircon and apatite. Lithic clasts (<1 %) include micro-graphic tonalite, plagioclase-biotite-chlorite hornfels, rare metaquartzite and quartz fragments up to 15 cm. The quartz fragments are a feature of S-type granites and associated volcanic rocks in the Lachlan Fold Belt of southeastern Australia according to Wyborn and others (1991), who interpret them as fragments of vein quartz derived from the metamorphic parent rocks of the granite. The matrix is typically recrystallised and comprises fine-grained quartz, feldspar and biotite. Few primary textures are preserved in the matrix.

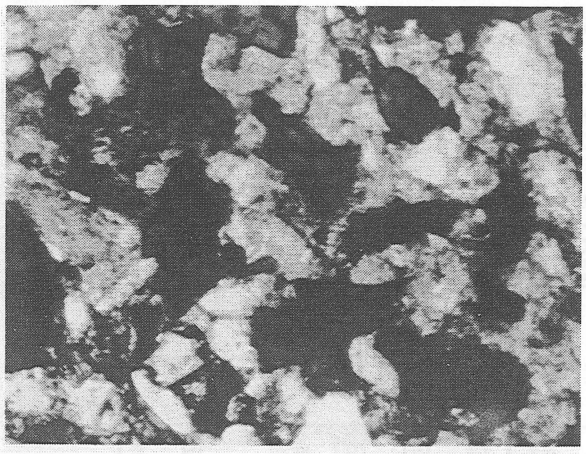


Fig. 4. *Photomicrograph of typical quartz-poor arenite of the Wyangle Formation, showing detrital hornblende (dark) and plagioclase (pale). Plane polarised light. Bar scale is mm.*

The bases and tops of units in the MDV are rarely preserved, but where they occur, they consist of zones, typically 1-10 cm, but up to 50 cm thick, of poorly sorted, lithic-rich dacitic crystal wacke. They are interpreted as either air fall tuff layers, where their lower contacts are sharp, or products of deposition from suspensions of fine material associated with the main dacitic debris flow.

The MDV units lack primary internal stratification or other sedimentary structures. Most outcrops of MDV lack evidence of hot emplacement. The thick, massive and poorly sorted nature of beds suggests they were deposited from debris flows (Dadd, 1992) in which the dominant support mechanism is matrix strength (Middleton & Hampton, 1973). Movement of the sediment mass as a rigid plug would account for the lack of grain shape modification, and for the presence of large, matrix-supported lithic clasts.

The MDV facies is interstratified with the siltstone-arenite-conglomerate facies of the Mundongo formation and includes outcrop-size blocks of most other facies. Rare outcrops of the MDV contain rootless and irregular folded and graded fine-grained dacitic arenite layers within the otherwise massive dacitic rocks (Stop 3). Several breccia types (e.g. Stop 1) occur only as large blocks or scattered areas of outcrop (up to about 20 m across) surrounded by outcrop of the MDV facies.

In rare outcrops, underlying units adjacent to massive dacitic rocks are hornfelsed indicating that the dacite was hot when emplaced. These units are typically conformable with surrounding units and are interpreted as sills comagmatic to rocks of the MDV facies.

Rocks of the MDV facies often contain almandine garnet and cordierite. Volcanic rocks of similar composition elsewhere in the Blowering and Goobarragandra Volcanics are classified as S-type (Chappell & White, 1974). S-type rocks are thought to

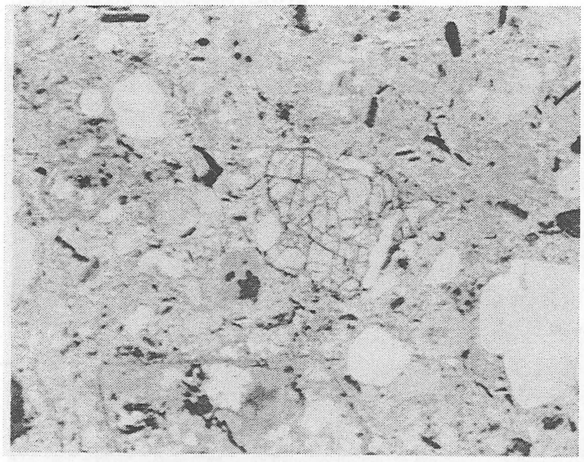
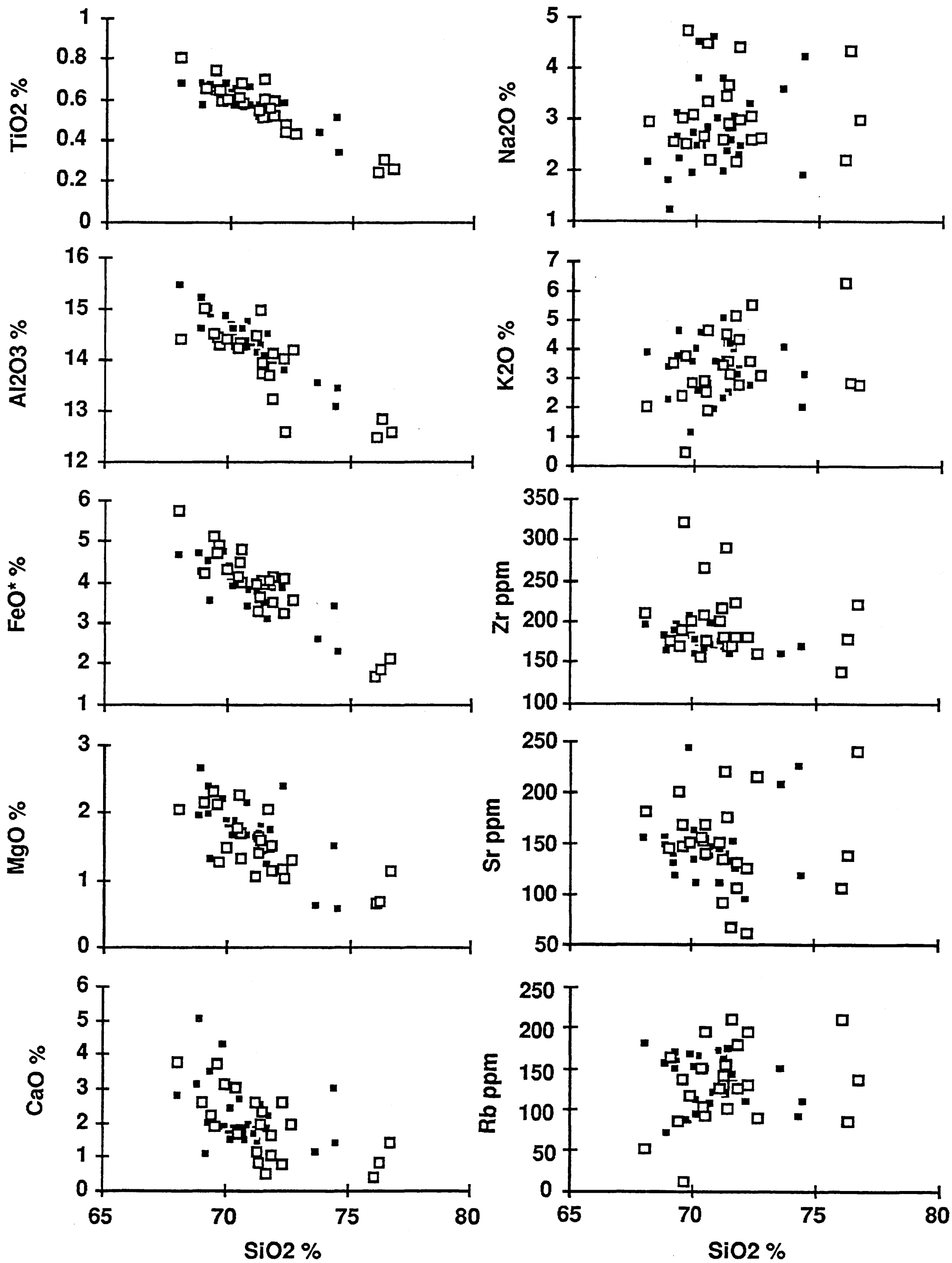


Fig. 5. *Photomicrograph of a massive dacitic volcaniclastic rock from the Blowering Formation. Crystals include volcanic quartz, plagioclase, biotite, minor altered hornblende, and garnet. The crystals are typically fragmented and the matrix which comprises fine-grained quartz, feldspar and biotite is recrystallised. Plane polarised light. Bar scale is mm.*

be derived from the melting of metasedimentary parent material and to be composed of a two component mix of melt and residual crystal mush. Trends on Harker variation diagrams should therefore be straight lines with the melt composition at the high silica end and the source composition toward the mafic end (Owen & Wyborn, 1979). Major element abundances of samples from the Goobarragandra Volcanics and the Blowering Formation (Fig. 6) largely conform with this ideal. TiO_2, Al_2O_3, FeO*, MgO and P_2O_5 show decreasing abundances with increasing silica. The elements that are concentrated into the feldspars including CaO, Na_2O and K_2O, have a considerable spread on the variation diagrams possibly due to the alteration of feldspar crystals but also due to alteration and devitrification of the originally glass-rich matrix during burial metamorphism.

The spread of trace element values on the Harker variation diagrams is difficult to interpret. The more mobile elements, Ba, Rb, and Sr show a considerable scatter and this is likely due to alteration of the felspars and alteration and devitrification of glass in the matrix. Zirconium abundances show a slight decrease with increasing silica, consistent with the zircon being found largely within biotite, a feature of S-type granites (Owen & Wyborn, 1979). Several analyses have elevated Zr, with values as high as 320 ppm.

The massive dacitic rocks have steep REE profiles (Fig. 7), with LREE approximately 100 times chondrite and HREE 15 times chondrite. All samples have similar shaped profiles with negative europium anomalies indicating one main source and feldspar fractionation. Flat HREE patterns indicate feldspar **Fig.**



6. Harker variation diagrams of major and trace element abundances in samples from the Goobarragandra Volcanics and Blowering Formation. The straight line trends should represent mixing trends between the melt composition at the high silica end and the source composition toward the mafic end (Owen & Wyborn, 1979). The spread of data on the CaO, Na_2O and K_2O diagrams is probably due to alteration of the feldspars and devitrification of the groundmass. The scatter on the Sr, Rb and Ba diagrams is likely due to alteration of feldspar and devitrification and alteration of the groundmass. Zr is largely controlled by biotite.

rather than garnet residue in source during partial melting.

