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Geology and geochemistry of the Tantangara and Brindabella area

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DEPARTMENT OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Geology and geochemistry of the Tantangara and Brindabella 1:100 000 Sheet areas,

New South Wales and Australian Capital Territory

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Front cover: The Blue Waterhole Formation exposed in bluffs on the banks of Cave Creek at grid reference 499570 (TANTANGARA). Two large allochthonous blocks of the Cooleman Limestone protrude above the surface of the spur to the right of centre of the photograph. (GB/2191).

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ABSTRACT

The Tantangara and Brindabella 1:100 000 Sheet areas cover 5030 km^2 between latitudes 35° and 36°S and longitudes 148°30′ and 149°E, in the southern part of the Lachlan Fold Belt in New South Wales.

The earliest record of sedimentation in the two Sheet areas is of mid-Ordovocian quartz-rich distal flysch, becoming more proximal in the Late Ordovician. In the west, a volcanic arc erupted tholeiitic basalts and (?later) shoshonites during the middle to Late Ordovician. A phase of deformation in the latest Ordovician mainly to the west of the mapped area interrupted flysch sedimentation, which recontinued in a meridional trough—the source being the deformed Ordovician flysch to the west. After a further deformational event—which destroyed the trough during the Llandoverian—a shelf environment became established in the east and centre, and shelf sedimentation continued in the centre almost to the end of the Silurian, when a major deformation terminated it. Elsewhere, S then ?I-type felsic volcanism—mostly subaerial, depositing ignimbrites—was widespread during the Wenlockian and Ludlovian; comagmatic S and I-type granitoids intruded the volcanic piles, and tholeiitic magmas intruded simultaneously in the west, during the Late Silurian. The felsic volcanics and granitoids are the anatectic products of a prolonged period of high heat flow in the crust which peaked in the Early Silurian and resulted in metamorphism to at least the upper greenschist facies grade.

At the start of the Early Devonian, S-type volcanics—again subaerial felsic ignimbrites—erupted in the southwest. Slightly later, I-type volcanics erupted from at least two large stratovolcanoes in the north, and a comagmatic granitoid suite intruded concurrently in the north and south. These Early Devonian volcanics and granitoids are believed to be the final products of the high heat flow in the Silurian. In the north during the late stage of volcanism, black mud accumulated locally in a restricted marine environment, and arenites, some originating as mudflows on the sides of the stratovolcanoes, were deposited in alluvial fans. During the latter half of the Early Devonian, open-marine sedimentation became established briefly in this northern area; it was terminated by a thick fluviatile sequence of conglomerate, sandstone, and shale—much of it deposited in cycles—in the northwest during the early Middle Devonian. This marked the final phase of Palaeozoic sedimentation.

After further folding and faulting, probably in the Carboniferous, an extensive peneplain developed during the late Palaeozoic and Mesozoic. Sandwiched between two episodes of Tertiary uplift, which progressively elevated the peneplain, lacustrine sediments accumulated locally in the west and south during the Miocene. Extensive colluvium has formed on the mountain slopes during the Quaternary, and alluvium is being deposited along the courses of many streams at the present time.

Known mineral deposits are small and mostly uneconomical. They include Mississippi Valley-type lead-zinc in Upper Silurian limestone; skarn deposits containing magnetite and minor lead-zinc associated with Silurian S-type granitoids; tungsten-bismuth and magnetite associated with Lower Devonian I-type granitoids; base metals associated with Silurian-Devonian acid volcanics; and gold in Tertiary gravel and Holocene alluvium.

INTRODUCTION

TANTANGARA and BRINDABELLA* are bounded by longitudes 148°30′E and 149°E and latitudes 35°S and 36°S; they share a common boundary along latitude 35°30′S. Together they cover an area of 5030 km², incorporating the western half of the Australian Capital Territory and adjoining parts of New South Wales (Fig. 1).

Mapping of the two Sheet areas by geologists of the Bureau of Mineral Resources (BMR) commenced in October 1971 in the southwestern part of TANTANGARA, and the fieldwork was essentially completed by April 1974. Those engaged in the fieldwork were: M. Owen, October 1971 to April 1974; D. Wyborn, March 1972 to April 1974; D. E. Gardner, October 1971 to March 1973; J. Saltet, October 1972 to April 1973; A. L. Jaques, January to March 1972; A. P. Langworthy, February to April 1972; P. Jell, November 1972; and M. S. Shackleton, February to April 1973. We traced several of the stratigraphic units that crop out in TANTANGARA and BRINDABELLA into adjoining Sheet areas, especially YARRANGOBILLY (to the west) and KOSCIUSKO (to the southwest), neither of which has yet been geologically mapped. As the YARRANGOBILLY topographic map had not been issued when this Bulletin went to press, we have quoted grid references of most localities in this Sheet area in terms of the Snowy Mountains Hydroelectric Authority Cabramurra and Batlow SMA 1-Mile Series Sheets. We wrote the text of this Bulletin from information that was available to us at the end of 1976.

Population distribution and access

No major towns lie within the two Sheet areas, though the western suburbs of Canberra encroach to within a kilometre of the eastern edge of BRINDABELLA. About three-quarters of TANTANGARA is in the Kosciusko National Park in New South Wales and the Gudgenby Nature Reserve in the southern Australian Capital Territory, and is virtually uninhabited. The only significantly populated part is in the southeast, where there are numerous grazing properties, and the small township of Adaminaby encroaches on the southern border of the Sheet area.

BRINDABELLA has several small settlements: at Uriarra Forest, Pierces Creek Forest (both for forestry workers in the ACT), and Wee Jasper. Grazing properties are numerous in the eastern and northern parts of the Sheet area, but are more scattered in the west; only the southwestern part of the Sheet area and the western part of the ACT lack any inhabitants.

Vehicular access reflects the distribution of population within the two Sheet areas: it is good in grazing areas but poor and generally limited to four-wheel-drive vehicles on fire trails elsewhere. Many of the four-wheel-drive trails in the Gudgenby Nature Reserve and Kosciusko National Park have locked gates on them, and access to the public is restricted. Permission for vehicular access to these trails may be sought from the relevant administrative bodies.

Climate and vegetation

Both the climate and vegetation of the Tantangara-Brindabella area reflect the large range in altitude of the two Sheet areas—from 1912 m on Mount Bimberi to less than 320 m downstream from Burrinjuck Dam. Rainfall is particularly influenced by altitude, and ranges from 1600 mm a year at Kiandra (Fig. 1) to 695 mm at Adaminaby. In the western part of the two Sheet areas, rainfall is highest during the winter, but in northeast BRINDABELLA the seasonal variation is small, with a slight tendency for a winter minimum and spring maximum. The average yearly rainfall for various localities within the two Sheet areas is as follows: Gudgenby, 773 mm; Cotter Hut, 876 mm; Bulls Head, 1048 mm; Cavan, 707 mm; and Burrinjuck Dam, 891 mm.

The temperatures in the area again reflect topography. In the highland areas in the west, winter frosts are common—Kiandra, for example, averaging 159 a year—and summer temperatures are mild, with maxima commonly around 20°C. To the east, at lower elevations, frosts are much less common—Canberra (which is typical of the northeastern part of BRINDABELLA), for example, averaging 77 a year—and mid-summer maxima average about 28° C.

Snow may fall anywhere in the two Sheet areas, but is rare below 500 m. Above 1000 m it is frequent and heavy in winter, when it commonly lies on the ground for several months above 1500 m.

The wide ranges in climate and altitude in the two Sheet areas have influenced the development of diverse vegetation communities. Costin (1954) divided the Monaro region, of which the two Sheet areas are part, into four height zones. In the two Sheet areas, the montane (1000 to 1500 m) and the subalpine (1500 to 1800 m) zones are widespread in the west and south; the alpine zone (above 1800 m, approximating the treeline) comprises the highest peaks; and the tableland zone (below 1000 m) is restricted to the

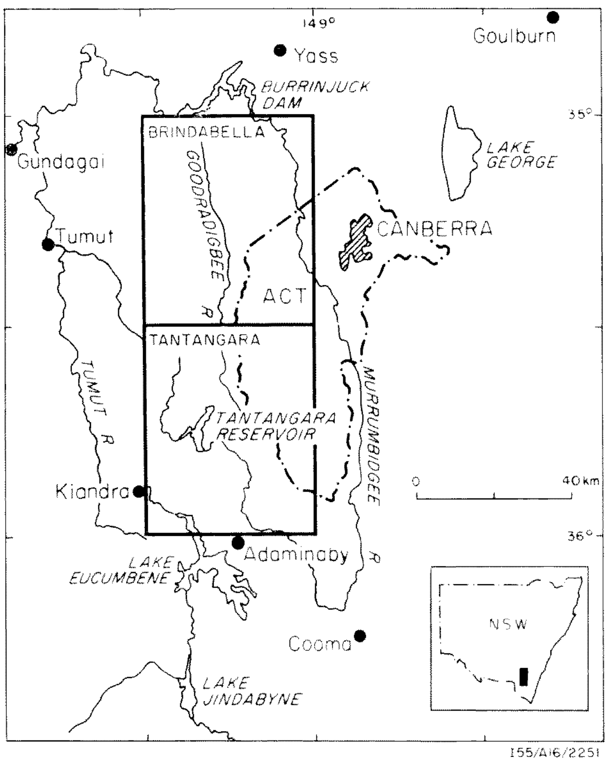

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Fig. 1. Location map.

* The names of 1:100 000 Sheet areas are printed in capitals throughout the text of this Bulletin.

Adaminaby area and north and northeast BRINDABELLA. This zonation is disrupted where cold air—trapped beneath a layer of warm air, and moving to a lower altitude—superimposes the features of the subalpine zone on the montane zone. These pockets of cold air, or frost hollows, often produce an inversion of the normal height sequence of vegetation (Moore, 1958).

The alpine zone is not well developed in the two Sheet areas; it is represented on the highest peaks by small patches of woodland *Eucalyptus pauciflora* (snow gum) broken by open grassland, in which *Poa* spp. predominate with many seasonally colourful perennial herbs.

The subalpine zone is dominated by woodland forests of *E. pauciflora* (previously *E. niphophila*). In places the woodland is open and covered with various small shrubs, grasses, and herbs; this community is fire-sensitive, and, in the past, considerable areas have been greatly modified. The subalpine grasslands, most common at higher altitudes in the zone and more particularly in frost hollows, carry a sod tussock community dominated by a *Poa caespitosa-Danthonia nudiflora-Themeda australis* alliance. Vegetation above the frost hollows in the subalpine zone is often a montane wet sclerophyll alliance of *E. dalrympleana-E. delegatensis* (mountain gum-alpine ash), which is also common below the subalpine zone.

The extensive areas of wet sclerophyll forest which occupy the steep mountain slopes in the montane zone are made up of two alliances (Burbidge & Gray, 1970). The alpine ash-mountain gum alliance is comparatively widespread on the upper slopes, merging at times into the snow gums of the subalpine zone. A shrubby understorey of *Acacia* and other legumes is usual, and a diverse ground flora is common where shrubs are not dense. Below this alliance is the *E. fastigata-E.viminalis* (brown barrel-ribbon gum) alliance, in which the ribbon (or manna) gum tends to occupy lower, wetter sites. Several storeys may be found below the closed canopy; they include discontinuous *Acacia melanoxylon* (to 20 m) above a 10-15 m layer of tall shrubs, and, in wetter gullies, a tree-fern community of *Dicksonia antarctica*.

The tableland zone—though extensively altered by grazing and pasture improvement—is widely developed in the northeast and north of BRINDABELLA. In its natural state it consists of scattered, low-branching eucalypts such as *E. melliodora* (yellow box), *E. polyanthemos* (red box), and *E. bridgesiana* (apple box), with an understorey of *Danthonia* spp. (wallaby grasses). Many of the low hills rising above the plains, such as near Kirawin (grid ref. 677163), are covered with dry sclerophyll forest commonly containing *E. rossii* (scribbly gum), *E. mannifera* var. *maculosa* (red spotted gum), and *E. macrorhyncha* (red stringybark). Along the banks of the Murrumbidgee River *Casuarina cunninghamiana* (river oak) is common.

Previous investigations

The earliest geological investigations of the Tantangara-Brindabella area, as for much of New South Wales, were by Clarke (1860). He collected the fossils from the Cavan area subsequently described by de Koninck (1876). Harper (1909) described in detail the geology of the Mount Boambolo area, and Mahony & Taylor (1913) made a brief reconnaissance of the proposed Australian Capital Territory. Since then, little was done until the late 1940s, when the formation of the Snowy Mountains Hydro-electric Authority (SMHA) provided the impetus for geological mapping in the Tantangara area. At the same time, the need to expand Canberra's water supply led to mapping in the Cotter River catchment. Much of this work remains unpublished, but was summarised in the first-edition Canberra 4-Mile Geological Series map (Joplin, Noakes, & Perry, 1953).

Apart from the detailed work around Tantangara Reservoir by SMHA, subsequent work included that of Browne (1959) on the Devonian sediments around Taemas; Snelling (1960) on the Murrumbidgee Batholith; and the extensive reconnaissance mapping for the second-edition Canberra 1:250 000 geological map (Best, D'Addario, Walpole, & Rose, 1964). Since 1964 the main work in the Sheet areas has been by Australian National University (ANU) students doing theses; topics include the Devonian sediments at Wee Jasper and Taemas, the Silurian and Devonian sedimentary and igneous rocks of the Cooleman Plain area, the area around Tantangara Dam, and the Murrumbidgee Batholith. Reference to the various theses is made in the relevant sections of the following text.

Nomenclature

Plutonic igneous rocks have been named according to the classification proposed by the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1976), except that we retain the term 'adamellite' for granitoids in which alkali feldspar is between 35 and 65% of the total feldspar, in line with common Australian usage.

Volcanic rocks are in general named according to the definitions given by Joplin (1971); where Joplin's definitions have proved inadequate the alternative schemes used are mentioned in the relevant part of the text.

Sedimentary rocks are named according to the classifications of Folk (1968).

Physiography

TANTANGARA and BRINDABELLA form part of the Southern Tablelands of New South Wales. This region displays a wide range of physiographic features, from deeply dissected tablelands and uplands with youthful valleys, cascades, and waterfalls, to mature valleys and plains. The major catchment is that of the Murrumbidgee River system; the Eucumbene River is the only major drainage basin east of the Great Divide, and flows in to the Snowy River south of Lake Eucumbene.

All the land surface is over 500 m above MSL, except the lower parts of the incised valleys of the Murrumbdigee and Goodradigbee Rivers. The uplands are well over 1000 m high, reaching 1912 m at Mount Bimberi (grid ref. 620522). The present relief is primarily the result of post-Cretaceous erosion on fault blocks that have moved differentially in the Tertiary and Quaternary.

Outline of geology

TANTANGARA and BRINDABELLA occupy the southern part of the Lachlan Fold Belt. Scheibner (1973, 1976) has divided the fold belt into ten regional structural units, of which only three occur in the two Sheet areas: the Forbes Anticlinorial Zone, the Cowra-Yass Synclinorial Zone, and the Molong-South Coast

Anticlinorial Zone. These broad structural subdivisions are not readily applicable on the scale of 1:100 000 mapping, so we have proposed a more relevant, detailed structural subdivision of the two Sheet areas (see p. 13). Before Scheibner's work a horst and graben nomenclature had been applied to the Canberra 1:250 000 Sheet area (Strusz, 1971, fig. 3). This again has been found to be not applicable to the Sheet areas after the detailed mapping, and is not considered further.

In the early part of the Ordovician the Sheet areas were on the outer part of a large submarine fan complex receiving sediment by means of turbidity currents, probably from the south. By the start of the Late Ordovician a north-south oriented, locally emergent volcanic chain had developed in the west, and turbidite deposition continued both east and west of it. Volcanism was short-lived, and by the end of the Ordovician, when the area was gently folded, the volcanic chain had probably been covered by turbidite sediments.

Early in the Silurian a small meridional trough in the centre was receiving turbidite sediments from the west. This trough was deformed in the middle of the Early Silurian, and, from then on through the Silurian, terrestrial erosion, felsic volcanism, and shallow-marine carbonate and terrigenous sedimentation predominated in different parts of the two Sheet areas.

At the end of the Silurian, further folding, which was both preceded and followed by granitic magma intrusion, arrested marine sedimentation. Large stratovolcanoes erupted acid lavas and pyroclastics during the early part of the Early Devonian, and, when their activity had ceased, extensive carbonate sedimentation developed in the north. By the end of the Early Devonian the sea had withdrawn, and the only subsequent deposition in the Palaeozoic was of a terrestrial alluvial sequence of Middle Devonian age.

After a ?middle Carboniferous fold episode, erosion through the late Palaeozoic and Mesozoic modified the land surface to form extensive peneplains. Renewed erosion of these peneplains following Early to middle Tertiary uplift, which was accompanied by the local extrusion of basalt flows, continues to the present day.

Acknowledgements

We thank the various BMR geologists who helped with the fieldwork, especially D. E. Gardner, whose detailed mapping in the Kiandra/Long Plains area greatly assisted our interpretation of the geology of the Ordovician of this geologically complex belt. We also thank Professor D. A. Brown and Dr K. S. W. Campbell, Department of Geology, ANU, for allowing us to examine student theses held in the departmental library. Although we did not use any parts of these theses to compile the maps, which are based entirely on fieldwork by BMR personnel, we derived from them a lot of useful information—including specific localities of interest—which served as an introduction to the geology of different part of the two Sheet areas.

We have also benefitted from lengthy discussions with Drs L. A. I. Wyborn and D. L. Strusz, and from palaeontological determinations by Drs D. L. Strusz and R. S. Nicoll. Mr K. Sharp, of the Snowy Mountains Engineering Corporation, kindly provided us with unpublished reports, and the Kosciusko National Park authorities allowed us access to areas within the park. Mr. A. Spate, CSIRO, provided us with notes on the vegetation of the area; Mr H. Berents assisted in the processing of a large amount of geochemical data; and Mrs R. Fabbo and Mr M. Steele drew the figures.

STRATIGRAPHY

Detailed descriptions of the Ordovician, Silurian, and Devonian sedimentary and volcanic units, and of the Siluro-Devonian granitoids, that crop out in the two Sheet areas are presented on the accompanying microfiche. The stratigraphy of the named rock units is summarised in Table 1, below.

METAMORPHISM OF THE KIANDRA GROUP AND GOOANDRA VOLCANICS

Most of the Ordovician rocks in TANTANGARA and BRINDABELLA have been regionally metamorphosed to low or very low grades. The extent of this metamorphism in the quartz-rich flysch deposits (the Ordovician Boltons, Nungar, and Adaminaby beds, and the Lower Silurian Tantangara Formation) has not been determined because their chemical composition is unsuitable for index minerals to develop. The crystallinity of illite could be used in these rocks to determine metamorphic grade (Kubler, 1967), but such a study is beyond the scope of this Bulletin. However, the basic to intermediate rocks of the Temperance Formation, Nine Mile Volcanics, Gooandra Volcanics, and their intrusive equivalents are ideal for the petrographic determination of metamorphic grade in the very low to low-grade zones of Winkler (1974).

Crook & others (1973) first recognised the presence of a very low-grade mineral assemblage in the Temperance Formation at Dairymans Plain, where they reported a widely developed assemblage of albite-prehnite-chlorite-carbonate. We have succeeded in dividing the volcanic sequence into five metamorphic zones based on mineralogical changes. These zones range from unmetamorphosed to upper greenschist and are characterised by:

zone 1: unalbitised calcic plagioclase
zone 2: albite + prehnite
zone 3: albite + prehnite + pumpellyite
zone 4: albite + actinolite (+ clinozoisite)
zone 5: albite + actinolite + biotite

The second and third zones correspond to very low-grade (Winkler, 1974) and the fourth and fifth zones to low-grade or greenschist facies metamorphism. The distribution of the zones is illustrated on the TANTANGARA map.

Plagioclase, typically unalbitised in zone 1, is also locally unalbitised in higher-grade regionally metamorphosed zones, probably because of a lack of sufficient interstitial fluid—for example, in lava fragments in an agglomerate at grid reference 369304 and in intrusions at grid references 356388 and 413423, which are in zones 3 and 4. Variable albitisation has been reported by a number of workers on very low-grade metamorphism. Dickinson (1962) suggested that the main

TABLE 1. SUMMARY DESCRIPTIONS OF NAMED PALAEOZOIC UNITS

Unit (map symbol)	*Distribution*	*Rock types*	*Mineral content (igneous units)*	*Environment/ mode of deposition*	*Thickness (m)*	*Stratigraphic relations*	*Effects of tectonism*	*Age*
Hatchery Creek Conglomerate (Dmh)	W of Goodradigbee valley, from Wee Jasper northwards	Conglomerate, sandstone, and siltstone in fining-upward cycles		Fluviatile; locally lacustrine	2900	Disconformable on Taemas Limestone	Broad folds; some overturned beds, and cleavage developed near Long Plain Fault	Middle Devonian (?Eifelian)
MURRUMBIDGEE GROUP								
Taemas Limestone (Dlt)	Goodradigbee valley at Wee Jasper, and Murrumbidgee valley at Taemas	Massive to thin-bedded fossiliferous limestone and thin calcareous shale		Subtidal marine; local bioherms	970 at Wee Jasper; 840 at Taemas	Conformable on Majurgong Fm; disconformable below Hatchery Creek Conglomerate	Broad folds with some cleavage in W; complex folds due possibly to gravity tectonics in E	Late Pragian to Zlichovian
Majurgong Formation (Dlj)	Goodradigbee valley at Wee Jasper, and Murrumbidgee valley at Taemas	Brown to red siltstone and shale		Estuarine	60 to 120	Conformable with Taemas Limestone above and Cavan Limestone below	Broad folds with cleavage in W; intense folds with cleavage in E	Pragian
Cavan Limestone (Dlc)	Goodradigbee valley at Wee Jasper, and Murrumbidgee valley at Taemas	Medium to thin-bedded limestone and shale		Shallow marine; often intertidal or supratidal	155 at Wee Jasper; 103 at Cavan	Conformable with Majurgong Fm above and Sugarloaf Creek Fm below	Broad folds with cleavage in W; intense folds in E (?gravity slumping)	Pragian
Sugarloaf Creek Formation (Dls)	Continuous arcuate belt from Wee Jasper to Taemas	Lithic arenite, siltstone, and shale		Alluvial fan with mudflows in W; fluviatile in E	1200 at Wee Jasper; 200 at Cavan	Conformable with Cavan Limestone above and Kirawin Fm or Mountain Creek Volcanics below	Broad folds, commonly with cleavage	Late Lochkovian to early Pragian
Kirawin Formation (Dlw)	Continuous belt from Wee Jasper, through Narrangullen to Kirawin homestead	Black shale and mudstone; minor rhyolite near base		Restricted, anaerobic marine	1000 at Wee Jasper; thins to zero at Cavan	Conformable with Mountain Creek Volcanics below and Sugarloaf Creek Fm above	Gentle folds near Narrangullen; more intense folds with cleavage to E and W	Late Lochkovian
Mountain Creek Volcanics (Dlm)	Brindabella Ra, u. Goodradigbee R, and E of Coolamine	Rhyolitic lava and ignimbrite; tuff, agglomerate, feldspathic sediments	Phenocrysts: albite, labradorite, pyroxene, quartz, biotite; groundmass: quartz, feldspar	At least two stratovolcanic centres flanked by pyroclastic and fluviatile deposits	Up to 5000	Overlies partly eroded Rolling Grounds Latite; unconformable on Cooleman Plains Gp; conformable below Kirawin Fm; intruded by Jackson Granite	Tight folds and cleavage in Brindabella Ra; tilted only in Cooleman Mtns area	Lochkovian, possibly to early Pragian
Rolling Grounds Latite (Dlr)	Rolling Ground Ridge, Cooleman Plain, McLeods Ridge	Porphyritic latite and andesite lava	Phenocrysts: clinopyroxene, orthopyroxene, plagioclase; groundmass: feldspar, quartz	Subaerial	Up to 250	Unconformable on Cooleman Plains Gp; overlain by Mountain Creek Volcanics after some erosion; intruded by Jackson Granite	Gently tilted in Cooleman Plain area, but steeper dips on McLeods Ridge; syncline on Rolling Ground Ridge	Lochkovian
Jackson Granite (Dgj)	Mt Black, Mt Jackson, McLeods Ridge	Pink granite, adamellite, aplite	Quartz, feldspar, biotite, magnetite, sphene			Intrudes Cooleman Plains Gp, Coolamine Igneous Complex, Mountain Creek Volcanics, Gurrangorambla Granophyre, and Rolling Grounds Latite	Cut by left-lateral wrench faulting on Mount Black Fault; foliated against Koorabri Fault	Early Devonian; K/Ar age on biotite of 413 $\pm$ 8 m.y.
Burrinjuck Adamellite (Dgb)	Burrinjuck Dam, Black Andrew Mtn	Pink adamellite, aplite	Quartz, feldspar, biotite, magnetite, sphene			Intrudes Goobarragandra Volcanics, Couragago Granodiorite, and Micalong Swamp Basic Igneous Complex	Thrust over Hatchery Creek Conglomerate on Long Plain Fault	Early Devonian; K/Ar *biotite age* 415 $\pm$ 8 m.y., Rb/Sr age on biotite of 399 $\pm$ 8 m.y.

Boggy Plain Adamellite (Dba, Dbg, Dbd)	Boggy Plain, Rocky Plain, Connors Hill	Adamellite, granodiorite, minor quartz gabbro	Feldspar, quartz, hornblende, biotite, clinopyroxene, orthopyroxene, magnetite, sphene, olivine			Intrudes Boltons beds, Tantangara Fm, and Gang Gang Adamellite	Displaced 5 km by left-lateral wrench faulting on Boggy Plain Fault	Probably Early Devonian; K/Ar age on biotite of 417 ± 10 m.y. and on hornblende of 417 ± 10 m.y.; Rb/Sr age on biotite of 406 ± 1 m.y. (D. Wyborn, 1977)
Hell Hole Creek Adamellite (Dhh)	Hell Hole Ck	Adamellite, minor granodiorite	Feldspar, quartz, biotite, hornblende, clinopyroxene, magnetite, sphene			Intrudes Tantangara Fm	None	Early Devonian
Coolamine Igneous Complex (Dlx, Dlp)	Cooleman Plain, Cooleman Mtns, Seventeen Flat, McLeods Ridge	Granodiorite, quartz monzodiorite, quartz gabbro, adamellite, pyroxenite	Feldspar, quartz, clinopyroxene, hornblende, biotite, orthopyroxene, magnetite, sphene			Intrudes Cooleman Plains Gp, Gurrangorambla Granophyre, Kellys Plain Volcanics; intruded by Jackson Granite	Displaced by left-lateral wrench faulting on Mount Black Fault	Early Devonian
Gurrangorambla Granophyre (Dlg)	Gurrangorambla Ra, Cooleman Plain, and E of Mt Black	Pink granophyre	Feldspar, quartz, chlorite, magnetite			Intrudes Cooleman Plains Gp and Kellys Plain Volcanics; intruded by Coolamine Igneous Complex and Jackson Granite	Displaced by left-lateral wrench faulting on Mount Black Fault	Early Devonian
Kellys Plain Volcanics (Dlk)	Kellys Plain, Currango Plain, Skains Hill, Peppercorn Ck, u. Goodradigbee R	Dacite and rhyodacite, ignimbrite, rhyolite, tuff, agglomerate	Phenocrysts: quartz, plagioclase, anorthoclase, biotite, cordierite, hypersthene, garnet; groundmass: feldspar, quartz	Subaerial ignimbritic eruptions	At least 300	Unconformable on Kiandra Gp, Tantangara Fm, and Cooleman Plains Gp; intruded by Gurrangorambla Granophyre and Coolamine Igneous Complex	Tilted to E and gently folded; displaced by about 200 m of thrust movement on Tantangara Fault	Early Devonian, possibly latest Silurian
YOUNG BATHOLITH — I-type:								
Coodravale Granodiorite (Syo)	S watershed of Wee Jasper Ck	Granodiorite, adamellite	Feldspar, quartz, hornblende, biotite, allanite, opaques			Intrudes Goobarragandra Volcanics and Micalong Swamp Basic Igneous Complex	Cut by Long Plain Fault; weakly deformed	Late Silurian
Kennedy Range Adamellite (Syk)	Headwaters of Feints Ck	Adamellite, granite, aplite	Feldspar, quartz, hornblende, biotite, hypersthene, opaques			Intrudes Goobarragandra Volcanics; intruded by Micalong Swamp Basic Igneous Complex	Brecciated by the Kennedy Range Fault	Late Silurian
Starvation Point Adamellite (Syp)	N of Yarrangobilly Mtn	Adamellite	Feldspar, quartz, hornblende, biotite, allanite, opaques, prehnite, pumpellyite			Intrudes Goobarragandra Volcanics	Weakly deformed	Late Silurian
YOUNG BATHOLITH — S-type:								
Spicers Creek Adamellite (Sys)	N of Yarrangobilly Mtn	Adamellite	Feldspar, quartz, biotite, ilmenite			Intrudes Goobarragandra Volcanics	Weakly deformed	Late Silurian
Couragago Granodiorite (Syc)	Couragago, Tumorrama Swamp, Jeremiah Ck	Granodiorite, adamellite	Feldspar, quartz, biotite, ilmenite			Intrudes Goobarragandra Volcanics and Micalong Swamp Basic Igneous Complex; intruded by Burrinjuck Adamellite	Weakly deformed	Late Silurian
Broken Cart Granodiorite (Syb)	Broken Cart, Dubbo, Emu Flat; Myers and Oaks Cks	Granodiorite, adamellite	Feldspar, quartz, biotite, cordierite, ilmenite			Intrudes Goobarragandra Volcanics and Micalong Swamp Basic Igneous Complex	Weakly deformed	Late Silurian

TABLE 1. SUMMARY DESCRIPTIONS OF NAMED PALAEOZOIC UNITS—*Continued*

Unit (map symbol)	Distribution	Rock types	Mineral content (igneous units)	Environment/ mode of deposition	Thickness (m)	Stratigraphic relations	Effects of tectonism	Age
Bugtown Tonalite (Sbt)	Bulgar Ck valley	Tonalite, granodiorite	Feldspar, quartz, hornblende, biotite, magnetite, allanite			Intrudes Tantangara Fm	Intensely deformed and foliated	Late Silurian
Condor Granodiorite (Scg)	Condor Ck	Granodiorite, tonalite	Feldspar, quartz, hornblende, biotite, clinopyroxene, magnetite			Intrudes Nungar beds. Overlain by Mountain Creek Volcanics	Weakly deformed	Probably Late Silurian
GINGERA BATHOLITH								
Bimberi Leucogranite (Sgb)	Mt Bimberi	Leucogranite and aplite	Feldspar, quartz, muscovite, biotite			Intrudes Nungar beds, McKeahnie Adamellite, and Half Moon Peak Adamellite	Intensely deformed	Silurian, probably Late Silurian
Ginini Leucoadamellite (Sgg)	Brindabella Ra; E and N of Mt Gingera	Leucoadamellite, adamellite, aplite	Feldspar, quartz, biotite, muscovite, ?cordierite pseudomorphs			Intrudes Nungar beds and probably McKeahnie Adamellite and Bendora Granodiorite	Intensely deformed	Silurian, probably Late Silurian
Half Moon Peak Adamellite (Sgh)	Mt Murray, Mt Morgan, Half Moon Peak, Platypus Lodge	Adamellite	Feldspar, quartz, biotite, muscovite, cordierite pseudomorphs			Intrudes Nungar beds, Tantangara Fm, and probably McKeahnie Adamellite; intruded by Bimberi Leucogranite	Deformed	Silurian, probably Late Silurian
McKeahnie Adamellite (Sgk)	Little Ginini, Mt Gingera; W of Mts Bimberi and Murray	Foliated adamellite	Feldspar, quartz, biotite, muscovite			Intrudes Nungar beds and Tantangara Fm; intruded by Bimberi Leucogranite and probably by Half Moon Peak Adamellite and Ginini Leucoadamellite	Intensely deformed	Silurian, probably Late Silurian
Bendora Granodiorite (Sgo)	E of Mt Aggie to S of Bulls Head	Foliated granodiorite	Feldspar, quartz, biotite, muscovite, cordierite pseudomorphs			Intrudes Nungar beds; probably intruded by Ginini Leucoadamellite	Intensely deformed	Silurian, probably Late Silurian
McLaughlins Flat Granodiorite (Sgm)	Willow Grove, McLaughlins Flat, Fontenoy; E of Big Bugtown Hill	Foliated granodiorite	Feldspar, quartz, biotite, muscovite			Intrudes Nungar beds and Tantangara Fm	Intensely deformed in most places	Silurian, probably Late Silurian; K/Ar age on biotite of 422 ± 8 m.y.; Rb/Sr age on biotite of 412 ± 8 m.y.
Cow Flat Granite Porphyry (Scf)	Cow Flat	Leucocratic quartz-feldspar porphyry	Feldspar, quartz; minor biotite, sphene, clinozoisite			Intrudes Tidbinbilla Quartzite	Cut by Cotter Fault	Probably Late Silurian
Booroomba Leucogranite (Smb)	Booroomba, Blue Gum Ck, White Horse Flat, Paddys R Road, Booroomba Rocks	Leucogranite and aplite	Feldspar, quartz, muscovite, biotite; rare garnet			Intrudes Adaminaby beds and Shannons Flat Adamellite	Weakly deformed	Probably Late Silurian; Rb/Sr whole-rock age of 415 ± 2 m.y.*
Westerly Leucogranite (Smw)	NW of Ashvale	Leucogranite	Feldspar, quartz, muscovite, biotite, garnet, andalusite			Intrudes Adaminaby beds, Callemondah Granodiorite, and Yaouk Leucogranite	Weakly deformed; contact-metamorphosed by a mafic I-type pluton	Probably Late Silurian; Rb/Sr ages on muscovites of 408 ± 4 and 405 ± 4 m.y.*
McDonald Granite Porphyry (Smm)	McDonald Hill; E of Uriarra Forestry Settlement	Porphyritic granite	Feldspar, quartz, altered biotite			Intrudes Walker and Uriarra Volcanics	Weakly deformed	Probably Late Silurian