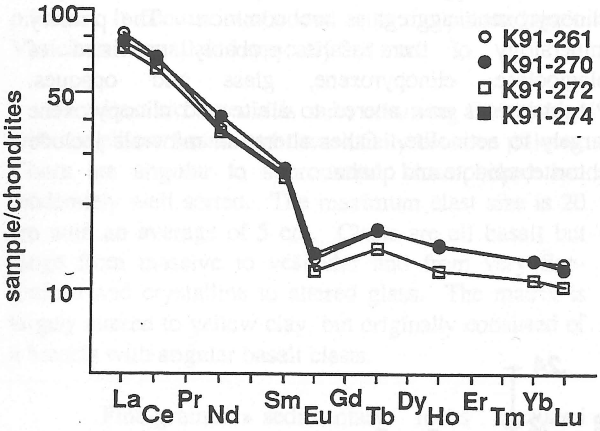


Fig. 7. *Rare earth element profiles for samples from the Goobarragandra Volcanics and Blowering Formation. All profiles are a similar shape with steep trends and a europium anomaly.*

Mundongo formation

The Mundongo formation (informal name) consists of epiclastic rocks ranging from mudstone to conglomerate. The dominant lithologies are feldslitharenite and siltstone. Grains comprise plagioclase, quartz, lithic fragments, biotite, minor chlorite aggregates after magmatic mafic minerals and rare zircon. The lithic clasts include dacitic volcaniclastics, basalt and chert. Arenite is dominant although wackes are also abundant.

Stratification in the finer-grained sedimentary rocks ranges from lamination to thick bedding. Both graded and ungraded arenite beds are present and some beds have poorly developed cross lamination. All beds have sharp bases, some are erosional and others have rare flame and load structures. Angular rip-up clasts of fine-grained arenite and siltstone up to 5 cm in longest dimension occur in some medium-grained, graded arenite beds. Siltstone and mudstone at the top of many beds has planar lamination. Rare intraformational folds with no associated axial plane cleavage are interpreted as slumped structures.

Coarser-grained sedimentary rocks will not be examined during this trip. They are of variable character and range from pebble conglomerate to coarse breccia. Both matrix and clast supported varieties are present.

The Mundongo formation is most probably a series of mass flow units. The graded beds with sharp to erosional bases and laminated tops are interpreted as the products of deposition from turbidity currents although complete Bouma sequences are rarely present. Most beds begin with the A division and are overlain by a laminated B horizon but only a few beds have a cross-laminated or convoluted C division. Thin, laminated siltstone to mudstone beds intercalated with the graded beds are either individual D or E(t) horizons or beds of hemipelagic sediment (E(h)).

Fig. 8. *Photomicrograph of quench textures in basalt of the Honeysuckle Beds showing swallowtail and belt buckle plagioclase. Plane polarised light. Bar scale is mm.*

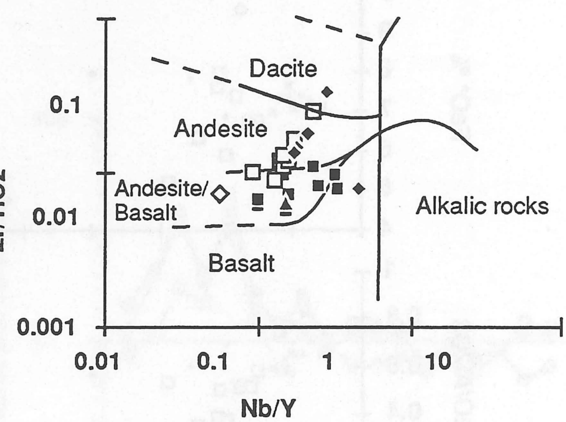


Fig. 9. *Nb/Y classification diagram (Winchester & Floyd, 1977) for mafic rocks of the Honeysuckle Beds. The mafic rocks range from basalt to andesite and are subalkalic.*

The Honeysuckle Beds

There are four main facies within the Honeysuckle Beds including pillow basalt, massive to vesicular basalt, basaltic breccia and a chert-siltstone-arenite association. Pillow basalts are the dominant lithology and may be more widespread than presently recognised due to the difficulty in recognising pillow structure in areas of poor outcrop or where deformation fabrics are intense. The chert-siltstone-arenite facies is the second most abundant and typically occurs overlying or interbedded with pillow basalt.

Pillows in the pillow basalt vary in shape from elliptical to dome-shaped to more irregular and from 15 cm to 80 cm across in outcrop. Pillow rinds are typically 1 cm thick and slightly finer-grained than pillow interiors. The interstices between pillows is an epidotised aphanitic rock or rarely laminated chert. Pillows with flat bases and domed tops, and pillows with irregular bases that fill the underlying uneven pillow surface, allow determination of younging direction.

The pillow basalts are altered and are a light grey-green colour and often very hard. The basalt ranges from porphyritic to even-grained and typically has quench textures including swallowtail and belt buckle plagioclase (Fig. 8), plumose and radiating acicular altered clinopyroxene and curved to fan-shaped clinopyroxene aggregates are common. The primary mineralogy of the basalts probably consisted of plagioclase, clinopyroxene, glass and opaques. Plagioclase is now altered to albite and clinopyroxene largely to actinolite. Other alteration minerals include chlorite, epidote and quartz.

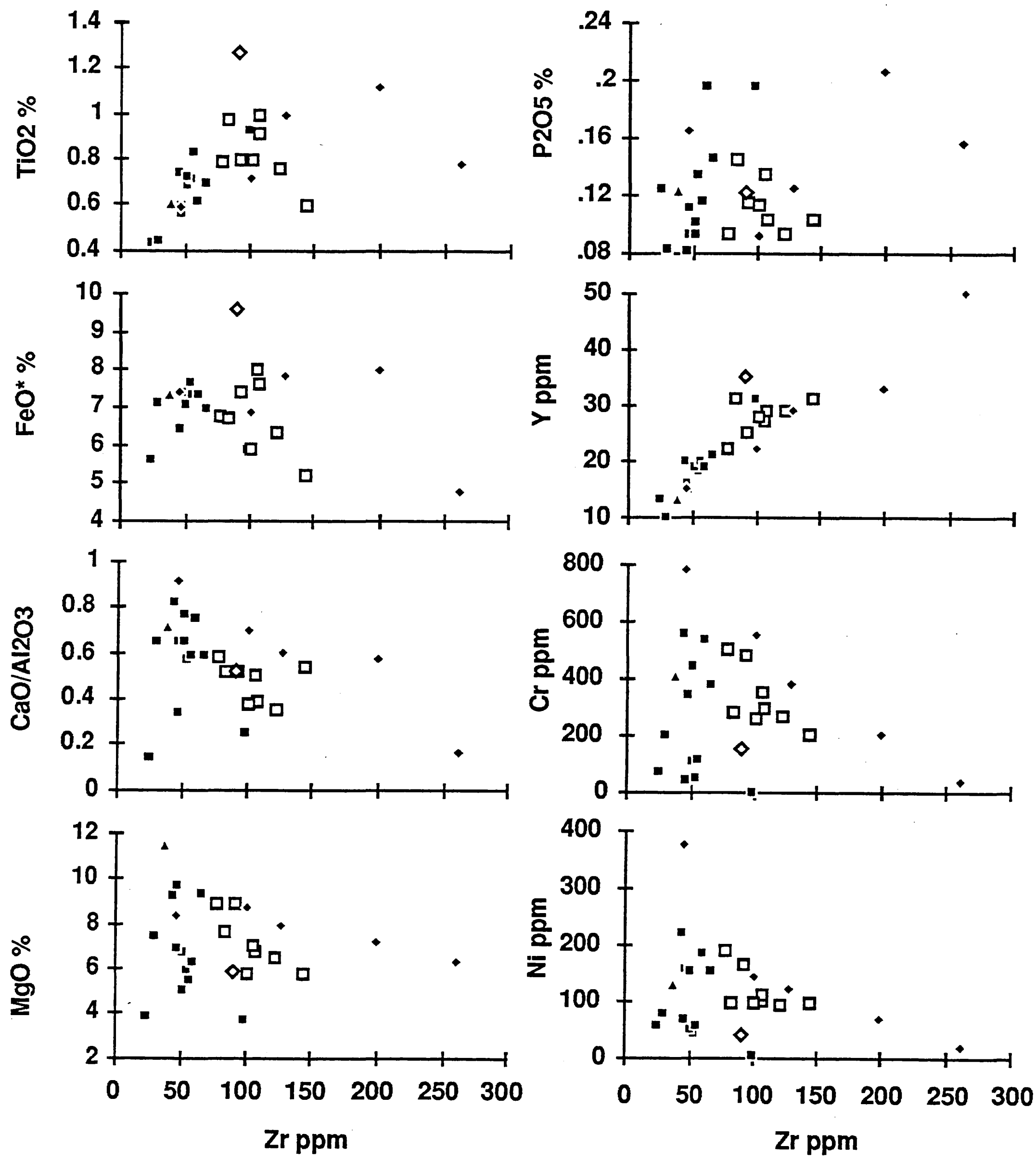


Fig. 10. *Major and trace element variation diagrams for mafic rocks of the Honeysuckle Beds. Elemental abundances are plotted against Zr, an index of fractionation. The steep negative trends on the FeO*, MgO, P_2O_5, Ni and Cr diagrams are due to crystal fractionation, whereas near horizontal trends on these plots are due largely to variations in partial melting, but may also indicate some contamination of primary melts. TiO_2 and Y have behaved as incompatible elements during both partial melting and fractionation events. Symbols indicate possible geochemical suites within the formation.*

The massive and vesicular basalt is in most cases similar to the pillow basalt but lacks obvious pillows. It occurs interbedded with the pillow basalt. Vesicles are small and typically 2-3 mm.