Murrumbidgee Batholith	Yaouk Leucogranite (Smy)	Scabby Ra, Yaouk Bill Ra, Ashvale	Coarse-grained leucogranite intruded by many aplitic bodies	Feldspar, quartz, muscovite, biotite	Intrudes Adaminaby beds, Bolairo Granodiorite, and Willoona Tonalite; probably gradational into Shannons Flat Adamellite; intruded by Westerly Leucogranite	Weakly deformed	Probably Late Silurian
Murrumbidgee Batholith	Shannons Flat Adamellite (Smf)	Shannons Flat, Boboyan Divide, Mt McKeahnie, Tidbinbilla Nature Reserve, Paddys R, Pierces Ck Pine Forest	Coarse-grained adamellite and leucoadamellite	Feldspar, quartz, biotite, muscovite	Intrudes Adaminaby beds, Paddys River Volcanics, Callemondah and Clear Range Granodiorites, and Willoona Tonalite; probably gradational into Yaouk Leucogranite; intruded by Booroomba Leucogranite	Weakly deformed; intensely deformed in places	Probably Late Silurian; Rb/Sr age on minerals and whole rocks of 414 ± 2 m.y.*
Murrumbidgee Batholith	Stewartsfield Granodiorite (Sms)	Near Stuartfield; S of Yaouk	Granodiorite and adamellite	Feldspar, quartz, biotite, muscovite, cordierite pseudomorphs, garnet	Intrudes Adaminaby beds	Weakly deformed	Probably Late Silurian
Murrumbidgee Batholith	Callemondah Granodiorite (Smc)	Boboyan Hill, Pheasant Hill, Flynns Ck	Foliated granodiorite	Feldspar, quartz, biotite, muscovite, cordierite pseudomorphs	Intrudes Adaminaby beds; intruded by Shannons Flat Adamellite	Deformed	Probably Late Silurian; Rb/Sr age on biotite of 410 ± 4 m.y.*
Murrumbidgee Batholith	Clear Range Granodiorite (Smr)	Rocky Crossing, Long Flat	Foliated granodiorite	Feldspar, quartz, biotite, muscovite, cordierite pseudomorphs	Intrudes Adaminaby beds; intruded by Shannons Flat Adamellite	Deformed	Probably Late Silurian; Rb/Sr age on biotite of 410 ± 4 m.y.*
Murrumbidgee Batholith	Bolairo Granodiorite (Sma)	N of Bolaro to Yarra Glen	Foliated granodiorite	Feldspar, quartz, biotite, muscovite, cordierite pseudomorphs	Intrudes Adaminaby beds; intruded by Westerly Leucogranite	Weakly deformed	Probably Late Silurian; Rb/Sr age on biotite of 402 ± 4 m.y.*
Murrumbidgee Batholith	Willoona Tonalite (Smo)	N of Jones Plain; W of Willoona	Foliated tonalite and granodiorite	Feldspar, quartz, biotite, muscovite, cordierite pseudomorphs	Intrudes Adaminaby beds; intruded by Shannons Flat Adamellite and Yaouk Leucogranite	Weakly deformed	Probably Late Silurian; Rb/Sr age on biotite of 410 ± 4 m.y.*
Murrumbidgee Batholith	Tonalite at Ashvale (Smt)	NW of Ashvale	Hornblende tonalite	Plagioclase, hornblende, quartz, biotite	Intrudes Yaouk and Westerly Leucogranites	Weakly deformed	Probably Late Silurian; K/Ar age on biotite of 414 ± 6 m.y.
Kosciusko Batholith	Lucas Creek Granite (Slg)	Lucas Ck, Studlands, Hughes Ck	Leucogranite, adamellite	Feldspar, quartz, muscovite, biotite	Intrudes Nungar beds and Tantangara Fm	Weakly foliated	Probably Late Silurian
Kosciusko Batholith	Gang Gang Adamellite (Sga)	Alpine, Gang Gang, and Waterhole Cks, Alpine Hill	Leucoadamellite, adamellite, sodic leucogranite	Feldspar, quartz, biotite, muscovite, garnet, andalusite	Intrudes Boltons and Nungar beds and Tantangara Fm; intruded by Boggy Plain Adamellite	Weakly foliated; displaced 5 km by left-lateral wrench faulting on Boggy Plain Fault	Probably Late Silurian
	Micalong Swamp Basic Igneous Complex (Sbm, Sim)	Large number of stocks and dykes between Jeremiah Ck in N and headwaters of Feints Ck in S	Gabbro, dolerite, quartz diorite, anorthositic gabbro, tonalite, leucogranodiorite, pyroxenite	Plagioclase, hornblende, clinopyroxene, uralite, magnetite, orthopyroxene, olivine, apatite, quartz, ferrohastingsite, antiperthite	Intrudes Goobarragandra Volcanics; intruded by most of the Young Batholith plutons and Burrinjuck Adamellite	Weakly deformed	Late Silurian; K/Ar age on hornblende of 430 ± 9 m.y.

*Age determinations from Roddick & Compston (1976).

TABLE 1. SUMMARY DESCRIPTIONS OF NAMED PALAEOZOIC UNITS—*Continued*

Unit (map symbol)	*Distribution*	*Rock types*	*Mineral content (igneous units)*	*Environment/ mode of deposition*	*Thickness (m)*	*Stratigraphic relations*	*Effects of tectonism*	*Age*
Goobarragandra Volcanics (Sg)	Belt between W of Burrinjuck Dam in N and Rules Point in S	Dacite, albitised dacite, volcanic breccia, tuff, reworked volcaniclastic sediments, limestone	Phenocrysts: plagioclase, quartz, biotite; rare cordierite, hypersthene, hornblende, actinolite; groundmass: feldspar, quartz	Subaerial ignimbritic and fissure eruptions	Unknown, probably over 1000	Intruded by Young Batholith, Micalong Swamp Basic Igneous Complex, and Burrinjuck Adamellite	Broad open folds; no foliation	Late Silurian; Rb/Sr whole-rock age of 429 ± 16 m.y.; porphyry dyke in volcanics dated as 429 ± 9 m.y. (K/Ar) and 417 ± 8 m.y. (Rb/Sr)
Ginninderra Porphyry (Spg)	Ginninderra Ck, Little Swamp Ck, The Horseshoe	Porphyritic microgranite	Phenocrysts: quartz, plagioclase, altered mafic minerals, allanite; orthoclase megacrysts; groundmass: feldspar, quartz			Intrudes Laidlaw Volcanics; unconformable below Mountain Creek Volcanics	Undeformed	Ludlovian
Uriarra Volcanics (Svu)	Narrow belt between Vanity Crossing in S and Tinkers Ck in N	Dark grey to pink rhyodacite	Quartz, albite (altered from calcic plag.), sanidine, biotite, allanite, hypersthene	Subaerial	Probably at least 2000	Disconformable on Walker Volcanics; unconformable below Mountain Creek Volcanics	Broad open folds	?Early Ludlovian
Tarpaulin Creek Ashstone Member (Svt)	Narrow belt between Cotter Dam in S and Tinkers Ck in N	Ashstone	Quartz, albite, K-feldspar	Subaerial ashfalls	2 to 10	Basal member of Uriarra Volcanics	Broad open folds	?Early Ludlovian
Laidlaw Volcanics (Svl)	Extensive area in NE BRINDABELLA; E of Cotter reserve	Rhyodacite	Phenocrysts: quartz, labradorite, sanidine, biotite, hypersthene, allanite; groundmass: feldspar, quartz	Subaerial ignimbritic eruptions	About 1000	Conformable on Yass Fm; ?unconformable on Glen Bower Fm; unconformable below Mountain Creek Volcanics; intruded by Ginninderra Porphyry	Broad open folds	Early Ludlovian
Yass Formation (Suy)	NE corner of BRINDABELLA	Interbedded siltstone, shale		?Marine	300-400	Conformable on Hawkins Volcanics; conformable below Laidlaw Volcanics	Broad open folds	Earliest Ludlovian
Glen Bower Formation (Sug)	Mt Boambolo	Interbedded limestone, sandstone, siltstone, red shale, minor conglomerate		Very shallow marine to estuarine or deltaic	1000	?Unconformable below Laidlaw Volcanics; conformable on Hawkins Volcanics	Gentle folds; extensively faulted	Earliest Ludlovian
Hawkins Volcanics (Svh)	NE corner of BRINDABELLA and near Mt Boambolo	Dacite	Phenocrysts: quartz, plagioclase (altered to albite), biotite, cordierite (altered), garnet; groundmass: feldspar, quartz	Subaerial ignimbritic eruptions		Conformable below Yass and Glen Bower Fms; base not seen in mapped area	Broad open folds	Late Wenlockian
Walker Volcanics (Svw)	Cotter Dam, Ranger Hill, Walker Hill, Pine Ridge, Fairlight Rd	Dacite ignimbrite, bedded tuff, volcaniclastic sediment, limestone	Phenocrysts: quartz, albite, biotite, cordierite, garnet; groundmass: feldspar, quartz	Terrestrial, with minor shallow-marine incursions	At least 2000	Conformable on unnamed volcanic sequence W of Belconnen; ?disconformable below Uriarra Volcanics	Broad open folds	Late Wenlockian

Paddys River Volcanics (Smp)	Paddys R, Uriarra Pine Forest, Cotter valley, The Mullion	Dacite ignimbrite; minor rhyolite, tuff, limestone, mudstone	Phenocrysts: quartz, albite, biotite, cordierite, garnet; groundmass: feldspar, quartz	Terrestrial, with minor shallow-marine incursions	At least 1000	Unconformable on Ordovician flysch; ?unconformable or ?disconformable on Tidbinbilla Quartzite; unconformable below Mountain Creek Volcanics; intruded by Shannons Flat Adamellite	Steep dips; well-developed foliation in S; weak foliation in N	Late Wenlockian
Micalong Creek beds (Sum)	Goodradigbee valley S of Wee Jasper	Limestone, siltstone, shale		Shallow marine	?200	In faulted contact with all surrounding units	Steep dip and intense cleavage	Ludlovian
COOLEMAN PLAINS GROUP								
Blue Waterhole Formation (Sbw)	Cooleman Plain, N to Koorabri	Bedded chert, siltstone, mudstone		Shallow marine	70 to 600	Unconformable below Kellys Plain and Mountain Creek Volcanics; conformable on Pocket and Peppercorn Fms; passes laterally into Cooleman Limestone	Open folds on Cooleman Plain; intense folds and cleavage to N	Ludlovian to Pridolian
Cooleman Limestone (Scl)	Cooleman Plain, u. Goodradigbee valley	Massive to well-bedded limestone, commonly recrystallised		Shallow marine, but not intertidal	Up to 650	Conformable on Peppercorn Fm; passes laterally into Pocket and Blue Waterhole Fms; disconformable and conformable below Blue Waterhole Fm	Open folds generally; intense folds and cleavage locally	Late Wenlockian to early Pridolian
Pocket Formation (Sps)	U. Goodradigbee valley	Mudstone, siltstone, shale, limestone		Shallow marine	At least 1000	Unconformable on Tantangara Fm; passes laterally into Cooleman Limestone and Peppercorn Fm	Intense folds and cleavage	?Late Llandoverian to ?early Ludlovian
Peppercorn Formation (Sme)	Discontinuous outcrops from Nungar Ck to Brindabella	Basal conglomerate, arenite, siltstone, shale, limestone		Shallow marine	Up to 1000	Unconformable on Kiandra Gp and Tantangara Fm; passes laterally into Cooleman Limestone and Pocket Fm, and conformably up into Blue Waterhole Fm	Broad open folds in S; intense folds with cleavage in N	Late Llandoverian to ?early Ludlovian
Tidbinbilla Quartzite (St)	Cotter valley W of Tidbinbilla Mtn; small area on Two Sticks Rd	Quartzite, minor shale		Marine, outer shelf	300	Unconformable on Adaminaby beds; ?unconformable or ?disconformable below Paddys River Volcanics	Gentle dip to W	Late Llandoverian to early Wenlockian
Tantangara Formation (Sa, Saq)	Wide belt from Pocket Saddle to L Eucumbene; Zinc Ridge, Mt Nattung	Coarse to fine quartz arenite, siltstone, and shale in graded units		Deep marine; by turbidity currents	Up to ?2000	Unconformable on Nungar beds and Kiandra Gp; unconformable below Cooleman Plains Gp and Kellys Plain Volcanics	Intense folds with cleavage E of Tantangara Fault	Early Llandoverian
Adaminaby beds (Oub, Og_1, Og_2)	From Adaminaby N to Tidbinbilla Ra and Bullen Ra; Shannons Flat to Orroral Valley	Coarse quartz arenite, siltstone, and shale in graded units; black graptolitic shale		Deep marine; by turbidity currents	At least 1000	?Unconformable below Tantangara Fm; probably conformable on Nungar beds	Intense folds except W of Tidbinbilla Ra, where folds are gentle	Late Eastonian to early Bolindian
Nungar beds (On, Ons)	Nungar Ridge, Nungar Plain, Monaro Ra, Brindabella Ra	Fine quartz arenite, siltstone, slate		Deep marine; by turbidity currents	At least 1000	?Passes laterally into Kiandra Gp and Boltons beds; unconformable below Tantangara Fm; base not exposed	Intense folds with well-developed cleavage	?Darriwilian to early Eastonian

TABLE 1. SUMMARY DESCRIPTIONS OF NAMED PALAEOZOIC UNITS—*Continued*

	Unit (map symbol)	*Distribution*	*Rock types*	*Mineral content (igneous units)*	*Environment/ mode of deposition*	*Thickness (m)*	*Stratigraphic relations*	*Effects of tectonism*	*Age*
KIANDRA GROUP	Nine Mile Volcanics (Oks, Okt, Okl, Oki)	N end of Long Plain, Little Peppercorn Plain	High-K porphyritic basalt, basaltic tuff; minor chert, feldspathic arenite; monzonite, hornblendite	Clinopyroxene, plagioclase, K-feldspar, altered olivine, hornblende, biotite, magnetite, apatite, prehnite, pumpellyite, actinolite	Deep to shallow-marine, locally subaerial	At least 1050	Passes laterally into Temperance Fm; unconformable below Tantangara and Peppercorn Fms	Intense folds with cleavage	Gisbornian
KIANDRA GROUP	Temperance Formation (Otd, Otc, Ott, Otb)	Kiandra to N end of Long Plain	Basaltic tuff, agglomerate, chert, volcaniclastic sediments	Feldspar, clinopyroxene, hornblende, prehnite, pumpellyite actinolite, quartz, magnetite, apatite, altered olivine	Submarine, as archipelagic aprons around volcanic centres	Up to 5000	Conformable on Boltons beds; passes laterally into Nine Mile Volcanics and Nungar beds; unconformable below Tantangara Fm	Intense folds with cleavage	Late Darriwilian to ?late Gisbornian
	Gooandra Volcanics (Ogl, Ogs, Ogi)	Long Plain to Kiandra Plain and Gooandra Ck	Basaltic to andesitic lava, and breccia; minor rhyolite, volcaniclastic sediment; gabbro	Albite, epidote, actinolite, chlorite, clinopyroxene, magnetite; minor quartz, biotite, sericite, K-feldspar	Probably all submarine, in deep water	At least 3000	Conjectural, as all contacts faulted	Intense folds and faults; well-developed cleavage, and schistosity in places	?Late Darriwilian to ?early Gisbornian
	Boltons beds (Oln)	Four Mile Hill, Tantangara Mtn, Blanket Hill, Blackfellows Hill	Fine quartz arenite, siltstone, shale		Deep marine, by turbidity currents	At least 2000	Conformable below Kiandra Gp; ?passes laterally into Nungar beds; base not exposed	Intense folds with cleavage developed	?Darriwilian

reason for selective albitisation in Jurassic andesitic tuff in Oregon was an unequal distribution of interstitial water. Jolly (1970) reported unalbitised plagioclase from the margins, of thick coarsely crystalline flows of the Las Tetas Lava in Puerto Rico. In volcanics in British Columbia, plagioclase in the cores of pillow lavas and flows is albitised and pumpellyitised, whereas that in tuffs and pillow rims is not; Kuniyoshi & Liou (1976) attributed the selective albitisation and pumpellyitisation to the variable composition of the pore fluid as Fe-Ti oxides recrystallised. This explanation does not account for selective albitisation in the TANTANGARA rocks in which TiO_2 is low and pumpellyite poorly developed (see zone 3). A further contrast with the British Columbian volcanics is that plagioclase in the tuffs in zones 2 to 4 in the TANTANGARA rocks appears to have been albitised before that in the thick lavas, intrusions, and massive lava fragments in agglomerates.

Zone 1: unalbitised plagioclase

This zone has been detected in three areas, all within the Temperance Formation: on the ridge northwest of Black Walters Creek, on the ridge south of Kiandra Creek, and near the unconformity with the overlying Tantangara Formation 2 km south of Black Hill. In this zone all original igneous minerals are unaltered. These minerals are plagioclase, orthoclase, clinopyroxene, and hornblende. Olivine is not apparent in rocks from this zone.

In the contact aureole of the Boggy Plain Adamellite, plagioclase is commonly unalbitised, yet clinopyroxene is almost completely altered to actinolite, chlorite, and biotite; apparently the dry heating in the contact zone had little effect in promoting the albitisation process.

Zone 2: albite + prehnite

Rocks in this zone have been mapped on the western edge of Dairymans Plain, northeast of Tantangara Mountain, and around the head of Kiandra Creek. South of Wild Horse Plain, a lack of samples has left the zone undetected, whereas near Black Hill the predominance of pure chert has precluded diagnostic minerals from developing; at both these places the presence of the zone can be inferred as they lie between zone 1 and higher-grade zones.

Zone 2 is distinguished by the breakdown of plagioclase and the appearance of prehnite. The plagioclase is perfectly pseudomorphed by albite, which is either clear or dusted with sericite flakes. Albite twinning is commonly absent or diffuse. Prehnite does not occur as inclusions in the albite, but is more common in the matrix of the rock or in veins. At the very lowest grade, prehnite is rare and invariably associated with primary opaques. In places it fills cracks or cavities, along with authigenic albite, chlorite, and iron-rich epidote. Iron-rich epidote, which first appears in this zone, is mostly interstitial, rarely included in albite, and generally not as abundant as prehnite.

Olivine pseudomorphs in lava fragments in zone 2 are completely pseudomorphed by chlorite, with minor sphene. Prehnite also partly replaces some crystals. Jolly (1970) reported prehnite replacing olivine in his zone 2 rocks in Puerto Rico.

Orthoclase, clinopyroxene, and hornblende remain unaltered in metamorphic zone 2.

Zone 3: albite + prehnite + pumpellyite

This zone is distinguished from zone 2 solely by the incoming of pumpellyite. Rocks of zone 3 crop out on Dairymans Plain, within the chert-rich inlier on the Murrumbidgee River west of Nungar Creek, and on Long Plain south of Peppercorn Hill. A large area around McPhersons Creek and a narrow belt southeast of Wild Horse Plain probably also contain rocks of zone 3, but none of the samples collected there has been of suitable composition.

The pumpellyite is not well developed. In lavas on Long Plain and volcanic arenites on Dairymans Plain it occurs as scattered interstitial patches less than 0.1 mm, along with chlorite and less commonly prehnite. It also occurs as inclusions in albitised plagioclase crystals. It is best developed in a clinopyroxene tuff on Long Plain (at grid ref. 457603) where, with minor prehnite, it forms patches up to 0.5 mm; two varieties are present: a brownish green type surrounded by the more familiar bluish green type. In a clinopyroxene porphyry intrusion on Long Plain, pumpellyite is associated with chloritised primary igneous biotite flakes. The pumpellyite is mostly granular, but often has a prismatic habit with characteristic Y elongation, and pleochroism $X = Z =$ colourless, $Y =$ bright blue-green. The petrographic determination of pumpellyite was confirmed by X-ray identification of the major reflections at 3.03Å, 2.74Å, and 2.45Å. The pumpellyite occupies textural positions similar to those of prehnite in zone 2, so the reaction involving the incoming of pumpellyite is probably a prehnite-consuming reaction such as that proposed by Seki (1969):

$$\text{prehnite} + \text{chlorite} + H_2O = \text{pumpellyite} + \text{quartz}$$

Prehnite is still common in zone 3, mostly as veins and large patches. One lava on Long Plain contains prehnite and pumpellyite as inclusions in albitised plagioclase phenocrysts, but also contains biotite phenocrysts which are almost completely replaced by prehnite and lesser chlorite, opaques, and epidote.

Clinopyroxene, orthoclase, and hornblende are unaltered in zone 3 whereas olivine is altered as in zone 2.

Zone 4: albite + actinolite (+ clinozoisite)

This zone is distinguished by the disappearance of prehnite and pumpellyite and the appearance of actinolite. The boundary between zone 3 and 4 is probably gradational. Several samples contain prehnite and actinolite, but none of them contains actinolite and pumpellyite.

Zone 4 is widely developed in the Nine Mile Volcanics east of Peppercorn Hill, in the Temperance Formation southwest of Cooinbil, and in a belt comprising mainly the Gooandra Volcanics and Temperance Formation either side of the Kiandra Fault between east of Rules Point and Kiandra; all the Gooandra Volcanics north of Gooandra Hill are in this zone.

In the Nine Mile Volcanics and Temperance Formation the onset of zone 4 is marked by clinopyroxene beginning to break down to actinolite. The first stage of this breakdown results in a pale fibrous overgrowth of actinolite on unaltered clinopyroxene, while actinolite needles grow in the rims of altered olivine crystals. As alteration continues, clinopyroxenes are veined by pale actinolite, and actinolite needles become more abundant in altered olivine grains. Some olivines also develop cores of composite quartz. In the most altered samples only a trace of clinopyroxenes is left, and chloritised olivine is cut by a network of actinolite needles; the clinopyroxene is commonly pseudomorphed by optically continuous actinolite.

The breakdown of pumpellyite from zone 3 to zone 4 probably results in the development of actinolite and epidote or clinozoisite, as suggested by Banno (1964) and Seki (1969). Epidote is not abundant in the Nine Mile Volcanics or Temperance Formation, probably because much of the original calcium in the lavas is present in clinopyroxene, and most of the original feldspar is orthoclase. Epidote does not markedly increase in abundance in zone 4 as a result of pumpellyite-consuming reactions, probably because pumpellyite is not abundant in zone 3. In a few samples coloured epidote is commonly surrounded by a colourless rim with anomalously coloured low birefringence; this is probably clinozoisite. The presence of orthorhombic zoisite in a metachert in YARRANGOBILLY (at grid ref. 985628 in the Cabramurra SMA 1-Mile Series Sheet area) is evidence of low-grade (greenschist facies) metamorphism (Winkler, 1974).

Hornblende and potash feldspar remained unaltered in zone 4. The persistence of potash feldspar into the lower greenschist facies is in marked contrast to that reported by Bishop (1972) in Otago greywackes, in which detrital potash feldspar broke down into white mica well before pumpellyite disappeared. In the Nine Mile Volcanics and Temperance Formation the abundance of potash feldspar and the lack of sufficient alumina to form white mica has resulted in potash feldspar remaining stable into the lower greenschist facies. X-ray examination of several rocks in zone 4 has shown that the potash feldspar is intermediate and maximum microcline, though the unaltered rock would probably have contained sanidine. Not until biotite became stable in the upper greenschist facies (zone 5) did potash feldspar begin to break down.

In the Gooandra Volcanics, zone 4 rocks consist of the assemblage albite-epidote-actinolite-chlorite-quartz-opaques. Epidote is much more abundant than in the Nine Mile Volcanics and Temperance Formation, reflecting the greater abundance of plagioclase in the original volcanics. Clinozoisite is rare, but epidote is commonly zoned with coloured cores and paler iron-poor rims; the zoning is a result of increasing temperature (Miyashiro, 1973).

Relict clinopyroxene is apparent in only one lava sample from the Gooandra Volcanics (at grid ref. 384462), but is quite common in the intrusives within the Gooandra Volcanics.

Zone 5: albite + actinolite + biotite

No rocks from the Kiandra Group are in this zone in TANTANGARA, but the Nine Mile Volcanics around Tumut Ponds (YARRANGOBILLY), in the type area, are in zone 5. These rocks still possess their original volcanic texture, but phenocrysts of plagioclase are albitised and those of clinopyroxene are actinolitised. Hornblende is still unaltered. The actinolite in the clinopyroxene pseudomorphs is commonly a darker green than in zone 4.

This zone is characterised by the breakdown of potash feldspar and the formation of biotite. In the groundmass of the lavas near Tumut Ponds the biotite forms monomineralic patches, and schistose zones which are parallel to the original flow alignment of plagioclase phenocrysts. It also fills cracks in albitised plagioclase phenocrysts and veins. Clinopyroxene pseudomorphs commonly contain biotite in their cores. The biotite is pleochroic from pale yellow to pale greenish brown or brown and is mostly interlayered with or partly altered to chlorite. Staining with sodium cobaltinitrite reveals that the rock still retains some unaltered potash feldspar, which has been partly mobilised along veins and into cracks in albite phenocrysts. The concentration of biotite and potash feldspar into veins and fractures is an indication of the mobility of K_2O in this zone, and is in marked contrast to its immobility in lower-grade zones. There may be a nett loss in K_20 from the rock at this stage.

In the breccia belt of the Gooandra Volcanics the assemblage is much the same as in zone 4, as K_2O is much less common in these lavas. In the 'rhyolitic' lavas, however, schistose zones rich in muscovite and minor green biotite are present. The Gooandra Volcanics are in general more highly deformed than the Nine Mile Volcanics and Temperance Formation, and have a well-developed secondary foliation commonly bent around augens of epidote and quartz.

Discussion

The Ordovician basic lavas and clastics in TANTANGARA have been metamorphosed up to the upper greenschist facies. The metamorphic grade appears to continue across the Kiandra Fault from the Temperance Formation into the Gooandra Volcanics, implying that the major movements on this fault antedate the metamorphism.

The textural rearrangement of the rocks has been minimal, and original igneous textures are still preserved in the upper greenschist facies (zone 5). Only in some parts of the Gooandra Volcanics could the rocks be called schists. As the rearrangement of minerals has been pronounced, zones can be mainly related to particular primary igneous minerals becoming unstable. With increasing grade, first plagioclase then clinopyroxene then orthoclase break down, and the resulting metamorphic products are albite, prehnite, pumpellyite, and epidote from plagioclase; actinolite from clinopyroxene; and biotite from orthoclase. As the primary igneous minerals are metastable the reactions are disequilibrium reactions, and cannot be accurately described in P-T space. The stability of individual metamorphic minerals will depend on temperature, load pressure, fluid pressure, and chemical composition including H_2O and CO_2 in the rock. Carbonate minerals are minor components in these rocks, indicating low CO_2 activity. Barron & Barron (1976) showed that the sequence of mineral reactions is totally different in the metamorphism of the Ordovician Sofala Volcanics (north of Bathurst), in which CO_2 activity and overall chemical mobility are much higher. The lack of CO_2 in the Nine Mile Volcanics may be one of the main reasons why the metamorphosed lavas are chemically similar to the original lavas.

Southwest of Wild Horse Plain the change from unrecrystallised rocks to upper greenschist facies takes place over a distance of only 5 km; this implies a high geothermal gradient, although the area has probably been complicated by faulting. The absence of lawsonite and the apparent lack of a pumpellyite + actinolite zone (Bishop, 1972) also imply a high geothermal gradient. According to the P_{H_2O}-T diagram of Winkler (1974, p. 183), the boundary between zones 3 and 4 (i.e., the start of greenschist facies metamorphism) was probably at pressures no higher than 3 kb at a temperature of 350°C, indicating that the minimum geothermal gradient during metamorphism was about

35°C/km. This gradient assumes vertical isograds and no postmetamorphic faulting, both of which are dubious assumptions; dipping isograds would increase the geothermal gradient, whereas postmetamorphic faulting—which is likely to have taken place along the Kiandra Fault—would most likely decrease it.

A feature of the metamorphic isograds in the Kiandra Group is that they are the reverse of the stratigraphic sequence: the lowest-grade rocks tend to be the oldest. This implies that the Kiandra Group was already folded into some sort of inclined position before it was metamorphosed. Also, the lowest-grade rocks tend to be beneath the unconformity with the overlying Tantangara Formation. Thus there is no evidence to suggest a metamorphic discontinuity between the Kiandra Group and Tantangara Formation, and the metamorphism could conceivably postdate the lower Llandoverian Tantangara Formation. The Nine Mile Volcanics immediately below the unconformity with the Peppercorn Formation are in zone 4 (lower greenschist facies), but sandstone in the Peppercorn Formation just above the unconformity contains unaltered detrital biotite. As biotite is chloritised well below the greenschist facies, there appears to be a metamorphic discontinuity between the Nine Mile Volcanics and the Peppercorn Formation. If this is correct the metamorphism must antedate the Peppercorn Formation and be older than late Llandoverian

STRUCTURE

TANTANGARA and BRINDABELLA comprise four structural blocks bounded mostly by faults (Fig. 2). Each of the blocks represents a different former level of the crust brought to the present-day erosion surface, and each has responded in its own way to post-Silurian deformation. The Goobarragandra and Canberra Blocks, which consist mostly of Silurian granitoids and volcanics have acted rigidly during post-Silurian deformation. The Tantangara Block is somewhat more deformed, but it too has resisted internal deformation as it is crossed by compressional wrench faults similar to faults in the Canberra Block. The Nungar-Brindabella Block has been highly deformed by post-Silurian latitudinal compression between the adjacent more rigid blocks.

Although the structural blocks were formed by post-Silurian tectonic events a number of older events can be recognised; in all six Palaeozoic tectonic events are known in the mapped area. These events are mostly inferred from unconformities within the well-preserved stratigraphic record. Past workers (David, 1950; Packham, 1960, 1969; Crook & others, 1973) have given orogenic names to deformations in the Lachlan Fold Belt. The deformations that we recognise correspond to these 'orogenies', so we have used their names here (Table 2), though we regard them as fold episodes, not orogenies. Although some fold episodes may represent only uplift and erosion in the mapped area, folding has been attributed to them elsewhere in the Lachlan Fold Belt.

In addition to these Palaeozoic fold episodes, two periods of Tertiary block-faulting, the Kiandra and Kosciusko Epochs (Browne, 1969), can also be recognised.

First Benambran fold episode

There is no evidence of this episode in the Goobarragandra and Canberra Blocks; indeed no rocks of this age crop out in the Goobarragandra Block. In the Canberra Block there may have been some uplift of the Adaminaby beds at this time, but, more likely, this occurred during the second Benambran fold episode.

In the Tantangara Block the episode is shown by the unconformable position of the Tantangara Formation on the Temperance Formation and Boltons beds. The unconformity itself is not exposed, but at grid reference 446455 the basal sandstone of the Tantangara Formation dips 34° northwest a few metres away from vertical Temperance Formation chert that strikes meridionally. This indicates an angular discordance of about 50° between the two formations. Elsewhere the unconformity is inferred by a mapped irregular contact,

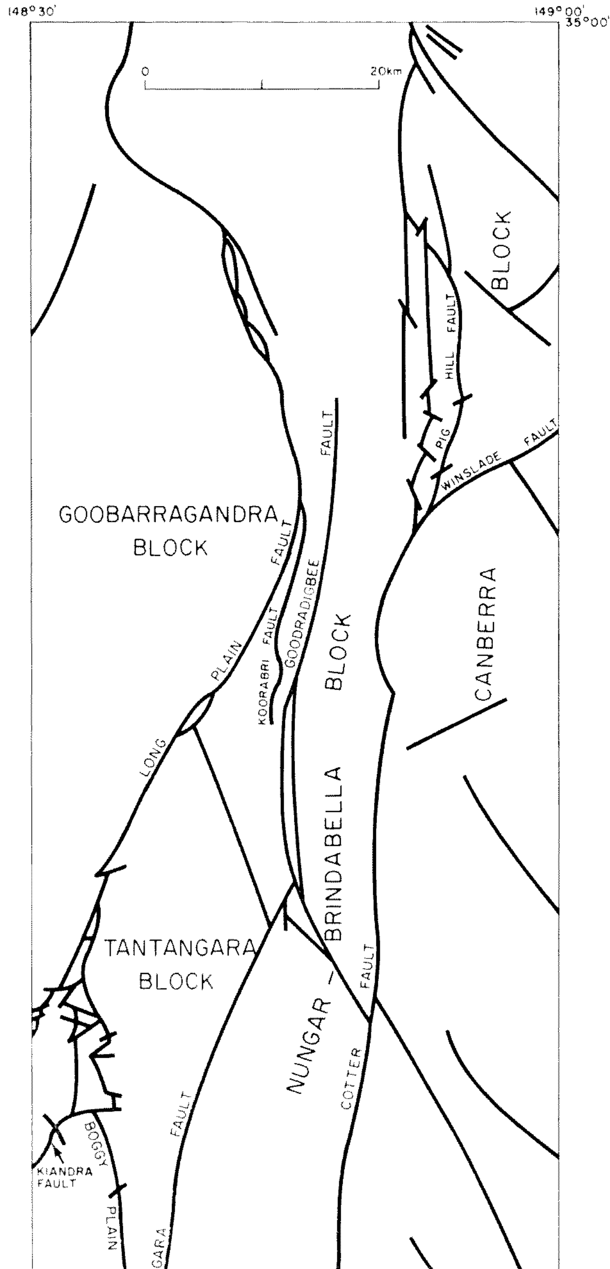


Fig. 2. Faults and structural blocks.

TABLE 2. FOLD EPISODES

Fold episode	*Age*	*Evidence for age*	*Effects*
KANIMBLAN	Pre-tertiary, post-Middle Devonian	Folded Middle Devonian Hatchery Creek Conglomerate overlain by flat Miocene basalt	Intense folds with cleavage developed in Nungar-Brindabella Block. Wrench and thrust faults elsewhere
TABBERABBERAN	Late Early Devonian	Hatchery Creek Conglomerate disconformable on limestone. Conglomerate deposition presumed initiated by uplift outside mapped area	No folds in mapped area. Minor uplift in Wee Jasper area
BOWNING	About Silurian-Devonian boundary	Ludlovian to Pridolian Blue Waterhole Formation unconformably overlain by Upper Silurian or Lower Devonian Kellys Plain Volcanics and Lower Devonian Mountain Creek Volcanics	Intense meridional folds in Nungar-Brindabella Block, and immediately E of Long Plain Fault in Tantangara Block. Elsewhere, folds less intense, and possibly on latitudinal axes in E Tantangara Block
QUIDONGAN	Early Wenlockian	Upper Wenlockian Paddys River Volcanics ?disconformable on upper Llandoverian to lower Wenlockian Tidbinbilla Quartzite	Only felt in E part of mapped area: uplift of Canberra-Yass Shelf
BENAMBRAN 2nd episode	Middle Llandoverian	Upper Llandoverian-?lower Ludlovian Peppercorn Formation unconformable on lower Llandoverian Tantangara Formation	Meridional deformation destroyed Tantangara Trough
BENAMBRAN 1st episode	Post-Bolindian, pre-early Llandoverian	Lower Llandoverian Tantangara Formation unconformable on upper Darriwilian-?upper Gisbornian Temperance Formation. Tantangara Formation also unconformable on Nungar beds, which probably range up into Eastonian, and on the ?Darriwilian Boltons beds	Tantangara Trough formed. Probable open folds adjacent to a block uplifted to W of mapped area

though in places the contact may be a fault folded by a later deformation.

The nature of this fold episode is difficult to gauge because the Tantangara Formation has been intensely folded by later deformations. Uplift of the area to the west (the Wagga Marginal Basin of Scheibner, 1973, or Wagga Trough of Webby, 1976) must have accompanied the fold episode, in order to provide a quartz-rich source for the Tantangara Formation. This uplift must have exposed and at least tilted the Temperance Formation and Boltons beds, which were partly eroded before the Tantangara Formation was deposited.

Large ?thrust movements on the Kiandra Fault probably occurred about this time, as two contrasting mafic volcanic suites, the Gooandra and Nine Mile Volcanics, were faulted together along it before regional metamorphism in the Early Silurian. Since its formation the Kiandra Fault has been cut by many younger cross-faults.

In the Nungar-Brindabella Block the Tantangara Formation unconformably overlies the Nungar beds; this is inferred by the mapped irregular contact. The best evidence for the unconformity is at grid reference 487272, on the southwest edge of Nungar Plain, where a persistent vertical bed of black slate 200 m thick in the Nungar beds is cut out by the unconformity. The angular discordance between the two units is only 15° to 20°—considerably less than the 50° discordance in the Tantangara Block to the west; this is consistent with the fold episode being related to uplift west of the mapped area.

Second Benambran fold episode

None of the rocks cropping out in the Goobarragandra Block is old enough to preserve this episode.

In the Tantangara Block the episode is inferred from the unconformity beneath the upper Llandoverian to ?lower Ludlovian Peppercorn Formation. This formation rests on the Tantangara Formation in the Nungar Creek Valley, but the area is intensely faulted and the degree of discordance between the two units is difficult to determine. Near grid reference 470385 the Peppercorn Formation basal conglomerate dips 40° to the east, only a few degrees less than the underlying Tantangara Formation. In general, in the Nungar Creek valley the Peppercorn Formation has gentle dips to the east, whereas the Tantangara Formation has a greater range of dips—up to 75°—to the east and west, implying that the Tantangara Formation was folded into closely spaced (but not isoclinal) meridionally trending synclines and anticlines before the Peppercorn Formation was deposited.