Basaltic breccia is rare, occurring interbedded with the pillow basalt and occasionally between pillows. Clasts are angular to subrounded, close-packed and moderately well sorted. The maximum clast size is 20 cm with an average of 5 cm. Clasts are all basalt but range from massive to vesicular and from very fine-grained and crystalline to altered glass. The matrix is largely altered to yellow clay, but originally consisted of a breccia with angular basalt clasts.

Fine-grained sedimentary rocks included within the Honeysuckle Beds vary from medium- or fine-grained arenite to chert. Beds are both graded and ungraded and the bases are sharp. They are most often laminated although the medium-grained arenite at the base of some beds is massive. Small rip up clasts, up to 4 mm, rarely occur at the base of beds. Chert is rare, volcanic in origin, and appears to form separate beds rather than the tops of graded beds. The sedimentary rocks occur interbedded with the pillow basalt. The percentage of interbedded sedimentary rocks increases to the east.

The mafic volcanic rocks of the Honeysuckle Beds are typically tholeiitic basalt to andesite. The Nb/Y ratio of all analyses is below 0.67 and therefore all are classified as subalkalic based on this criteria (Fig. 9). Major and trace element abundances for the mafic volcanic rocks are shown plotted against Zr in Figure 10. The spread of data for most major and compatible trace elements can be explained by a combination of varying degrees of partial melting (horizontal trends) and low pressure fractionation (steep negative trends). TiO_2 however has a positive correlation with Zr suggesting that it behaved incompatibly during both partial melting and fractionation events.

REE profiles resemble those for basalt and basaltic andesite erupted in back-arc basin environments (Fig. 11). All profiles have moderate slopes with (La/Yb)n from 2.0 to 6.5. LREE are moderately enriched with abundances 18 to 44 times chondrite. HREE are 4 to 13 times chondrite. The spider diagram patterns for the basalts are very spiky and again similar to those of back-arc basalts (Fig. 12) and may be due to crustal contamination of an originally flat spider diagram typical of tholeiites.

A plot of (La/Sm)n vs Zr/Nb (Fig. 13) shows variation within a suite that can be modelled by mixing of enriched and depleted mantle sources and also variation due to contamination. Analyses from the Honeysuckle Beds are most similar to P-type MORB but with highly variable Zr/Nb indicating crustal contamination.

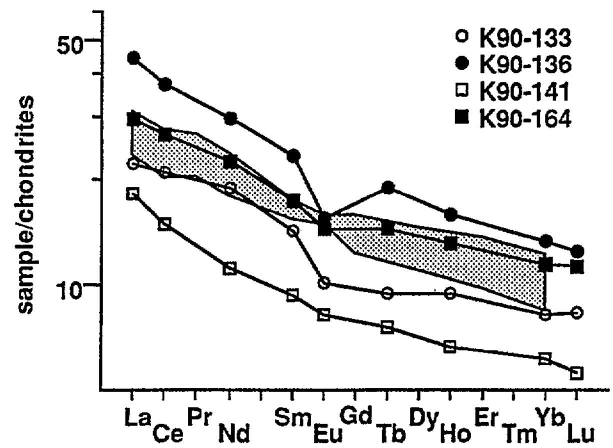


Fig. 11. *Rare earth element profiles for mafic rocks of the Honeysuckle Beds. The profiles are moderately steep with light rare earth enrichment. The shaded area represents the field of back arc basin basalts (BABB) from the Fiji Basin (Price & others, 1990). The slope of BABB is similar to that of mafic rocks from the Honeysuckle Beds.*

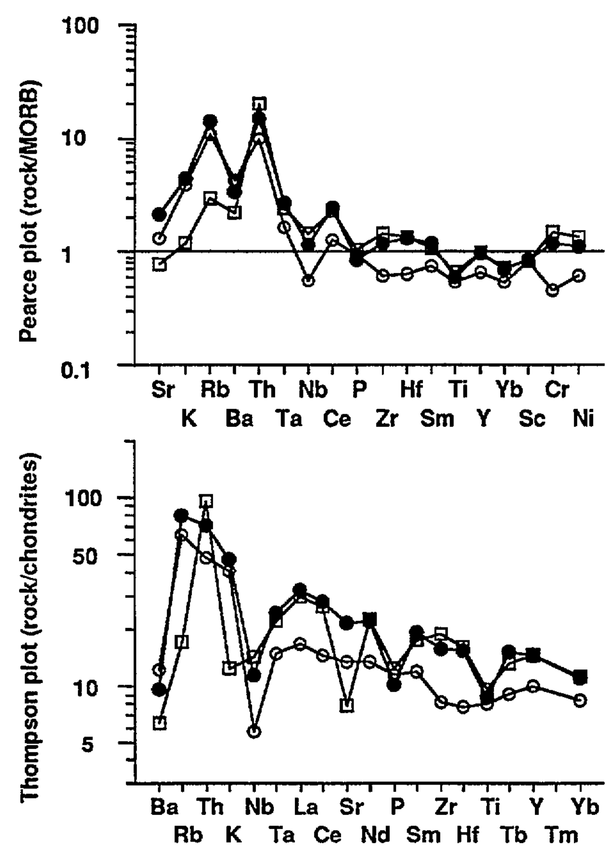


Fig. 12. *Spider diagrams for mafic rocks of the Honeysuckle Beds (after Pearce, 1983; Thompson & others, 1984). The plots are spiky with enrichment of incompatible elements and a Nb anomaly and the patterns resemble those of back arc basin basalts.*

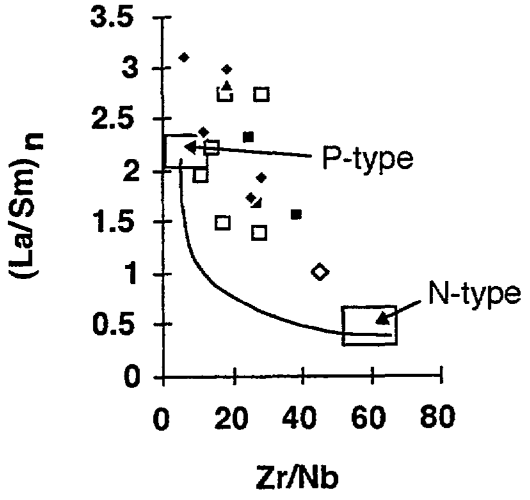


Fig. 13. *A plot of (La/Sm)n versus Zr/Nb for mafic rocks of the Honeysuckle Beds. Sample show a range of values along a mixing line of N-type MORB to P-type MORB with values of (La/Sm)n closest to and greater than P-type MORB. The shift of values to the right of the mixing curve is likely due to contamination. Diagram after Wilson (1989) with mixing curve derived from data after Le Roex & others (1983).*

Contact relationships of the Blowering Formation and Honeysuckle Beds

The Honeysuckle Beds are bounded to the east by the Coolac Serpentinite and to the west by the Blowering Formation (Fig. 2). The contact with the Coolac Serpentinite is a fault along which are small bodies of gabbro and ultramafic rocks, including the North Mooney Complex. The contact between the Honeysuckle Beds and the Blowering Formation, once thought to be faulted (Ashley & others, 1983; Basden, 1990), is now recognised as conformable and interfingering (Stuart-Smith, 1990b; Warner et al., 1992) and field relationships indicate that the Honeysuckle Beds overlie the Blowering Formation and therefore occur at the top of the Silurian sequence, rather than near the base as previously interpreted.

The nature of the contact varies along its length. In the south, basalt is adjacent to coarse dacitic rocks of the Blowering Formation and the two do not interfinger. The contact is not exposed and could be either conformable or faulted. Here the contact is complicated by mafic intrusions included within the Micalong Swamp Basic Intrusive Complex (Owen and Wyborn, 1979) and possibly related to those in a similar position to the north (e.g. North Mooney Complex).

Further north, the contact zone is moderately well exposed. The contact varies from a simple conformable relationship to zones of complex interfingering and occasional sections in which there is a poorly-sorted, matrix-supported, sedimentary breccia containing both basalt and dacitic clasts in a siliceous siltstone matrix (Stop 5).

DEVONIAN VOLCANICS

Gatelee Ignimbrite

The Gatelee Ignimbrite (Ashley & others, 1971) forms remnants of a subhorizontal sheet of ignimbrite, resting unconformably on Silurian and older deformed volcanics and sediments. The unit, up to 200 m thick (Basden, 1990), comprises mostly ignimbrite with minor basal polymictic conglomerate in places (Kennard, 1974). Based on similar stratigraphic relationships and petrographic affinity to the palaeontologically dated Minjary Volcanics, the Gatelee Ignimbrite is assumed to be Early Devonian in age.

Kennard (1974) described a variety of ignimbrites within the unit. These vary mainly in colour, are gradational with one another, and form an overall consistent stratigraphic succession which is shown diagrammatically in Fig. 14. Outcrop is characterised by alternating cliffs and benches possibly reflecting successive flow sheets in part or zonal variations within the one ash-flow (Kennard, 1974).

Limited geochemical data indicates that the ignimbrite is dominantly rhyolitic with subordinate dacitic compositions (Basden, 1990). Ashley and others, (1971) suggested that the Gatelee Ignimbrite may have been contemporaneous with, and related to, the nearby Devonian Killimicat Granite, however, Crook and Powell (1976) argued that this interpretation is not supported by geochemical data. The volcanic unit, however, may represent a more mafic, less fractionated magma, possibly related to another nearby Devonian granite intrusion, the Bogong Granite (Basden, 1990). Both granites and the ignimbrite were placed by Wyborn and others (1987) into the Boggy Plain Supersuite, a belt of I-Type granitic and volcanic rocks extending for over 500 km in the central Lachlan Fold Belt. Wyborn and others (1987) suggested that the suite was derived from basaltic sources at high temperatures with compositional variation of the resultant magmas due to fractional crystallisation.

EXCURSION STOPS

Stop 1. Goobarragandra Volcanics, Hume Highway

Stop 1 is within the northern Goobarragandra Volcanics where coarse dacitic breccia with an arenite matrix (Fig. 15) is exposed in a road cutting. The breccia is included within the massive dacitic volcaniclastic (MDV) facies. The coarse breccia is poorly sorted, matrix to clast supported and comprises 30-50% clasts including blocks of MDV and rare blocks of flow-banded dacite with 10-20% phenocrysts. The blocks range from angular to sub-rounded in shape, are equant, have sharp boundaries and are up to 75 cm across. The matrix is a medium to very coarse-grained feldslitharenite of similar mineralogical composition to the clasts (Fig.16).