Near Cooinbil (grid ref. 444556), Mufflers Creek (grid ref. 485465), and Peppercorn Creek (grid ref. 490640) the Peppercorn Formation is unconformable on the Temperance Formation and Nine Mile Volcanics. This implies that the Tantangara Formation was removed before the Peppercorn Formation was deposited. At Peppercorn Creek, where the basal conglomerate of the Peppercorn Formation is well exposed, the unconformity surface dips steeply to the north, but the underlying Nine Mile Volcanics are in the form of a tight northeast-plunging syncline with tuffaceous and cherty siltstone in the core. The second, rather than the first, Benambran fold episode is most likely to have produced the syncline, and the northwest plunge was produced when the overlying Peppercorn Formation was tilted steeply north during the Bowning fold episode.

Evidence for the second Benambran fold episode is poor in the Nungar-Brindabella Block, which has been intensely folded by a later deformation. The subaerial to shallow-marine upper Wenlockian Paddys River Volcanics unconformably overlie the deep-marine turbidites of the Nungar beds north and south of Pig

Hill (grid ref. 725007). To the north the later deformation is not as strong, and gently folded volcanics overlie more intensely folded and meridionally cleaved Nungar beds. Meridional cleavage in the Paddys River Volcanics becomes stronger to the south, and so is probably not associated with the second Benambran fold episode. The break below the Paddys River Volcanics embraces the Quidongan and both Benambran fold episodes; but as the Quidongan folding is only minor in the Canberra Block to the east and did not occur to the west (see below), and since the first Benambran folding is probably more intense west of the mapped area, the break can mostly be attributed to the second Benambran fold episode.

In the Canberra Block this fold episode is shown by the angular unconformity between the upper Eastonian to lower Bolindian Adaminaby beds and the upper Llandoverian to lower Wenlockian Tidbinbilla Quartzite. The unconformity surface is exposed on the southern side of Tidbinbilla Mountain, and is spectacular when viewed from several kilometres to the south. Both units are tilted to the west, the angular discordance between them being about 15°. This discordance is more likely a result of the second rather than the first Benambran fold episode.

Quidongan fold episode

No rocks of this age are present at the surface in the Goobarragandra Block, and Lightner (1977) has shown that no folding occurred at this time around Tumut, immediately west of the mapped area. Nor was there any effect in the Tantangara Block, as the Cooleman Plains Group extends from the late Llandoverian to the Pridolian without significant breaks.

In the Nungar-Brindabella Block there may have been some uplift before the Paddys River Volcanics were deposited, but most of this uplift is better assigned to the second Benambran fold episode.

In the Canberra Block there is some evidence of a break between the Tidbinbilla Quartzite and Paddys River Volcanics, as the boundary is not gradational: the absence of tuffaceous beds from the upper part of the Tidbinbilla Quartzite implies that there is an erosional break between the two units. Farther east in the Canberra Block, outside the area mapped, minor folding occurred at this time (Crook & others, 1973).

Bowning fold episode

The Goobarragandra Volcanics in the Goobarragandra Block were probably folded during the Bowning fold episode. There is no direct evidence for this in the mapped area, but Moye & others (1963), Ashley & others (1971), and Barkas (1976) have mapped a major unconformity at the end of the Silurian in the Tumut area. The few bedding planes evident in the Goobarragandra Volcanics indicate broad ?meridional folds with dips up to 60°. No axial-plane cleavage is present in the volcanics.

In the Tantangara Block the Bowning fold episode is shown by the unconformity beneath the Kellys Plain Volcanics and Rolling Grounds Latite, and the folding of the Cooleman Plains Group. The Kellys Plain Volcanics unconformably overlie the Temperance Formation, Nine Mile Volcanics, Tantangara Formation, and Cooleman Plains Group, indicating considerable erosion before they were extruded. The unconformity above the Tantangara Formation is exposed at grid reference 466341, and that above the Cooleman Plains Group at grid reference 476395. As the Kellys Plain Volcanics are flat-lying north of Peppercorn Creek and in the Cooleman Mountains, and tilted gently to the east farther south, the Cooleman Plains Group must have been folded during the Bowning fold episode. The folds are quite intense at Peppercorn Creek and Tinpot Creek, where a northeast-trending axial-plane cleavage is well developed. Farther south the folds are more open, and fold axes have a range of orientations from meridional to almost latitudinal but mainly northeast trends.

Poles to bedding planes of the Tantangara Formation in the Tantangara Block (Fig. 3) suggest two periods of open folding: one on roughly meridional axes during the second Benambran fold episode; the other on roughly northeasterly to latitudinally trending axes during the Bowning fold episode. Cleavage was only locally developed during both episodes.

The Bowning fold episode has a marked effect in the Nungar-Brindabella Block. In TANTANGARA the effects of this deformation are well exposed in a road-cut in the Nungar beds at grid reference 522192 (Fig. 4), and in isoclinally folded and meridionally cleaved Tantangara Formation and Nungar beds unconformably overlain by virtually undeformed Kellys Plain Volcanics near Currango (grid ref. 530449). In all plutons of the Gingera Batholith and in the Bugtown Tonalite, intense secondary foliation parallel to the cleavage in the adjacent sediments indicates that the deformation postdates these Upper Silurian granitoids, and must therefore be attributed to the Bowning fold episode—not an earlier one. The Paddys River Volcanics are also intensely meridionally cleaved, but this cleavage is less pronounced in the north, where the deformation was presumably less intense.

The effect of the Bowning fold episode in the Canberra Block was not as marked as in the adjacent Nungar-Brindabella Block. Uplift and tilting took place in the area now occupied by the Tidbinbilla Range, and, immediately east of the Cotter Fault and north of Corin Dam, open north-northwest-trending folds developed. Elsewhere adjacent to the fault, changes in

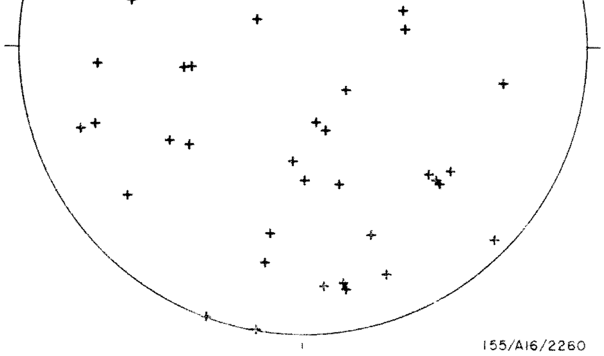


Fig. 3. Poles to bedding planes of the Tantangara Formation in the Tantangara Block. The large scatter of points can be explained by two periods of open folding at a high angle to one another.

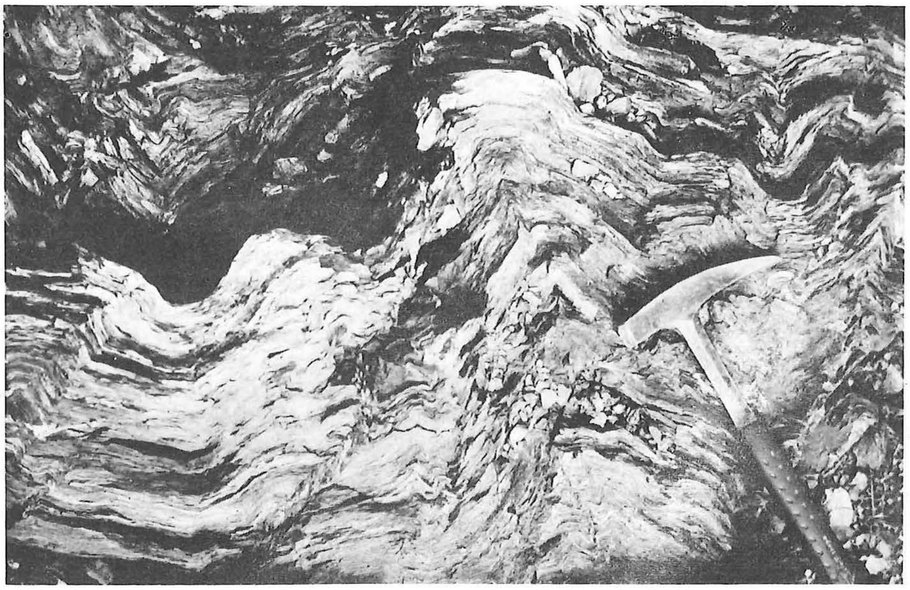


Fig. 4 Folds in the Nungar beds attributed to the Bowning fold episode; grid reference 522192. (GB/1803)

dip and even overturning (grid ref. 710850) are due to complex minor faulting. Secondary foliation in the bulk of the Murrumbidgee Batholith is much less pronounced than in the Gingera Batholith, in accord with the weaker effect of the Bowning fold episode in the Canberra Block.

North of the Winslade Fault the Bowning fold episode is shown by the unconformity between Silurian felsic volcanics and the intrusive Ginninderra Porphyry, and the overlying Mountain Creek Volcanics. The unconformity is weak and could easily have been achieved with a few hundred metres of uplift and erosion, but it is more likely that gentle meridional folding took place.

Tabberabberan fold episode

The evidence for the Tabberabberan fold episode is weak in the mapped area, but a disconformity beneath the Hatchery Creek Conglomerate is here tentatively assigned to it. The deposition of the conglomerate is presumed to have been initiated by uplift outside the mapped area. The Middle Devonian age for the Hatchery Creek Conglomerate indicates a late Early Devonian age for the episode; this is a little older than Tabberabberan events in Victoria. There is still disagreement on the effects of Tabberabberan folding in New South Wales (Powell, Edgecombe, Henry, & Jones, 1976), and it may eventually be shown that the folding of the Hatchery Creek Conglomerate, here assigned to the Kanimblan fold episode (see below) is actually Tabberabberan.

Kanimblan fold episode

For want of evidence to the contrary, the intense deformation of the Mountain Creek Volcanics, Kirawin Formation, Sugarloaf Creek Formation, Murrumbidgee Group, and Hatchery Creek Conglomerate has been attributed to the middle Carboniferous Kanimblan fold episode, although it may be as old as early Late Devonian. Near Wee Jasper the folding has been controlled by thrusting of the rigid Goobarragandra Block over the Hatchery Creek Conglomerate along the Long Plain Fault (D. Wyborn, 1977). In places the conglomerate is overturned against the fault, and cleaved. Farther east in the Taemas area, the Murrumbidgee Group is highly contorted with a roughly meridional trend and variable plunge. To the south a well-developed cleavage is present in the Mountain Creek Volcanics adjacent to the Long Plain Fault, but this becomes progressively weaker eastward. Still farther south, the Kellys Plain Volcanics are gently tilted, and wrench faulting along the Mount Black and Boggy Plain Faults was probably contemporaneous with the folding farther north. Wrench faulting, rather than folding, would have been the more rigid southern block's response to the stress; it was probably associated with thrust faulting along the Long Plain Fault and has been correlated with wrench faulting in BERRIDALE (D. Wyborn, 1977).

Tertiary uplift

Two Tertiary uplifts in the Southern Uplands followed the development of a widespread ?Cretaceous peneplain. These have been referred to as the Kiandra and Kosciusko Epochs by Browne (1969), but are here called the Kiandra and Kosciusko Uplifts. At least 350 m of pre-basalt relief in the upper Tumut valley (Hall & Lloyd, 1954), and an upland microflora preserved beneath the basalts at Kiandra (Owen, 1975), indicate that the Kiandra Uplift antedates the extrusion of lower Miocene basalts.

There is abundant evidence of post-Miocene movement (Kosciusko Uplift) along many of the older faults, such as the Cotter, Tantangara, and Murrumbidgee Faults, persisting to the present day (Cleary, Doyle, & Moye, 1964). Near Yaouk the western side of the Cotter Fault has been uplifted by 80 m relative to the eastern side since the deposition of ?Upper Tertiary gravels, and at grid reference 613282 landslips have occurred along the fault scarp. Uplift by thrusting on the east side of the Tantangara Fault near Currango was probably of the order of 220 m, but some of this uplift may be older than the Miocene.

Conclusions

The effects of five locally intense fold episodes are apparent in the mapped area. Only the Bowning and

Kanimblan fold episodes produced a well-developed axial-plane cleavage of considerable extent, although in some areas these episodes had almost no effect.

The first Benambran fold episode was probably more intense west of the mapped area, and the second Benambran fold episode destroyed the trough into which the Tantangara Formation was deposited. The Quidongan fold episode uplifted a trough which was best developed east of the mapped area. These first three deformations took place progressively eastwards, whereas the Bowning and Kanimblan fold episodes affected mainly the less rigid belts lying between more rigid areas that had previously been intruded by batholiths and had achieved partial stabilisation. Major faults—such as the Long Plain, Tantangara, Cotter, and Murrumbidgee Faults—acted as strain discontinuities for these two post-granitoid deformations. The other post-granitoid deformation—the Tabberabberan fold episode—is tentatively correlated with a disconformity between Lower and Middle Devonian sediments.

GEOMORPHOLOGY

TANTANGARA and BRINDABELLA comprise five geomorphic units (Fig. 5). Öpik (1958) named and described the Canberra Plain immediately east of the Sheet areas, and gave its age of formation as Devonian. Jennings (1972) and Ollier & Brown (1975) disputed this age, and reasoned that planation during the Tertiary was more likely. The Canberra Plain extends into BRINDABELLA, occupying most of its east and northeast parts. The Kiandra and Adaminaby Tablelands (Süssmilch, 1909) developed as a result of widespread erosion before the Kiandra and Kosciusko Uplifts (Browne, 1969) in the Tertiary. The Bimberi-Brindabella and Mount Kelly Uplands were resistant ranges that escaped this planation.

Differential movement along pre-existing faults during the Tertiary to Quaternary uplifts, the consequent rejuvenation of streams, and differential erosion of rock types, have contributed to moulding the present relief.

Kiandra Tableland

The Kiandra Tableland occupies over one-third of BRINDABELLA and one-half of TANTANGARA. It extends from the Goodradigbee River westwards to the Honeysuckle Range in TUMUT, northwards to merge with the Yass Plain, and southwards to merge with the Kosciusko Plateau. It is tilted from a general level of 1500 m in the south to 800 m in the north. The uplifting and tilting have been controlled by movements along the Cotter, Long Plain, Goodradigbee, and Koorabri Faults to the east, and along the Mooney Mooney Thrust System (Basden, 1974) to the west.

Basalt flows on the Kiandra Tableland have been dated by the K/Ar method as early Miocene (Wellman & McDougall, 1974). They overlie: lacustrine deposits at Kiandra (1500 m above MSL); a planated area adjacent to Macphersons Swamp Creek, south of Burrinjuck (800 m above MSL), where they are at the same height either side of the Long Plain Fault; and older rocks at intermediate elevations between these two places. Thus the tableland was planated, and possibly partly uplifted and tilted, before the early Miocene. Tilting of the tableland along the Long Plain and Koorabri Faults since the early Miocene may have been along a hinge a few kilometres north of Wee Jasper.

A number of monadnocks stand above the tableland. The highest are Big Dubbo Hill and Tantangara Mountain, which rise about 250 m above the planated surface. They indicate that the relief before Tertiary volcanism was of the order of 200 to 250 m.

Since it was uplifted, the Kiandra Tableland has been deeply dissected by many youthful streams such as the Goobarragandra River, Peppercorn Creek, and Micalong Creek. Some of these streams flow 400 m below the old plateau surface.

Adaminaby Tableland

The Adaminaby Tableland is a weakly dissected plateau separated from the Kiandra Tableland by the Cotter Fault except in the Goorudee Rivulet valley, where an old erosion level of about 1180 m is preserved west of the Cotter Fault at McLaughlins Flat. East of the Cotter Fault the old erosion level is at 1100 m, the level at which extensive Tertiary gravels were deposited near Yaouk. This indicates 80 m of uplift on the western side of the Cotter Fault since the tableland was planated.

Bimberi-Brindabella Upland

This is a mountainous region of resistant Ordovician sediments, Silurian granitoids, and Devonian rhyolitic volcanics. In the south it consists of a central north-south ridge with short spurs dropping steeply either side to the fault-controlled Cotter and Goodradigbee valleys. Farther north, where the belt of rhyolitic volcanics becomes much broader, the upland is a dissected area with a number of subparallel ranges such as the Blue, Webbs, Brindabella, and Baldy Ranges and Wombat Ridge. These ranges roughly follow the more resistant massive rhyolite units, while the valleys between them (such as Mountain Creek, Flea Creek, and Gunners Gorge) follow the less resistant tuff and tuffaceous sediment interbedded with the rhyolite. The crest of the upland slopes from around 1700 m in the south to 1000 m in the north, and so is several hundred metres higher than the Kiandra Tableland at a similar latitude.

Mount Kelly Upland

Much of the Mount Kelly Upland is bounded by faults: the Murrumbidgee Fault to the east, the Cotter Fault to the west, and the Winslade Fault to the northwest. It includes the Tidbinbilla, Bullen, Scabby, and Yaouk Bill Ranges, and the Paddys River, Orroral River, Rendezvous Creek, and Naas Creek valleys. In the north, sedimentary screens and roof pendants in granitoids form resistant hills such as Sugarloaf, Murrays Hill, and Black Hill. Southward the upland is formed by more resistant granitic rock rising above the Adaminaby Tableland. Many streams in the upland flow parallel to northwesterly and northeasterly trending faults and lineaments in granitoids.

The mature plain through which Paddys River flows is almost certainly an outlier of the Canberra Plain, but is now 70 m higher. Recent movements along the Murrumbidgee and/or Bullen Range Faults must have uplifted the Paddys River plain, and rejuvenated the river downstream near the fault lines.

Canberra Plain

The Canberra Plain occupies an area east of the Murrumbidgee and Pig Hill Faults and north of the

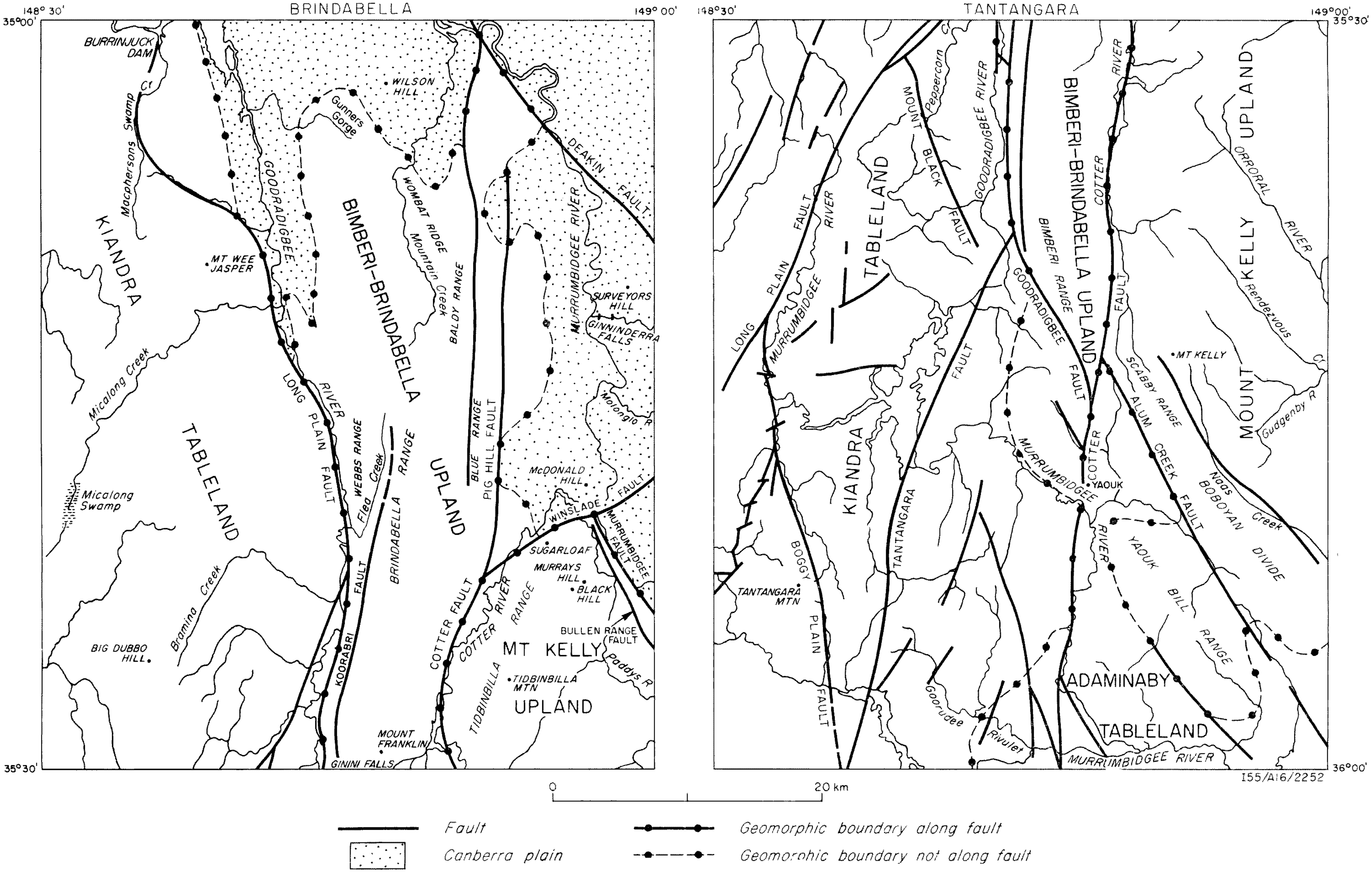


Fig. 5. Geomorphic units.

Mountain Creek Volcanics in the Bimberi-Brindabella Upland. It extends well east of the mapped area, where its boundaries are difficult to define, and to the north it merges with the Yass Plain. It is at an elevation of 550 to 600 m, but has been incised by the Murrumbidgee, Goodradigbee, and Molonglo Rivers; the deepest incision—150 m—is on the Murrumbidgee River above Burrinjuck Dam. Tributary creeks of the Murrumbidgee commonly drop steeply off the plain to the river—for example, Ginninderra Creek drops over two waterfalls, one 30 m high and the other 15 m high, to reach the incised Murrumbidgee River.

Monadnocks are common on the Canberra Plain; in the mapped area they include Surveyors Hill, Mount McDonald (grid ref. 764909), and Wilson Hill, which are up to 150 m higher than the plain. The northern ends of the Bimberi-Brindabella Upland, the Mount Kelly Upland, and the northeastern part of the Kiandra Tableland are resistant residual masses that have not been eroded to the level of the Canberra Plain. The Mount Kelly Upland has been uplifted by about 70 m since the Canberra Plain formed.

Most of the plain is underlain by Silurian dacitic volcanics and interbedded sediments. In the northwest the rocks are predominantly Devonian shale, limstone, and tuffaceous sandstone. Most of these rocks erode relatively easily, though there are some more resistant massive volcanic units and tuffaceous sandstone. The location of monadnocks is related to these more resistant units.

The Canberra Plain contains no Tertiary basalts, so its age is difficult to estimate. It was probably planated by continuous erosion since the area became land in the Devonian, and may have been at the same level as the Kiandra Tableland; planation was essentially complete by the Early Tertiary. The post-Miocene incision of the Canberra Plain was most likely hindered by low rates of erosion where the Murrumbidgee River flows through the resistant Burrinjuck Adamellite near Burrinjuck Dam: downstream from the dam there is a prominent knick point in the river where the stream gradient increases from about 10 m per 10 km to 65 m per 10 km.

GEOCHEMISTRY AND PETROGENESIS

Synopsis

In the course of mapping we collected over 280 igneous rock samples for major and trace-element geochemical analyses. The samples were analysed at the Australian Mineral Development Laboratories (AMDEL): by X-ray fluorescence spectroscopy (using a Philips PW 1220 spectrometer) for SiO_2, Al_2O_3, total Fe, CaO, K_2O, P_2O_5, Ba, Rb, Sr, Pb, Th, U, Zr, Nb, Y, La, and Ce; by atomic absorption spectroscopy after total solution in hydrofluoric acid for MgO, Na_2O, V, Cr, Co, Ni, Cu, and Zn; and by wet chemistry for FeO, H_2O^+, H_2O^-, and CO_2. The precision and accuracy of analyses are given in Appendix 1. The geochemical analyses are tabulated in Appendix 2.

We have divided the igneous rocks into five groups on the basis of age and mineralogy, and have documented the geochemistry of each in turn. The groups are:

1. Ordovician basic volcanics and related intrusions: the Gooandra and Nine Mile Volcanics.
2. Siluro-Devonian S-type granitoids and volcanics: the Murrumbidgee, Gingera, Kosciusko, and Young Batholiths; and the Goobarragandra, Kellys Plain, Paddys River, and Walker Volcanics.
3. Silurian I-type granitoids and volcanics: the Bugtown Tonalite, tonalite at Ashvale, Condor Granodiorite, and I-type granitoids in the Young Batholith; the Laidlaw and Uriarra Volcanics; and the Ginninderra Porphyry, a high-level stock intruding the Laidlaw Volcanics.
4. Lower Devonian I-type granitoids and volcanics: the Boggy Plain Adamellite, Coolamine Igneous Complex, Jackson Granite, Gurrangorambla Granophyre, Burrinjuck Adamellite, and a number of unnamed minor intrusions petrographically similar to the Boggy Plain Adamellite; and the Mountain Creek Volcanics and Rolling Grounds Latite.
5. Silurian basic intrusions of the Micalong Swamp Basic Igneous Complex.

The classification of granitoids as S-type and I-type follows the criteria of Chappell & White (1974). We have also used this classification for the felsic volcanics of the mapped area, mainly on the basis of mafic phenocrysts such as cordierite, garnet, clinopyroxene, orthopyroxene, and hornblende.

Ordovician basic volcanics and related intrusions

Two groups of basic volcanics crop out in TANTANGARA; they form the southernmost exposures of the Molong Volcanic Arc—a partly buried belt of Ordovocian mafic volcanics, at least 500 km long, in central and southern New South Wales. The Gooandra Volcanics are similar to modern island-arc tholeiites (Jakes & Gill, 1970); they show a weak tholeiitic fractionation pattern, contain less than 1.25% TiO_2, and are more potash rich than ocean-floor basalts. The Nine Mile Volcanics are basalts enriched in incompatible elements such as K, Rb, Sr, and P, but unlike alkali basalts they are low in Ti and Zr; we have called these rocks shoshonites. The limited available chemical data suggest that most of the volcanics in the Molong Volcanic Arc to the north are also shoshonitic. We conclude that the abundance of shoshonitic volcanism in the Molong Volcanic Arc indicates that the mantle beneath the arc had been modified by the introduction of incompatible elements. This modification may have occurred up to 200 m.y. before volcanism, but it may instead be related to coeval subduction and volcanism.

Siluro-Devonian S-type granitoids and volcanics

Chemical results support the mineralogical evidence that the Kellys Plain, Goobarragandra, Walker, and Paddys River Volcanics are derived from the same source material as the S-type granitoids of the Kosciusko, Gingera, Murrumbidgee, and Young Batholiths. This indicates that a large amount of relatively uniform sedimentary material partially melted to form these batholiths and volcanics. L. A. I. Wyborn (1977) has shown that the calcium and sodium contents of this source material is too high to be Ordovician turbidites, and she postulates an Upper Proterozoic to Lower Cambrian feldspar-rich sedimentary layer as the source.

We discount the association of partial melting, plutonism, and volcanism with Lachlan Fold Belt 'orogenies'. Rather, we postulate that a prolonged period of high heat flow culminating in the Early Silurian and crustal extension in the Late Silurian were responsible for the partial melting and magma migration. The Basin and Range Province in the western USA (Atwater, 1970; Proffett, 1977) is probably the closest Cainozoic analogue.

Silurian I-type granitoids and volcanics

We recognise two intrusive Silurian I-type granitoid suites—the Jindabyne Suite (Hine, Williams, Chappell, & White, 1978) and Coodravale Suite—and one volcanic suite—the Laidlaw Suite—in TANTANGARA and BRINDABELLA. The Coodravale Suite has high SiO_2, Na_2O, and Zr. The Jindabyne Suite has high Na_2O and CaO and low SiO_2 and Zr. The Laidlaw Suite volcanics plot on similar trends to the Jindabyne Suite for most elements, but have higher SiO_2, Ba, and Zr. These I-type suites, each of which has a more restricted geographical distribution than the S-type rocks, imply that the I-type rocks had a more heterogeneous source region. We presume that the Silurian I-type melts originated during the same period of crustal anatexis as the S-type melts, as the I-types' slightly younger age reflects their larger distance of ascent.

Lower Devonian I-type granitoids and volcanics

In TANTANGARA these rocks—known as the Boggy Plain Suite—are restricted to the area between the Long Plain and Tantangara Faults, and extend northwards in a meridional belt through BRINDABELLA. The Boggy Plain Suite has higher MgO, K_2O, P_2O_5, Ba, Rb, Sr, and Zr, and lower CaO, than the Jindabyne Suite. Although much of the chemical variation in the suite can be explained in terms of the unmixing of a high-temperature water-undersaturated melt from a restite (White & Chappell, 1977) composed of clinopyroxene, orthopyroxene, calcic plagioclase, and minor olivine, in some plutons concentric zoning and aplitic segregation have been caused by fractional crystallisation as well. We suggest that the likely source of the Boggy Plain Suite lies in high-potassium gabbroic bodies intruded into the lower crust during the Ordovician volcanism of the Molong Volcanic Arc.

Upper Silurian basic intrusives

These rocks are concentrated in the western part of BRINDABELLA and to a lesser extent TANTANGARA. They are classic examples of low-potassium tholeiitic liquids that have undergone fractional crystallisation at low pressure. The presence of amphibole rather than iron-rich pyroxene in the middle to late stages of fractionation indicates that the magma was more hydrated than the Skaergaard, Bushveld, or Stillwater plutons (Wager & Brown, 1967). The availability of this tholeiitic magma in the Late Silurian is evidence of a period of crustal extension at the same time as the upwelling of crustal melts to form the Silurian felsic volcanics and batholiths. Indeed, intrusion of the tholeiites into the crust may have been a major source of the high heat flow in the crust during the Silurian.

ORDOVICIAN BASIC VOLCANICS AND RELATED INTRUSIONS

Analyses of the Gooandra and Nine Mile Volcanics are presented in Tables A1 and A2 (Appendix 2). In Table A2 (Nine Mile Volcanics) a number of intrusive equivalents are also included.

Analyses of the Nine Mile Volcanics, which are clustered near the centre of an AFM diagram (Fig. 6), show no apparent iron enrichment. The Gooandra Volcanics have only a weak iron-enrichment trend, but a spread to more alkali enrichment is due to the presence of rhyolites.

Plots of selected major oxides and trace elements versus solidification index (SI*) for the Nine Mile and Gooandra Volcanics are illustrated in Figure 7; they include data from L. A. I. Wyborn (1977).

The Nine Mile Volcanics have a somewhat lower SiO_2 content than the Gooandra Volcanics, and show little silica enrichment with differentiation; the only samples to show silica enrichment are two quartz monzodiorites (71840297 and 72840264) believed to be intrusive equivalents of the Nine Mile Volcanics.

Many samples from the Nine Mile Volcanics and its intrusive equivalents have low concentrations of TiO_2. According to Manson (1967), basalts with TiO_2 contents of around 0.5% are uncommon, especially those with high alkali contents. The Gooandra Volcanics have a higher TiO_2 content, which (except in the rhyolite samples) increases with differentiation. If this is a primary trend, it indicates iron enrichment, typical of tholeiites. Perhaps the lack of a good iron enrichment trend for the Gooandra Volcanics is due to the migration of iron in the basalts to form epidote veins.

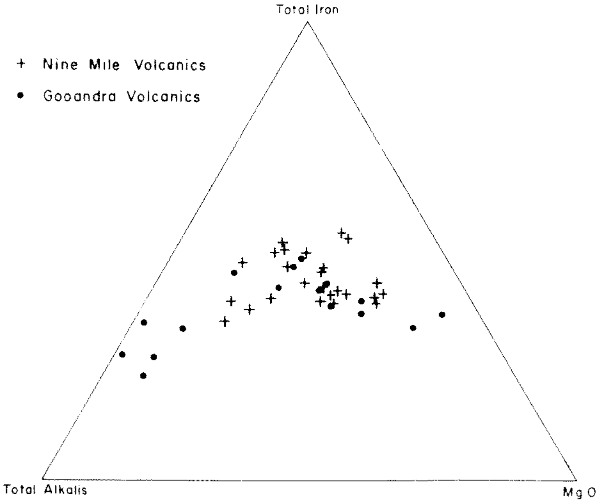
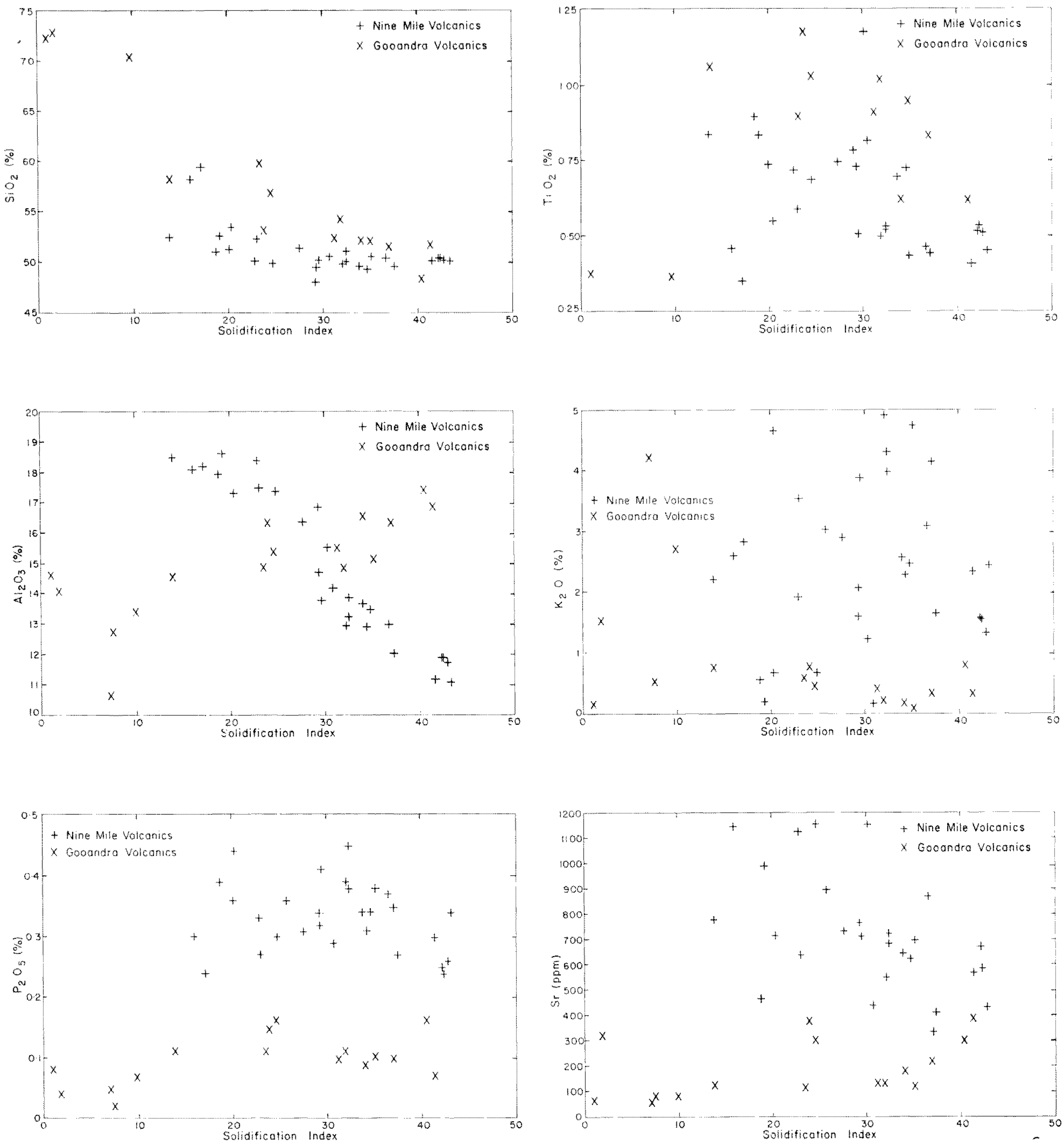


Fig. 6. AFM diagram of the Nine Mile and Gooandra Volcanics (from data in this Bulletin; and L. A. I. Wyborn, 1977).