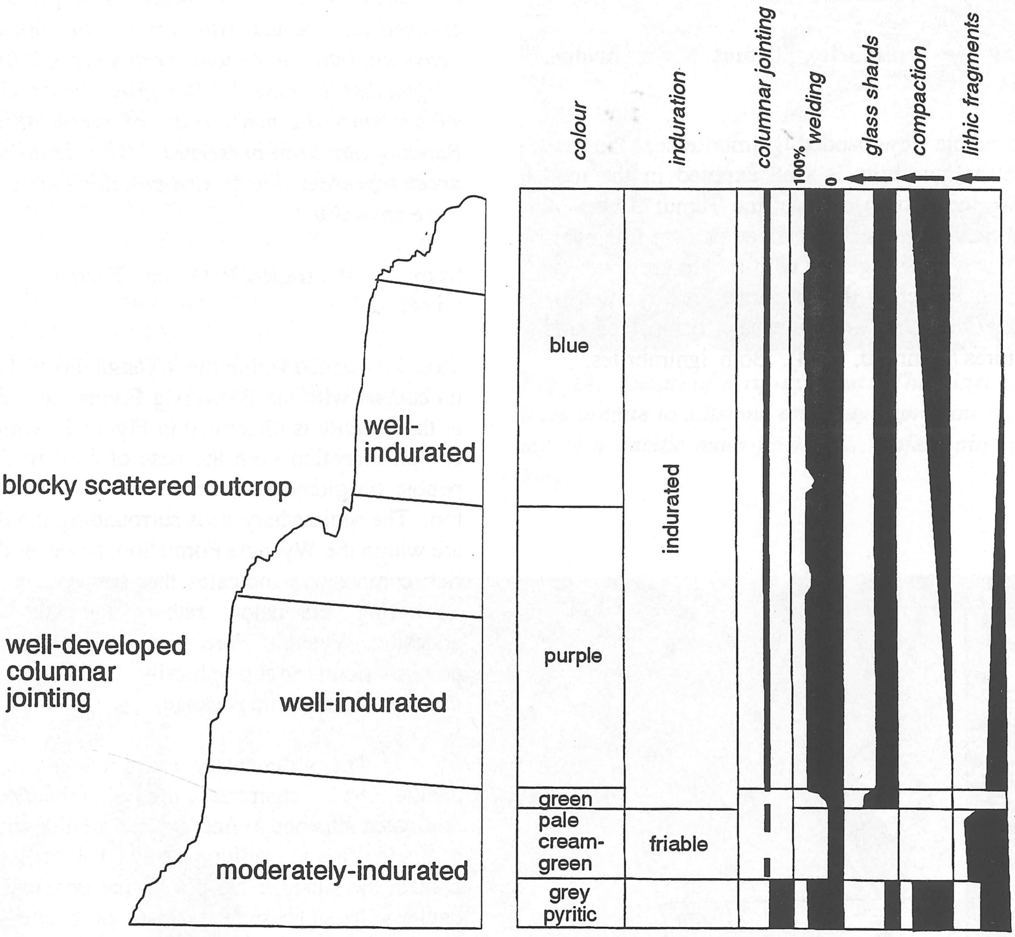


Fig. 14. *Diagrammatic cross-section and log of the Gatelee Ignimbrite (modified from Kennard (1974).*

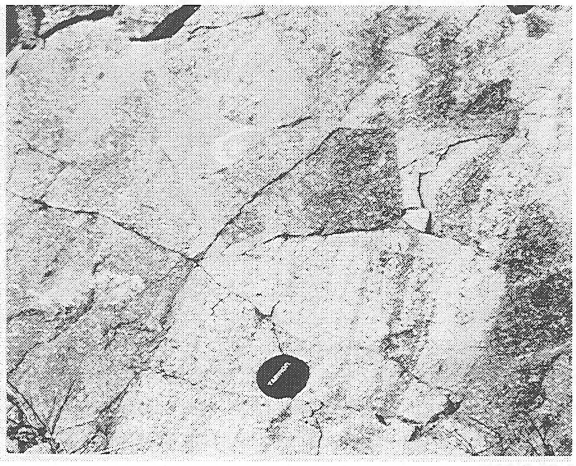


Fig. 15. *Coarse dacitic breccia with arenite matrix. The breccia is poorly sorted, matrix to clast supported and comprises 30-50% clasts. The clasts shown in this view include massive dacitic volcaniclastics and a block of flow-banded dacite.*

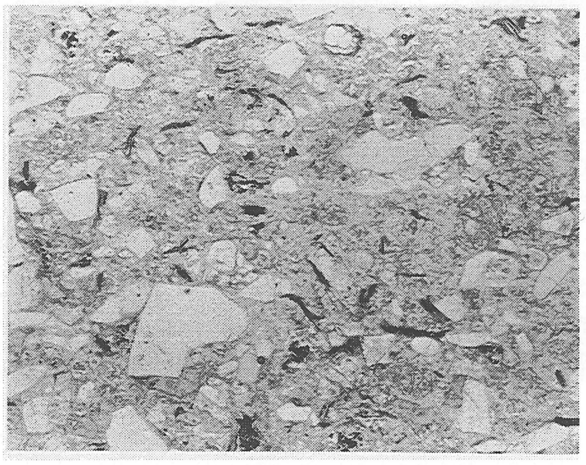


Fig. 16. *Photomicrograph of the matrix to the coarse dacitic breccia in Fig. 15. The matrix is quartz lithic arenite to wacke. All grains are angular and include felsic lithics, quartz, plagioclase, biotite and garnet indicating that the rock is both texturally and compositionally immature. Felsic lithics have perlitic cracking. Bar scale is mm.*

Clasts within the breccia show no evidence for quench fragmentation. The flow-banded clasts may have been derived from an exposed dyke or lava flow within the dacitic volcaniclastic pile.

Stop 2. Gatelee Ignimbrite, Tumut River bridge, Brungle

At this stop purple flow-banded ignimbrite near the base of the Gatelee Ignimbrite is well exposed in the road cutting along the eastern bank of the Tumut River. A eutaxitic fabric with possible flattened pumice fragments is evident. This rock together with a blue grey variety, more common higher in the sequence, are typified by complex flow banding and intensely compacted and welded textures (Kennard, 1974). Both ignimbrites, together account for over 90% of the unit and are described by Basden (1990) as *"..... weakly (10% or less) porphyritic in plagioclase and lesser quartz and K-feldspar to 2 mm in size. The phenocrysts are cracked and veined with sericite; the feldspars show heavy alteration to sericite, carbonate and limonite. Plagioclase is zoned. The groundmass comprises a <0.05 mm - 0.2 mm mosaic of recrystallised grains. Banding has been preserved. Occasional sub-arcuate areas represent shards, and possible pumice fragments were observed."*

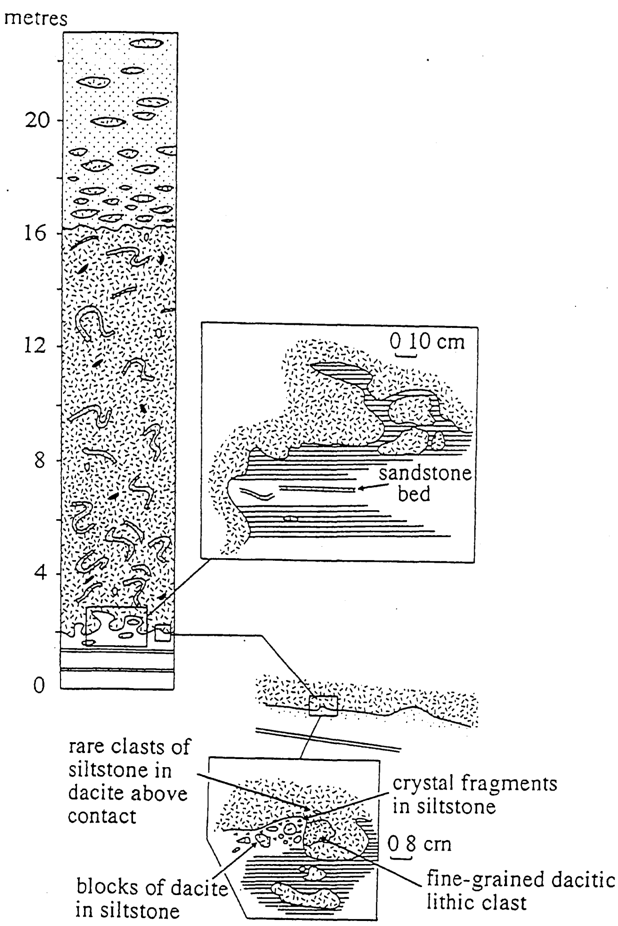


Fig. 17. *Measured section through a very coarse dacitic arenite bed within siltstone of the Wyangle Formation. The bed has an irregular base with loads and flame structure indicating that the siltstone was only partially consolidated when the dacitic material was deposited. Fine-grained siliceous rip-up clasts occur throughout the dacitic bed.*

Stop 3. Wyangle/Blowering Formations, Brungle Creek

Stop 3 is located within the Wyangle Formation, close to its contact with the Blowering Formation. The geology at this locality is illustrated in Figure 17 which shows a complete section from the base of a 14 m thick dacitic pebble conglomerate where it overlies siltstone, to its top. The sedimentary beds surrounding the dacitic layer are within the Wyangle Formation, however their quartz-rich composition indicates that they are similar to the Blowering Formation rather than the underlying andesitic Wyangle Formation. This bed of dacitic arenite occurs stratigraphically below the dominantly dacitic volcaniclastic package.

The sedimentary rocks underlying the thick dacitic bed comprise thinly-interbedded, poorly-laminated siltstone to fine-grained arenite with rare beds of graded fine to medium arenite, 1-4 cm thick. At the contact the siltstone has flame-like protrusions into the dacite. Irregular-shaped clasts of dacite and crystal fragments occur in the siltstone up to several centimetres from the contact.