The difference in trend for Al_2O_3 versus SI between the Gooandra and Nine Mile Volcanics is striking. The Nine Mile Volcanics show a good trend of increasing Al_2O_3 with differentiation. Such a trend would be produced by the removal of early-crystallising ferromagnesian phases poor in Al_2O_3. This is consistent with the abundance of clinopyroxene and pseudomorphed olivine phenocrysts in the basalts high in MgO, and with plagioclase phencrysts becoming abundant only in basalts lower in MgO. The Gooandra Volcanics have the opposite trend (though the points are more scattered) of decreasing Al_2O_3 with differentiation, consistent with the important role that plagioclase has played in fractionation. Relict ophitic textures in the

$$* \ SI = \frac{100\ MgO}{MgO + FeO + 0.9\ Fe_2O_3 + Na_2O + K_2O}$$



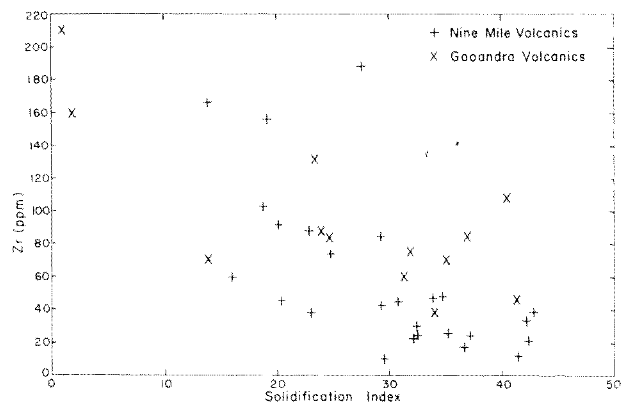


Fig. 7. Selected major oxides and trace elements *v* solidification index for the Nine Mile and Gooandra Volcanics (from data in this Bulletin; and L. A. I. Wyborn, 1977).

comagmatic dolerites intruding the Gooandra Volcanics indicate that plagioclase is close to a liquidus phase.

The Nine Mile Volcanics have a variable but high concentration of K_2O. Much of the variation can be attributed to the degree of metamorphism: most samples from TANTANGARA are metamorphosed in the lower greenschist facies, or lower, and have high K_2O contents (up to almost 5%), yet the more highly metamorphosed rocks from the Tumut River (YARRANGOBILLY) and farther south (L. A. I. Wyborn, 1977) are poorer in K_2O, probably because potassium was mobilised when potash feldspar became unstable in the upper greenschist grade. The presence of potash feldspar in primary igneous textures in the intrusive equivalents of the Nine Mile Volcanics, and the presence of plagioclase rimmed by potash feldspar in the lavas, similar to that reported for high-potassium basalts in Papua New Guinea (Mackenzie & Chappell, 1972; Jaques, 1976), leads us to conclude that the high potassium content of these basalts is a primary feature. Thus, these basalts would be termed shoshonites and absarokites in the chemical classification of Mackenzie & Chappell (1972), or trachybasalts according to the nomenclature of Johnson, Mackenzie, & Smith (1978a), but are not alkali basalts because of their low TiO_2 content (Kesson & Smith, 1972). In contrast to the Nine Mile Volcanics the Gooandra Volcanics are low in potassium (except for the rhyolites), having a concentration of less than 1%—typical of tholeiitic basalts. As potassium is generally lost in low-grade metamorphism (Beloussov, 1971; Cann, 1969; Pearce, 1975), the Gooandra Volcanics may originally have had a somewhat higher K_2O content.

The Gooandra Volcanics and Nine Mile Volcanics are quite separate on a P_2O_5 versus SI diagram: the Gooandra Volcanics have a P_2O_5 content of less than 0.2%, whereas the Nine Mile Volcanics contain more than 0.2%, and generally more than 0.3%; the concentration shows no apparent change with differentiation in both volcanics. The P_2O_5 content of the Nine Mile Volcanics is higher than that in a typical high-alumina calcalkali basalt of Jakes & White (1971), but is similar to that in shoshonitic rocks from Fiji (Gill, 1970) and Papua New Guinea (Jaques, 1976). Other shoshonitic rocks from the highlands of Papua New Guinea (Mackenzie, 1976) have slightly higher P_2O_5. The P_2O_5 content of the Gooandra Volcanics is similar to the majority of tholeiites studied by Floyd & Winchester (1975). As P_2O_5 is generally considered to be relatively immobile during alteration and low-grade metamorphism (Floyd & Winchester, 1975; Smith & Smith, 1976), the difference between the P_2O_5 content of the Nine Mile and Gooandra Volcanics is thought to be primary.

Like P_2O_5, the strontium content also separates the Gooandra and Nine Mile Volcanics. The high strontium content of the Nine Mile Volcanics is typical of shoshonitic rocks, whereas the low strontium content of the Gooandra Volcanics is typical of tholeiites low in compatible elements.

Zirconium is variable, but generally low in both the Nine Mile and Gooandra Volcanics (less than 100 ppm). Such values are rare in alkali basalts (Gill, 1970; Pearce & Cann, 1973; Floyd & Winchester, 1975), and thus, like titanium (Kesson & Smith, 1972), zirconium is a good discriminant between alkali basalts, and shoshonites such as the Nine Mile Volcanics.

Electron-probe analyses of primary igneous clinopyroxenes in terms of Ca, Mg, and Fe + Mn atoms are plotted in Figure 8. Data from the Nine Mile Volcanics, Gooandra Volcanics, and Jagungal volcanics are all from L. A. I. Wyborn (1977), and the Sofala Volcanics are from Barron (1976). The Jagungal volcanics are high-titanium tholeiites (L. A. I. Wyborn, 1977) believed to be older than the Gooandra and Nine Mile Volcanics; they crop out about 18 km southwest of the mapped area. The Sofala Volcanics analyses are the only other available data on pyroxenes from Ordovician volcanics in the Lachlan Fold Belt.

The Nine Mile Volcanics pyroxenes (Fig. 8a) have a high Ca content, typical of alkaline igneous rocks such as the Black Jack Sill (Wilkinson, 1957), Mount Dromedary Complex (Boesen, 1964), and Shonkin Sag Laccolith (Nash & Wilkinson, 1970). The most fractionated pyroxenes in the Nine Mile Volcanics are also enriched in acmite; they contain up to 17% acmite component (end members calculated by the method of Finger, 1972, and Ryburn, Raheim, & Green, 1976). This is also a feature of pyroxenes in the Shonkin Sag Laccolith, and in shoshonites from Papua New Guinea (Smith, 1976). Thus in terms of the end members Ca, Mg, and Fe + Mn, pyroxenes from alkaline and shoshonitic rocks are indistinguishable, though pyroxenes from the Nine Mile Volcanics are much lower in titanium

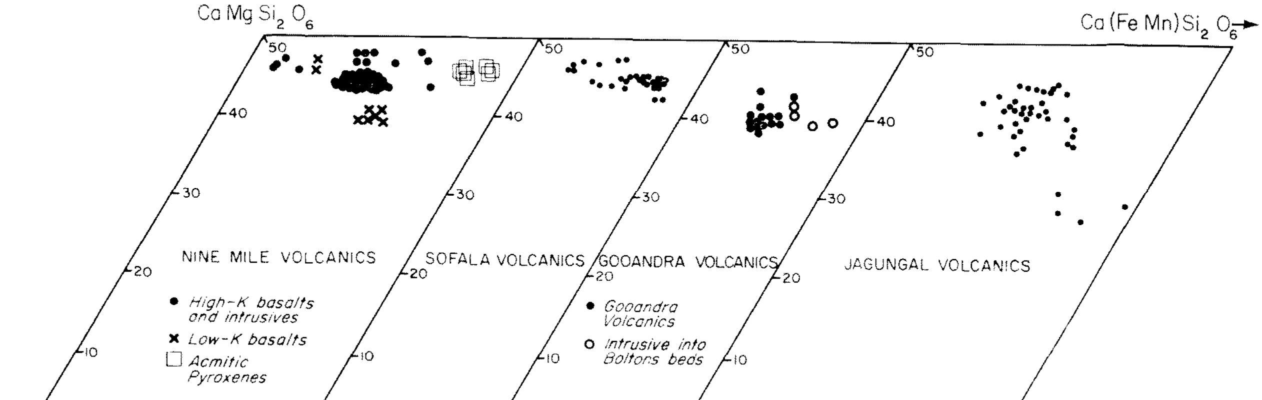


Fig. 8. Electron-probe analyses of Ca, Mg, and Fe + Mn in igneous pyroxenes from Ordovician volcanics of the Lachlan Fold Belt (data in a, c, and d are from L. A. I. Wyborn, 1977; data in b are from Barron, 1976).

(less than 0.5%) than those in alkaline rocks (cf. Wilkinson, 1956). Pyroxenes in two samples from the Nine Mile Volcanics (sample 71840501 from grid ref. 491624, and a basalt dyke from grid ref. 369304 collected by L. A. I. Wyborn, 1977) show depletion of calcium with differentiation; the reason for this is not known, but the rocks that contain these pyroxenes are lower in potassium than those containing the more calcium-enriched pyroxenes, and therefore resemble calcalkaline basalts rather than shoshonites. Analyses from the two low-potash rocks are shown separately in Figure 8a.

The trend for the Sofala Volcanics (Barron, 1976; Fig. 8b) is almost identical to that for the Nine Mile Volcanics, except that no acmitic pyroxenes have been recorded. Barron concluded that—apart from their low titanium content—the Sofala Volcanics pyroxenes are similar to pyroxenes from alkali basalts. We consider that both the Sofala Volcanics and the Nine Mile Volcanics are shoshonitic. Petrographically the Sofala Volcanics are strikingly similar to the Nine Mile Volcanics, and analyses of relatively unaltered Sofala Volcanics (Barron, 1976, table I) are quite similar to Nine Mile Volcanics analyses, except that albitisation of plagioclase has increased sodium and decreased calcium in the Sofala Volcanics. Potassium in the Sofala Volcanics is lower than in the least altered samples of Nine Mile Volcanics but similar to that in the more highly altered samples.

Analyses of relict pyroxenes in dolerite intrusives within the Gooandra Volcanics are plotted in Figure 8c; also plotted are analyses from a dolerite that intrudes the Boltons beds and is believed to be equivalent to the Gooandra Volcanics. The pyroxenes are lower in calcium than those in the Nine Mile and Sofala Volcanics. Although only a limited spread of Mg to Fe is present in the analyses, the low calcium contents resulting from iron substituting for calcium as well as magnesium is typical of tholeiitic pyroxenes such as those in the Skaergaard (Brown, 1957) and Bushveld (Atkins, 1969) intrusions.

Analyses of relict low-iron pyroxenes in the Jagungal volcanics (Fig. 8d) overlap with analyses of pyroxenes in both the Nine Mile and Gooandra Volcanics. However, a marked substitution of iron for calcium in pyroxenes in the more differentiated rocks of the Jagungal volcanics illustrates a much better trend to tholeiitic iron enrichment than the Gooandra Volcanics. Distinction between the Gooandra Volcanics and Jagungal volcanics is simplest on the TiO_2 contents of the rocks: the Gooandra Volcanics have TiO_2 less than 1.25%, but the Jagungal volcanics mostly have greater than 1.75% TiO_2 (L. A. I. Wyborn, 1977).

Discussion

Gooandra Volcanics. The Gooandra and Nine Mile Volcanics are petrographically and geochemically distinct magmatic suites. Despite common alteration to an albite-epidote-actinolite metamorphic assemblage the available evidence indicates that the Gooandra Volcanics are weakly tholeiitic, and that their fractionation has been partly controlled by early-formed plagioclase. Fractionation probably continued until minor rhyolites formed. According to Pearce & Cann (1973) tholeiitic suites with less than 1.25% TiO_2 can be formed in two types of environments: ocean ridges (ocean-floor basalts), and volcanic arcs at convergent plate boundaries (island-arc tholeiites, Jakes & Gill, 1970). Several lines of evidence suggest that the Gooandra Volcanics more closely resemble island-arc tholeiites than ocean-floor basalts:

1. Island-arc tholeiite suites commonly contain more silicic differentiates such as andesite and rhyolite (Gill, 1970; Jakes & White, 1971; Miyashiro, 1974; Blake & Ewart, 1974), as do the Gooandra Volcanics.

2. Plagioclase phenocrysts are characteristic of island-arc tholeiites (Jakes & Gill, 1970; Ewart, Bryan, & Gill, 1973; Blake & Ewart, 1974), but phenocrysts of plagioclase and clinopyroxene are subordinate to those of olivine in ocean-floor basalts (Frey, Bryan, & Thompson, 1974; Bougault & Hekinian, 1974; Bryan, Thompson, Frey, & Dickey, 1976). Mafic phenocrysts are rare in the Gooandra Volcanics.

3. K_2O is extremely low in ocean-floor basalts—Bryan & others (1976) gives the average as 0.15% for 155 analyses—but is higher in island-arc tholeiites. Gooandra Volcanic basalts contain 0.3% or more K_2O, which is probably a low estimate because low-grade metamorphism generally decreases K_2O (Cann, 1969; Beloussov, 1971; Pearce, 1975).

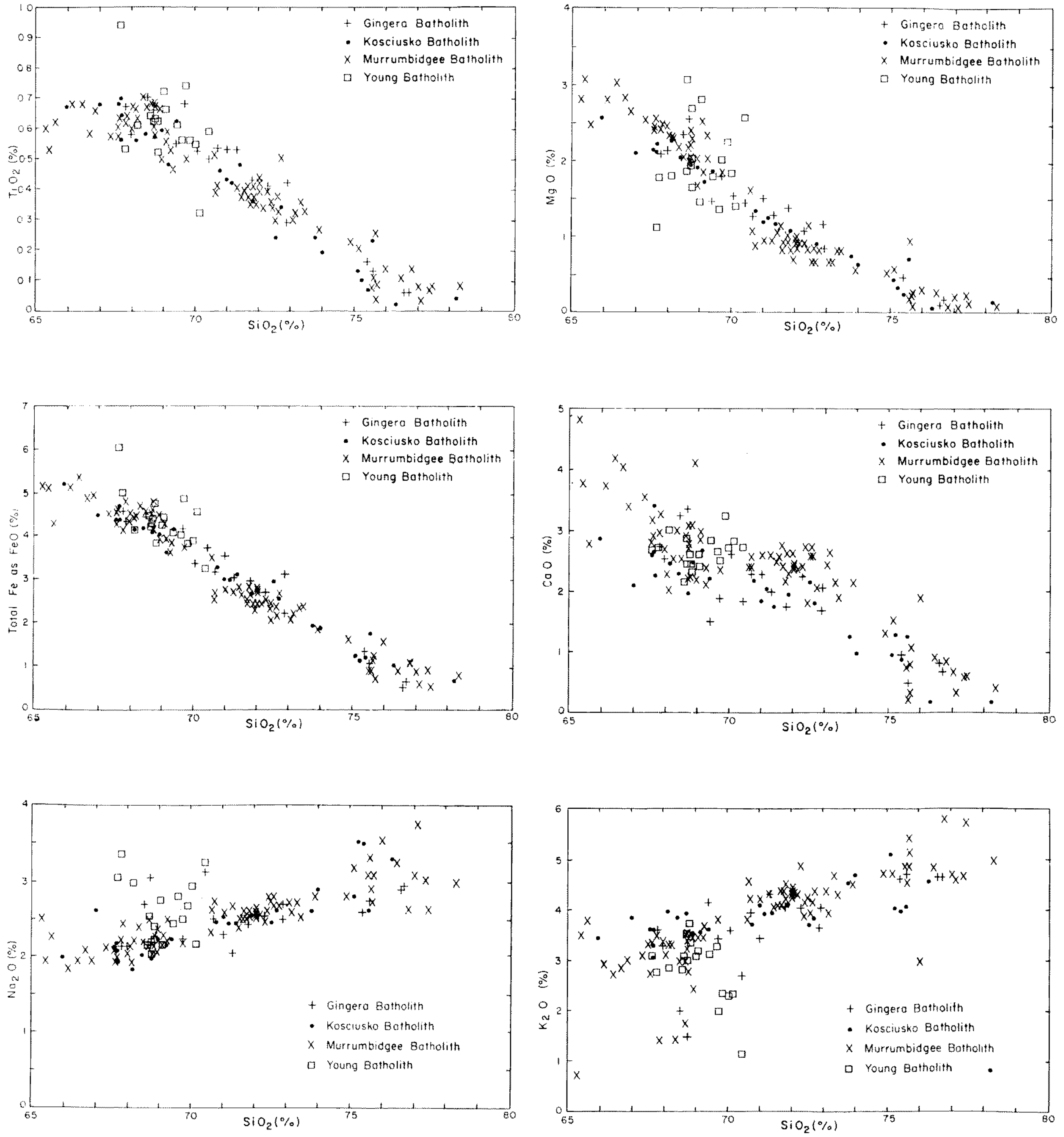
We therefore tentatively assign the Gooandra Volcanics to the island-arc tholeiite suite as a result of the comparison of their petrographic and geochemical character with known modern volcanics, but stress that submarine alteration and low-grade metamorphism may well have changed the chemistry of the Gooandra Volcanics to such a degree that this is an erroneous interpretation. There also remains the possibility that modern analogues to island-arc tholeiites may yet be found in other tectonic environments.