At the base of the massive dacitic volcaniclastic it consists of crystal-rich dacite with 50% crystals of quartz, plagioclase, biotite and rare garnet up to 5 mm, elongate lithic clasts up to 40 cm and rare quartz fragments up to 6 cm. Within 30 cm of the contact there are fine-grained, discontinuous and folded bands within the dacite. The bands vary in size up to 25 x 5 cm but are typically 1-2 cm thick. Some are graded from medium arenite to siltstone (Fig. 18).

Above the dacitic bed is a graded breccia consisting of rounded to irregular and ellipsoidal-shaped dacite blocks in a siltstone matrix. The blocks are matrix supported and the breccia is poorly sorted with blocks from <1-40 cm. The breccia is graded by loss of clasts upward with 30-50% clasts at the base and ~1% at 10 m above the contact. There is no gradation in the size of clasts.

The dacitic bed was deposited by mass flow processes. The underlying sediment was only partially consolidated and was deformed by the overlying flow. The fine-grained graded bands may represent fine-grained tops of thin flow units that were ripped up and incorporated within the overlying flow. The overlying breccia indicates that more proximal areas of the dacite bed were reworked after partial lithification.

Stop 4. Wyangle Formation, Brungle Creek

This stop provides an opportunity to examine part of the Wyangle Formation which forms a proximal quartz-poor to quartz-intermediate flysch unit locally at the base of the Late Silurian Tumut Basin sequence. The conglomerate and diamictite, which are well exposed further downstream, are interpreted to represent debris-flow deposits (Kennard, 1974; Crook & Powell, 1976). At this stop a sequence of very thickly-bedded to laminated, pebbly to very fine-grained quartz-poor arenites are well exposed along Brungle Creek (Fig. 19). The beds are commonly graded with rounded clasts of dacite (Blowering Formation) and intraformational arenite.

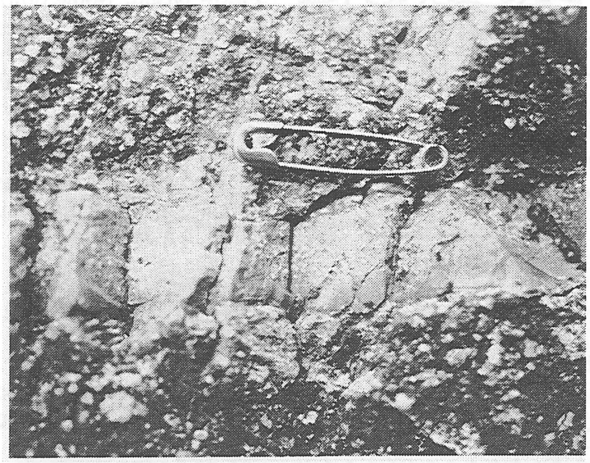


Fig. 18. *Detail of a rip-up clast. The clast is graded from arenite to siltstone and may represent the graded top of a dacitic mass flow unit. Safety pin is 25 mm long.*

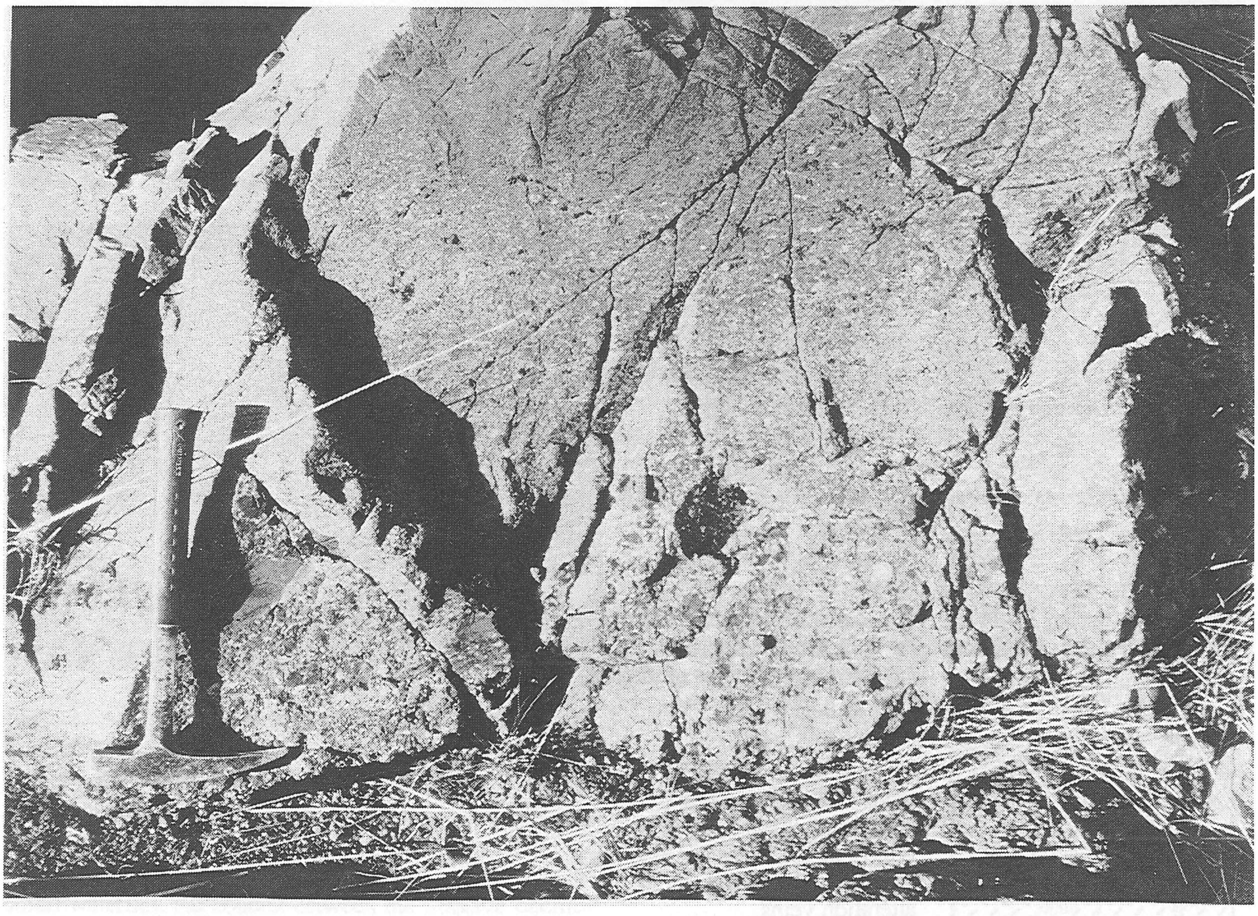


Fig. 19. *Typical graded quartz-poor volcanilithic pebble conglomerate, Wyangle Formation.*

Stop 5. Blowering Formation/Honeysuckle Beds contact

Stop 5 is located at the contact of the Blowering Formation and the overlying Honeysuckle Beds. The sequence youngs and dips to the east. Further to the east, the Honeysuckle Beds are in fault contact with the Coolac Serpentinite. The serpentinite forms the sharp ridge to the east with a characteristic flora, including grass trees, honeysuckle heath and she-oaks. The contact of the Blowering Formation and the Honeysuckle Beds is well exposed in the small creek at this locality. A detailed section across the contact is shown in Figure 20. The base of the section is within the massive dacitic

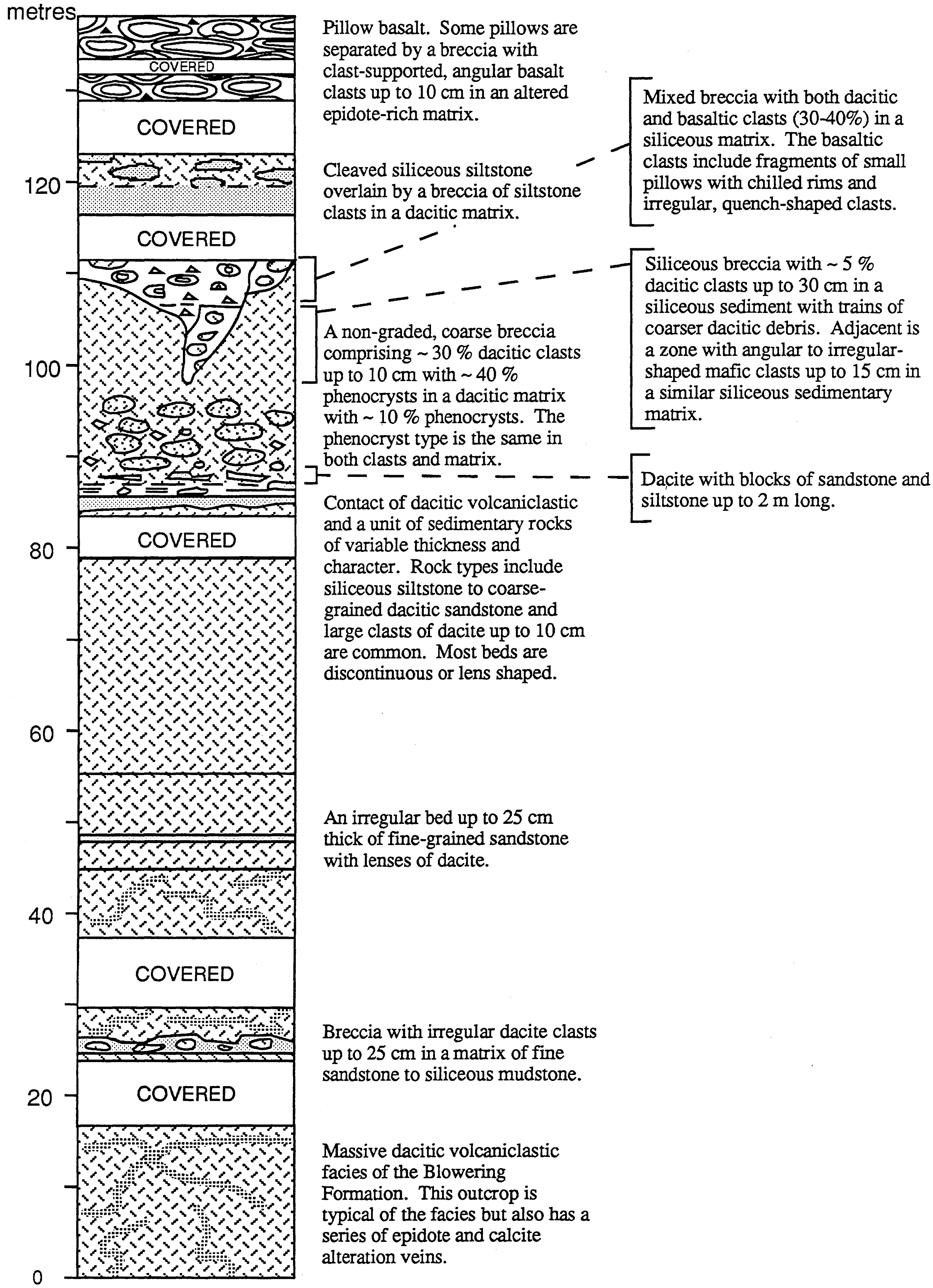


Fig. 20. *Measured section through dacitic volcaniclastic rocks, sedimentary rocks, mixed mafic and felsic breccia and pillow basalt at the contact of the Blowering Formation and the Honeysuckle Beds. The presence of the mixed breccia indicates that mafic and felsic volcanic activity were contemporaneous. The irregular bed contacts suggest that the area was unstable and subject to disruption by faulting.*

volcaniclastic facies of the Blowering Formation. This outcrop is typical of the facies but also has a series of epidote and calcite alteration veins. At approximately 25 m above the base of the section there is a breccia with irregular dacite clasts up to 25 cm in a matrix of fine arenite to siliceous mudstone. At 50 m is an irregular bed up to 25 cm thick of fine-grained arenite with lenses of dacite (Fig. 21).

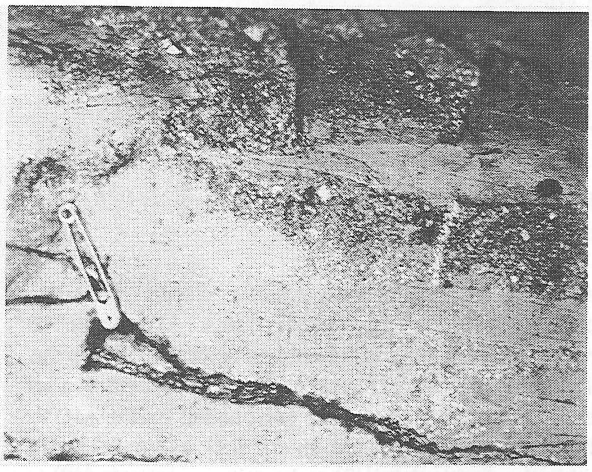


Fig. 21. *Irregular lens of dacitic material within arenite at 50 m above the base of the section in Fig. 21. Safety pin is 25 mm long.*

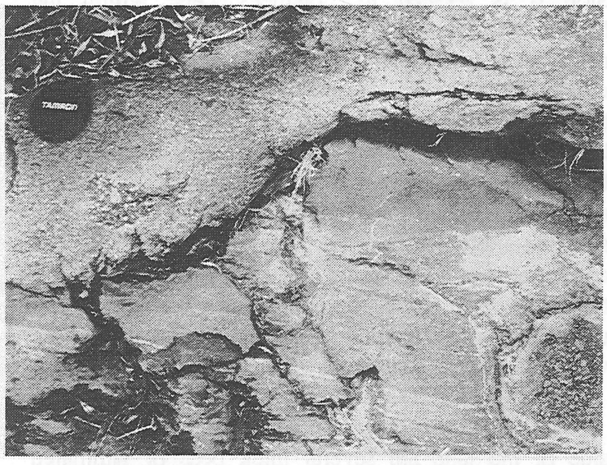


Fig. 22. *A bed of coarse dacitic arenite with a scoured base at 85 m above the base of the section in Fig. 21. The erosive base of this unit indicates an easterly younging direction.*

At approximately 85 m up the profile, near a small waterfall, the contact between the massive dacitic volcaniclastic and overlying arenite is exposed. This unit of sedimentary rock is of variable thickness and character. Rock types include a range from siliceous siltstone to coarse-grained dacitic arenite and large clasts of dacite up to 10 cm are common. Most beds are discontinuous. Sedimentary structures that indicate an easterly younging direction include scours (Fig. 22) and graded beds. The arenite unit has a gradational contact with the overlying coarse dacitic volcaniclastic. At the base of this bed, the dacite contains blocks of arenite and siltstone up to 2 m long. These clasts are poorly graded in number upwards. Overlying this zone, the dacitic volcaniclastic is a non-graded, coarse breccia comprising about 30 % dacitic clasts up to 10 cm and with approximately 40 % crystals in a dacitic matrix with approximately 10 % crystals (Fig. 23). The crystal type is the same in both clasts and matrix.

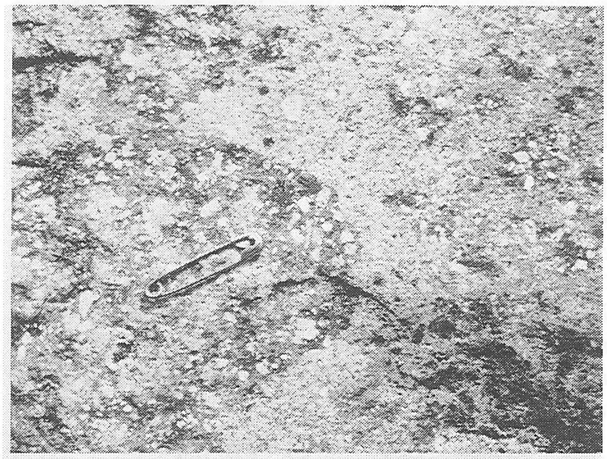


Fig. 23. *A coarse dacitic breccia with dacitic clasts and matrix. The clasts contain a greater abundance of phenocrysts (~40%) than the matrix (~10%). Clasts are irregular in shape and matrix supported. The breccia occurs from 90-95 m above the base of the section in Fig. 20. Safety pin is 25 mm long.*

Above the dacitic breccia the stratigraphy is difficult to establish and bed contacts appear to cross-cut the previous strike direction. The contact of the dacitic breccia and a breccia with a siliceous matrix is very irregular and may indicate syn-depositional faulting within the sequence. The siliceous breccia is shown as a tongue into the dacitic breccia on Figure 20. This breccia comprises about 5 % dacitic clasts up to 30 cm but averaging 1-2 cm in a siliceous sediment with trains of coarser dacitic debris. Adjacent to this breccia is a zone with angular to irregular-shaped mafic clasts up to 15 cm in a similar siliceous sedimentary matrix (Fig. 24). To the east of this breccia is a mixed breccia with both dacitic and basaltic clasts (30-40%) in a siliceous matrix. The basaltic clasts include fragments of small pillows with chilled rims and irregular, quench-shaped clasts (Fig. 25).

At about 115 m above the base of the section is a bed of well cleaved siliceous siltstone approximately 3 m thick. The siltstone is overlain by a breccia of siltstone clasts in a dacitic matrix similar to that just above the waterfall. This is the uppermost dacitic unit in the section and can be traced to the south around the hillside indicating a change in strike from the sedimentary beds at the waterfall. The dacitic breccia is overlain by pillow basalt of the Honeysuckle Beds. The outcrops in the creek have well preserved pillow forms (Fig. 26) that unfortunately give ambiguous younging

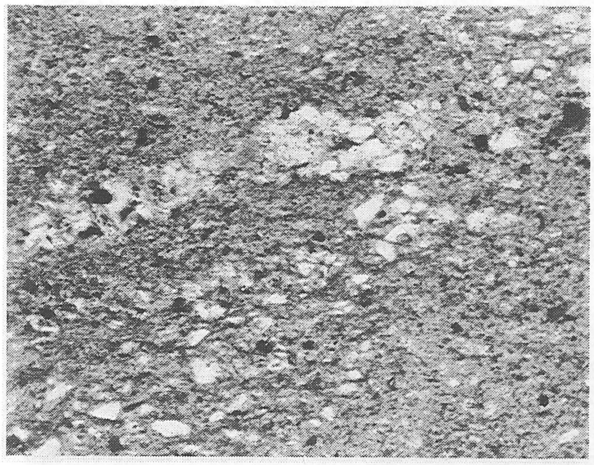


Fig. 24. *Photomicrograph of the siltstone matrix to a breccia composed of mafic clasts at 110 m above the base of the section in Fig. 20. The siltstone has a siliceous matrix and 5-75% grains including quartz, plagioclase, mica and siliceous lithics. Grains are angular. Laminae in the siltstone are irregular in thickness and discontinuous. Plane polarised light. Bar scale is mm.*

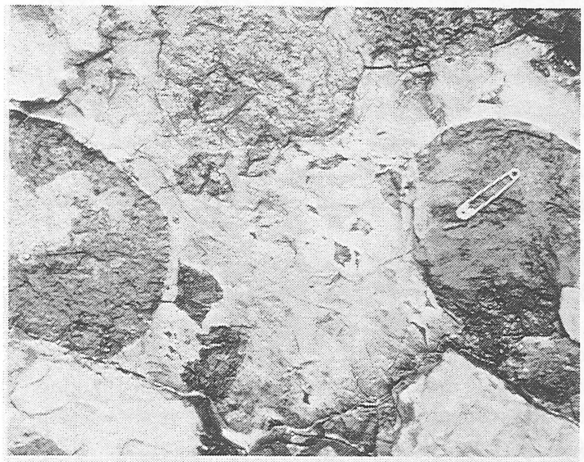


Fig. 25. *A mixed breccia with mafic pillow fragments, dacitic clasts and mafic hyaloclastite shards in a siliceous siltstone matrix. The pillow fragments have chilled rims. Clasts are matrix supported and highly variable in size and shape with dacitic clasts more rounded than mafic clasts. The breccia occurs at 110 m above the base of the section in Fig. 20. Safety pin is 25 mm long.*

directions. Some pillows are separated by a breccia with clast-supported, angular basalt clasts up to 10 cm in an altered epidote-rich matrix.

To the south of the creek section, within the dacitic volcaniclastics of the Blowering Formation, is an isolated outcrop of a limestone-clast bearing breccia. Clasts in the breccia (~50%) include dacite, similar to the surrounding MDV, fine-grained igneous rocks, porphyritic basalt, and limestone. The limestone clasts are largely weathered out and form holes in the outcrop. The matrix of the breccia is a fine to coarse-grained

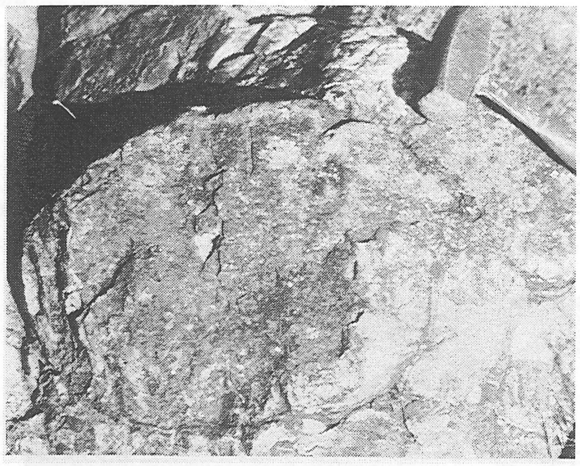


Fig. 26. *Mafic pillow lava of the Honeysuckle Beds at the top of the section in Fig. 20.*

dacitic volcaniclastic with smaller clasts of similar composition to the framework clasts. This type of breccia has been mapped at only one other locality in the Blowering Formation further to the north where it also occurs as an isolated outcrop surrounded by the MDV. The breccia outcrops are interpreted as large clasts within the dacitic debris flow deposits.

Stop 6. Mundongo formation, Lowther's Lane

Stop 6 is located in Lowther's Lane within the Mundongo formation. This is an informal formation name given to the sedimentary rocks presently included within the Blowering Formation. Figure 27 is a log of the sequence in the cutting on the western side of the lane. The section comprises interbedded medium and fine-grained arenite and siltstone with laminated siltstone to fine arenite making up about 80 %. The siltstone alternates from purple to buff in colour. The coarser arenite beds consist of a hard grey arenite. They typically have sharp tops, erosional bases and are ungraded. The arenite and siltstone form discrete beds with no apparent grading.

In a more recent road cutting on the eastern side of the lane are several thick beds of laminated siltstone with intraformational folding.

The coarser-grained arenite in the cutting is a lithic arenite. Framework grains include siliceous rock fragments (20-25%), volcanic quartz (10-20%), plagioclase (10-20%), siltstone (10-15%), quartz aggregates (~5%), epidotised fragments (~2%), basalt (1-2%), and minor opaque minerals and biotite (Fig. 28). The matrix generally comprises <15%. The arenite is immature with angular grain shapes and relatively fresh plagioclase.

The sequence in Lowther's Lane does not contain graded Bouma sequences as seen elsewhere in much of the Mundongo formation. Sedimentary structures in this section suggest deposition below wave base, possibly as a series of channel levee deposits and crevasse splays.

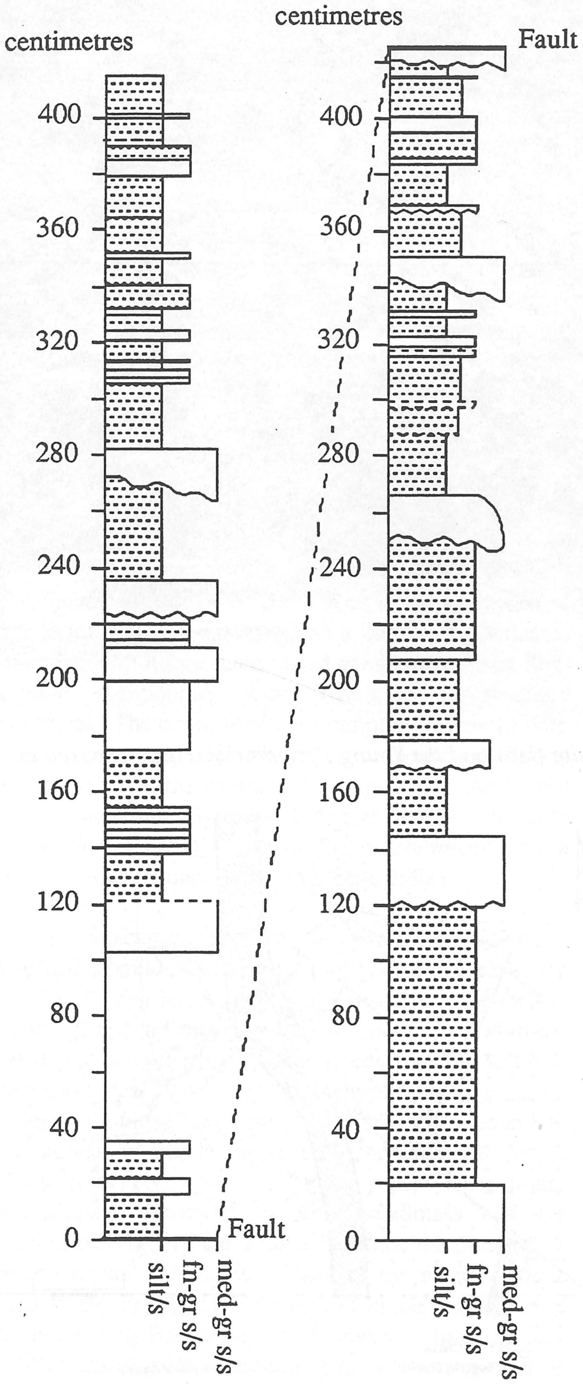


Fig. 27. *Measured section through the Mundongo Formation in Lowther's Lane. The section comprises interbedded medium and fine-grained arenite and siltstone. The coarser arenite beds typically have sharp tops and erosional bases and most are ungraded. The arenite and siltstone form discrete beds with no apparent grading.*

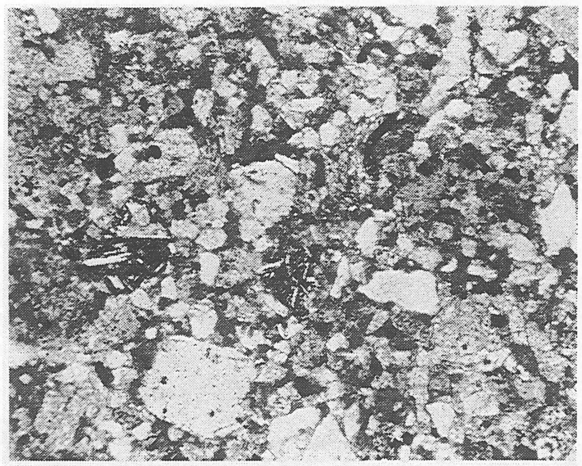


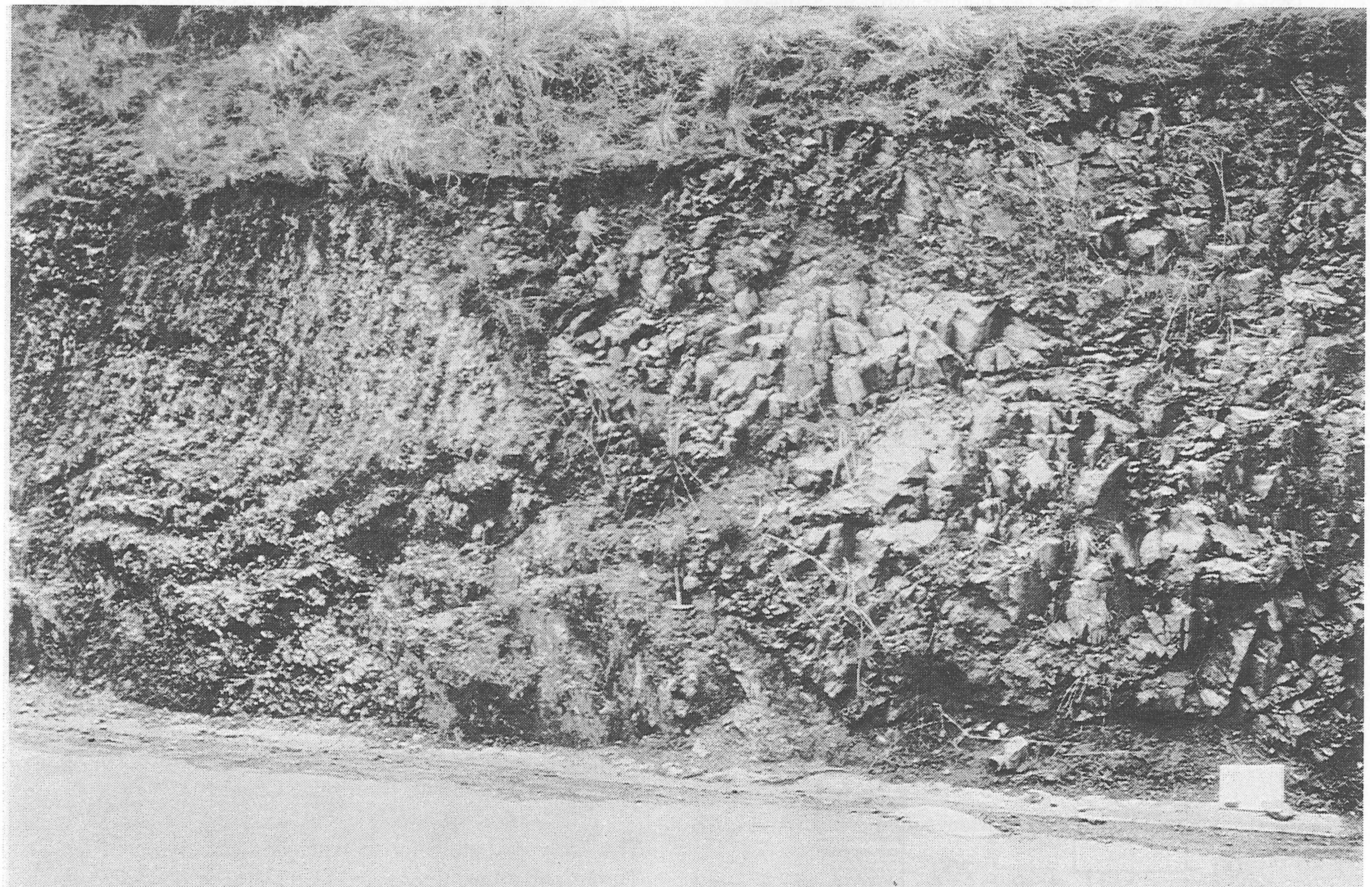
Fig. 28. *Photomicrograph of arenite from the section in Fig. 27. Framework grains include siliceous rock fragments, volcanic quartz, plagioclase, siltstone, quartz aggregates, epidotised fragments, basalt and minor opaque minerals and biotite. The arenite is both texturally and compositionally immature. Plane polarised light. Bar scale is mm.*

Stop 7. Faulted Coolac Serpentinite/Young Granodiorite contact, Bumbolee Creek.

The Early to Late Silurian volcanics and flysch of the Tumut region are interpreted to have been deposited in an elongate pull-apart basin, about 80 km long, flanking the Mooney Mooney Fault Zone (Stuart-Smith & others, 1992). This fault zone, active during basin extension, separated basinal shallow-marine deposition of the Wyangle, Blowering, and Mundongo Formations and Honeysuckle Beds to the west from subaerial deposition of the Goobarragandra Volcanics, and coeval granite intrusion (Young Granodiorite) to the east. A complex history for the fault zone is interpreted with the Coolac Serpentinite, possibly part of the Cambrian-Ordovician basement, being emplaced during the Early Silurian extensional event (Stuart-Smith, 1990b).

Spectacular exposures of deformed granodiorite and serpentinite within the Mooney Mooney Fault Zone occur along the Bumbolee Creek road where it traverses the Honeysuckle Range east of Tumut (Fig. 29). The stop commences with a walk down the road through granodioritic mylonite to the tectonic contact with the serpentinite.

The Young Granodiorite is a coarse, relatively homogeneous, S-type granite, the bulk of which is massive to slightly more foliated approaching the fault contact where the rock grades into an ultramylonite (Fig. 30). Fabrics within the mylonite reflect three discrete phases of deformation with different movement directions. The dominant fabric is a steep east-dipping foliation with a steeply pitching weak to strong mineral elongation lineation reflecting reverse movement. This fabric is deformed by spaced moderately east-dipping shear bands which formed during latter brittle deformation associated with minor thrusting of the **Fig.**



29. *Steeply dipping faulted contact between the Coolac Serpentinite (left) and the Young Ganodiorite (right) exposed in road cutting at Stop 7.*

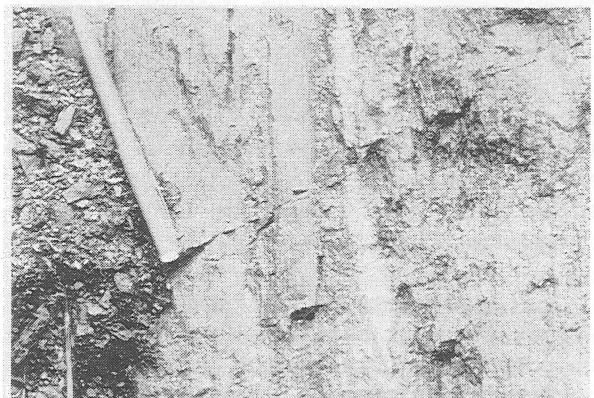


Fig. 30. *Ultramylonite developed in the Young Granodiorite adjacent to the contact with the Coolac Serpentinite, Stop 7.*

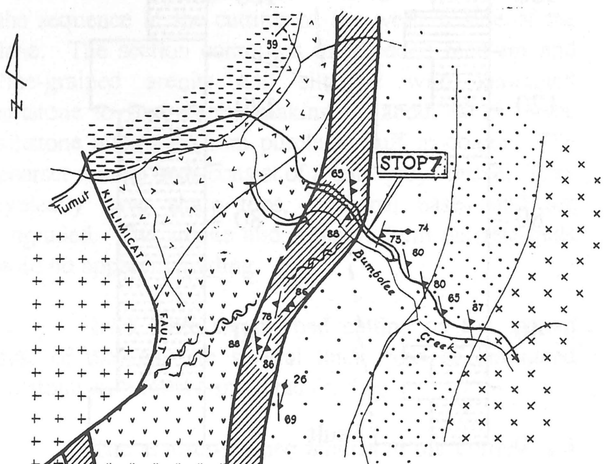


Fig. 31. *Stop 7. Geology, Coolac Serpentinite/Young Granodiorite contact, Bumbolee Creek (after Stuart-Smith & others, 1988).*

granodiorite to the west during the Siluro-Devonian Bowning Orogeny. Near the contact with the serpentinite, fabrics within a narrow band of ultramylonite show a dextral strike-slip motion. This zone forms part of a dextral shear zone which passes through the serpentinite and displaces the Killimicat Fault by about 1 km (Fig. 31).

The contact between the mylonite and serpentinite is sharp and dips steeply to the east parallel to the main foliation in the mylonite and shear planes within the adjacent serpentinite. A vertical to steep SE-dipping foliation is also present in the serpentinite in this area indicating oblique-slip with a dominantly sinistral strike-slip motion except where the dextral shear zone transgresses the belt south of Bumbolee Creek. The serpentinite, a metasomatised harzsburgite (Ashley & others, 1971), is mainly schistose, the foliation anastomosing around scattered lenses of more massive material. Tectonically included pods of metadolerite, a small magnesite body and a narrow, relatively undeformed, rodingite dyke occur within the serpentinite.

Stop 8. Frampton Volcanics, Gundagai Quarry

The Frampton Volcanics are located to the northwest of Gundagai (Fig. 2) and comprise a dominantly volcanic sequence with minor intercalated conglomerate and fine-grained sedimentary rocks restricted to southern exposures. The contacts of the Frampton Volcanics with surrounding units are ambiguous or not exposed and their position in the stratigraphic sequence of the Tumut area is uncertain (Skilbeck & others, 1992). A U-Pb zircon date of 428 $\pm$ 6 Ma has been determined from a volcanic rock (Stuart-Smith, & others, 1992).

Volcanic rocks of the Frampton Volcanics comprise dominantly rhyolitic to rhyodacitic crystal-rich vitric tuff, with lesser dacitic tuff and rare andesite and basalt. There are several compositional units within the felsic volcanic pile, but it has not been possible so far to map individual flow units. The rhyolitic to rhyodacitic crystal-rich vitric tuff consists of sparse to abundant phenocrysts of quartz (up to 15%) and feldspar (up to 15%) in a grey, aphanitic groundmass. No primary textures are preserved in the groundmass and the pyroclastic origin of the units is based on the presence of broken crystal fragments. Many of the felsic volcanic units in the Frampton Volcanics resemble the dacite of the Blowering Formation. Differences include the lack of lithic clasts (<1% in the Frampton Volcanics), and the absence of garnets, large quartz fragments and in most units, mafic phenocrysts in the Frampton Volcanics.

Conglomerate within the Frampton Volcanics ranges from oligomictic with locally derived volcanic clasts to several polymictic conglomerates comprising arenite, siltstone, volcanic clasts, limestone and rare granite. The type and percentage of clast varies from north to south (Skilbeck & others, 1992).

All lithologies of the Frampton Volcanics are deformed with the intensity of the dominant foliation decreasing to the north and away from the faulted eastern contact. The conglomerate is typically intensely deformed with rotation of more competent clasts into the foliation and flattening of less competent clasts.

The volcanic rocks are dominantly rhyolite with a few analyses falling in the rhyodacite and dacite fields of the TAS diagram. All samples are subalkalic. Preliminary analysis of data indicates that there are two geochemical groups, a higher silica differentiation series with moderate enrichment of incompatible trace elements and a lower silica group with more abundant incompatible trace elements and lower MgO. Basden (1990) suggested that the rhyolite could be divided into A- and S-types, however none of the samples have an unambiguous affinity, for example, most samples classified as A-type lack the diagnostic high Ga/Al_2O_3.

The lithologies present in the quarry at **Stop 8** include rhyolite and rare arenite and siltstone. The sedimentary rocks occur as large boulders within the quarry and have only been mapped in outcrop at one poorly exposed locality above the main quarry. The contact is not exposed. The rhyolite in the quarry has 20-30% phenocrysts of quartz and feldspar up to 10 mm. The matrix is grey-green, chloritic and aphanitic. The rhyolite has a well developed cleavage.

A notable feature of the rhyolite at this locality is the presence of black, chloritic smears up to 30 by 40 cm on cleavage faces (Fig. 32). Some of the larger smears are cross-cut by the cleavage. A possible origin for the chloritic patches is extremely altered and flattened pumice lenticles.

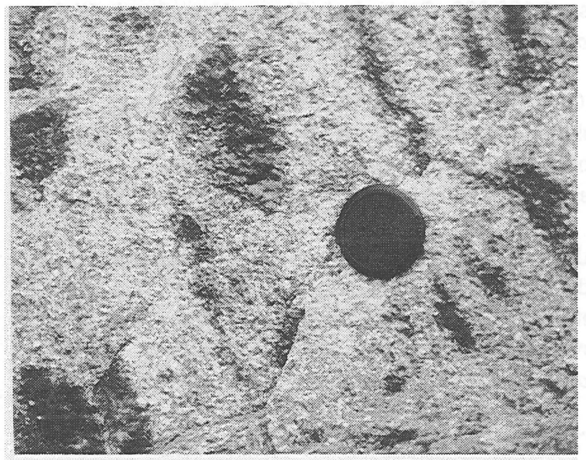


Fig. 32. *Chloritic smears on cleavage planes in rhyodacitic crystal vitric tuff of the Frampton Volcanics. The black smears may have originally been pumice now flattened and stretched within the cleavage.*

The blocks of sedimentary rock consist of interbedded arenite and siltstone. Arenite beds are up to 12 cm thick but typically <1 cm, are ungraded and are rarely cross bedded. Small siltstone clasts occur at the base of the some arenite beds. Siltstone beds are up to 5 cm thick. Contacts are sharp.

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