Nine Mile Volcanics. The Nine Mile Volcanics are a suite of basalts characterised by abundant phenocrysts of calcium-rich clinopyroxene, altered olivine, and plagioclase, and by enrichment in incompatible elements such as K, Rb, Sr, and P. The least altered basalts from Peppercorn Creek contain up to 5% K_2O, but the more altered rocks from Tumut River (L. A. I. Wyborn, 1977) contain lower and more variable K_2O. These more altered rocks still retain their high Sr and P, and a trend of Al_2O_3 increasing with differentiation is well defined irrespective of alteration. This trend is present in other high-potassium suites such as the Shonkin Sag Laccolith (Nash & Wilkinson, 1970), and we suspect that the high potassium content of the magma suppresses the formation of plagioclase until the solidus is almost reached, thus increasing Al_2O_3 in the liquid. The low titanium and zirconium contents of the Nine Mile Volcanics distinguish them from the alkali basalt suite, but they are similar to shoshonites derived at consuming plate margins (Gill, 1970; Mackenzie & Chappell, 1972; Jaques, 1976; Mackenzie, 1976). Despite the plea of Nicholls & Carmichael (1969), we feel that we must use the term shoshonite (Joplin, 1965) to describe the Nine Mile Volcanics, because we know of no other appropriate term to describe high-potassium basalts with low titanium and zirconium. We therefore use the term in a strict chemical sense. Perhaps the term trachybasalt (Johnson & others, 1978a) is an appropriate petrographic term.

The pyroxene chemistry and major-element geochemistry of the Sofala Volcanics (Barron, 1976) and the Nine Mile Volcanics are similar, so we consider that the Sofala Volcanics are shoshonites too. Chemical data on the rest of the Molong Volcanic Arc are sparse. Smith & Smith (1976) described in detail the geochemistry of the Walla Andesite (a unit in the Molong Volcanic Arc) at Cliefden (65 km west-southwest of

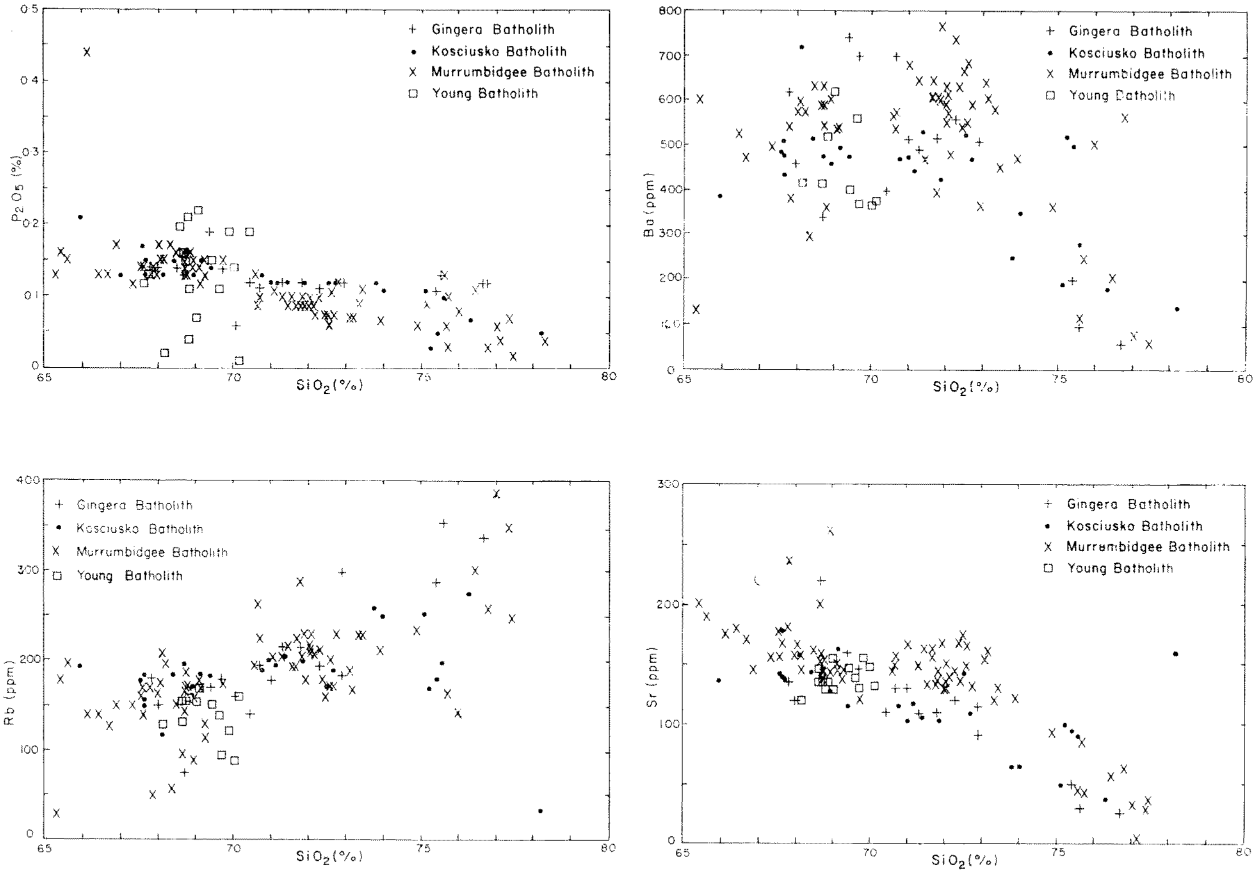
Bathurst), first studied by Smith (1968). Their analyses show that, like the Nine Mile Volcanics, the Walli Andesite is low in titanium and zirconium, but high in strontium and phosphorus. K_2O is variable, but is highest in the least altered domain of their 'albite basalt', in which it is as high as 3.98% in sample 35035 and 3% in sample 35002. Obviously much of the feldspar identified as albite in the Walli Andesite is potash feldspar, and, like the Nine Mile Volcanics, the least altered rocks are the richest in K_2O. The Walli Andesite at Cliefden, therefore, also appears to be shoshonitic. Cooke (1975) analysed several basaltic lavas from the Ordovician Kenyu Formation northeast of Boorowa (100 km north-northwest of Canberra). These lavas are enriched in incompatible elements and are almost identical in mineralogy and chemistry to the Nine Mile Volcanics. The Kenyu Formation is the southernmost part of the Ordovician volcanics in the northern outcrop of the Molong Volcanic Arc. From here southwards the Molong Volcanic Arc is covered by younger rocks until it emerges from beneath the Peppercorn Formation as the Nine Mile Volcanics. There is no direct evidence of continuity between the Kenyu Formation and Nine Mile Volcanics, but the Nine Mile Volcanics have a similar chemistry to the Walli Andesite, Kenyu Formation, and Sofala Volcanics, suggesting that they have close links with these central New South Wales volcanics. Although there may be many volcanic centres (two of which are known—at Tumut Ponds Dam and Peppercorn Creek), there is no evidence against a semicontinuous belt of subcropping volcanics between Peppercorn Creek and Boorowa.

Shoshonites have been correlated with the deepest parts of subduction zones in island arcs showing an advanced stage of evolution (Jakes & White, 1969,



1972; Gill, 1970; Ninkovich & Hayes, 1972; Keller, 1974). Smith (1972) related the shoshonitic rocks of southeastern Papua New Guinea to instability in the mantle as a result of block-faulting and uplift. Mackenzie & Chappell (1972) postulated partial fusion of eclogite detached from the base of downbuckled parts of the crust to explain the origin of shoshonites in the highlands of Papua New Guinea, and found no direct evidence to relate the volcanics to a subduction zone. Mackenzie (1976), modifying the model of Mackenzie & Chappell (1972), related the volcanism to diapirs derived from a large-ion lithophile-enriched low-velocity zone and triggered by buckling and uplift. Jaques (1976) found no evidence of the three-stage development of an island arc (viz. island-arc tholeiites followed by calcalkaline volcanics followed by shoshonites) in the Finisterre Volcanics of the Early to mid-Tertiary arc of northern Papua New Guinea, where shoshonitic rocks directly overlie pelagic and hemipelagic sediments, and no rocks of continental derivation occur within the sequence. Recently, Johnson, Mackenzie, & Smith (1978b) have suggested that the 'shoshonites' of the Papua New Guinea highlands and eastern Papua New Guinea were not related to contemporaneous subduction, but originated in a part of the mantle that had been modified by the introduction of water and incompatible elements from a previously existing subduction zone; they were later activated (according to this hypothesis) when the onset of a new tectonic regime (upwarping) favoured anatexis of the modified mantle.

The controversy surrounding the generation and apparently diverse tectonic setting of Cainozoic shoshonites precludes any speculation of a plate-tectonic setting for the Ordovician Nine Mile Volcanics, and indeed the whole of the Molong Volcanic Arc. If the arguments



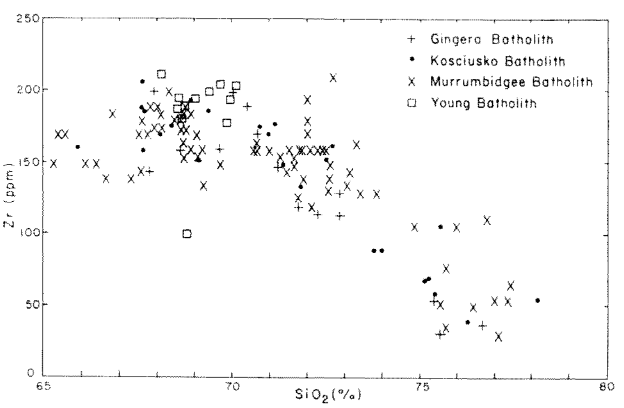


Fig. 9. Selected major oxides and trace elements *v* SiO_2 for the S-type granitoids (sources of data explained in text).

of Johnson & others (1978b) can also be applied to magmas not so enriched in large-ion lithophile elements, such as the Gooandra Volcanics, then all we can say is that the mantle was modified in some way beneath the Molong Volcanic Arc. This modification may have been caused by subduction or may be related to the incorporation of material from the low-velocity zone into the melts (Mackenzie, 1976). If the modification was related to subduction, this subduction was not necessarily coeval with volcanism. Johnson & others (1978b) have used strontium isotope initial ratios of Papua New Guinea volcanics to date the time interval between subduction and extrusion. Strontium isotope work on the Nine Mile Volcanics (see p. 37) indicates an initial ratio of about 0.7046 for one sample, if an Ordovician age is assumed. This value is high enough to account for a considerable time span between modification of the mantle and volcanism (in the order of 100 to 200 m.y.), but does not negate the possibility of subduction and volcanism being coeval.

Siluro-Devonian S-type granitoids and volcanics

We have extended the classification of granitoids by Chappell & White (1974) into I-type and S-type, according to their source (igneous, I, or sedimentary, S), from the type area in BERRIDALE (White & others, 1976) to cover the granitoids in TANTANGARA and BRINDABELLA. We have also extended the classification to cover the felsic volcanics in the two Sheet areas, as cordierite and almandine-rich garnets (two minerals typical of high-grade metasedimentary rocks) are common and in some places abundant phenocrysts in the Goobarragandra, Kellys Plain, Paddys River, and Walker Volcanics, which are therefore classified as S-type. Similarly, the Ainslie, Mount Painter, Gladefield, and Hawkins Volcanics in CANBERRA are also S-type.

Chappell (1966) and White & Chappell (1977) have shown convincingly that many granitoid magmas are composed of a two-component mix of melt plus residual crystals. Many melts are close to a minimum melt composition (Tuttle & Bowen, 1958), and the addition to them of crystalline phases such as biotite, calcic plagioclase, hornblende, cordierite, and garnet produces a crystal mush. Chappell (1966) has shown that these crystalline phases are derived from the region of granitoid genesis—not from the accidental incorporation of xenocrysts and xenoliths into the melt at some higher level in the crust. Thus, for any group of granitoids which have been derived from the same source material, there should be a spread in chemical composition along a two-component mixing line, with the melt composition at the high silica end, and the average composition of the source material at some point along the trend towards the low silica end.

Our analyses of the Gingera, Kosciusko, and Young Batholiths are presented in Tables A3 and A4 (Appendix 2). In addition to our analyses, we have included in our variation diagrams (Fig. 9) analyses from the Murrumbidgee Batholith (Joyce, 1970), Kosciusko Batholith (Hine & others, 1978), and Young Batholith (Stevens, 1952; Veeraburus, 1963; Ashley, 1973; Clark, 1974; and Franklin, 1975). Relatively linear trends for the Gingera, Kosciusko, Murrumbidgee, and Young Batholiths on the Harker variation diagrams support the model of two-component mixing, and also show that these four batholiths were derived from source materials that were similar in composition. Good mixing-lines are evident for TiO_2, MgO, total Fe, and P_2O_5; CaO, Na_2O, K_2O, Rb, and Sr are more scattered, but a mixing-line trend is still evident. Ba and Zr do not show linear trends, so some additional factor must be influencing their distribution. Two other features of the trends do not apply to all the batholiths:

1. Analyses from the Young Batholith have a wide scatter on most diagrams. This may be partly due to the inclusion in the variation diagrams of a number of old, possibly less accurate analyses from the literature, but it is also partly related to intense deformation which resulted in a decrease in K_2O (Fig. 10) and a slight increase in Na_2O (Ashley & Chenhall, 1976).
2. The samples from the Shannons Flat Adamellite (Murrumbidgee Batholith, silica range 70-74%) tend to be a little higher in calcium and strontium than the general trends, possibly indicating more calcic plagioclase in the source for the Shannons Flat Adamellite.

Barium produces a wide scatter of points, but appears to increase up to about 73% SiO_2. A trend of increasing barium with increasing silica content would fit a two-component mixing model if almost all the potash feldspar in the source had melted, otherwise barium would be partitioned into the residual source material through capture by potassium in residual feldspar. The marked decrease in barium in most leucogranites (SiO_2 greater than 74%) indicates that a pure two-component mixing model cannot account for these rocks. Therefore the leucogranites must have been physically separated from an adamellite which had already started crystallising potash feldspar. This might have been achieved by filter pressing (Carmichael, Turner, & Verhoogen, 1974, p. 63), which the presence of xenocrysts of biotite, quartz, and plagioclase in the leucogranites supports.

Zirconium increases slightly between 65 and 70% SiO_2, and then decreases towards a minimum melt composition at high silica values. We have no satisfactory explanation for this trend, but it may be only an apparent trend caused by low-silica rocks from the Murrumbucka Tonalite (MICHELAGO) of the Murrumbidgee Batholith (Joyce, 1970) having a quite different source—rich in hornblende and poorer in zirconium. For minimum melt two-component mixing from a sedimentary source, zirconium should produce a straight line trend decreasing with increasing silica, because zircon is mostly present as inclusions in residual biotite.

The Kellys Plain, Goobarragandra, Walker, and Paddys River Volcanics (Tables A5 to A8, Appendix 2)

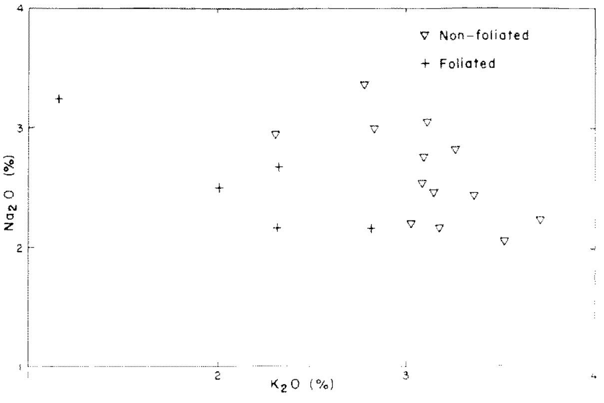


Fig. 10. Na_2O v K_2O for foliated and non-foliated granodiorites in the Young Batholith (from data in this Bulletin; Franklin, 1975; and Ashley & Chenhall, 1976).

have the same silica range as the granitoids, but their data are much more scattered on Harker variation diagrams (Fig. 11), so that the trends are not well defined. This is to be expected for ignimbrites which have undergone a great deal of alteration, the most intense being the widepsread albitisation of plagioclase (Fig. 12, which also includes data from our unpublished analyses of samples of S-type volcanics from CANBERRA).

Despite the scatter in Figure 11 the volcanics and S-type batholiths share similar trends. The lower Ca and higher Na in the volcanics are due to albitisation of calcic plagioclase, but calcium shows greater depletion than sodium shows enrichment, perhaps because the feldspars are sericitised as well as albitised. The higher barium values in the volcanics can be directly related to high potassium values in the Walker and, to a lesser extent, Paddys River Volcanics; the Walker Volcanics appear to have been altered by potash metasomatism rather than albitisation, as their calcium and sodium are lower and their potassium and barium are higher than the granitoid trends. Allowing for such alteration in the volcanic rocks, we feel that there is overwhelming chemical and mineralogical evidence for the S-type granitoids and S-type volcanics being comagmatic; this is further supported by their initial strontium isotope ratios (see p. 37).

Discussion

The linear trends for most elements support Chappell's (1966) two-component mixing model of granitoid genesis. This model allows the average source composition to be calculated, provided that the silica content of the source is assumed. By assuming realistic figures for the percentage of partial melting (at least 25%) into granitoid magma, we can estimate the silica content of the sedimentary source. The most mafic S-type plutons, such as the Clear Range Granodiorite, contain mostly residual crystals and little minimum melt material (perhaps only 20%), and these rocks have 66-69% SiO_2. The most mafic S-type analysis known is from the Corryong Batholith (KOSCIUSKO, L. A. I. Wyborn, 1977); this has 63% SiO_2 and is probably even more mafic than its source material. A reasonable average silica value for the source material would be not less than 65%. By using this estimate the concentration of other elements can be read directly from the Harker diagrams, and an average source composition can be calculated. L. A. I. Wyborn (1977) has shown that the calculated average source composition is close to the composition of the Ordovician sediments at the same silica level, except that its sodium and calcium contents are much too high. For this reason she has postulated a source which has undergone less sedimentary fractionation and therefore contains more feldspar. Such a source is thought to lie in an Upper Proterozoic to Lower Cambrian sedimentary layer underlying the Ordovician turbidites, or perhaps a Precambrian crystalline basement (White, Williams, & Chappell, 1976).

The origins of granitoid magmas in the Lachlan Fold Belt and their relation to orogenic events have been extensively debated (Browne, 1929, 1931; Vallance, 1954, 1969; Joplin, 1962; Kolbe & Taylor, 1966; Joyce, 1973; White, Chappell, & Cleary, 1974; Chappell & White, 1974); Browne (1931), Joplin (1962), and Brooks & Leggo (1972), for example, have stressed that plutonism is a cyclic process. The stratigraphic control on the age of emplacement is poor for the S-type granitoids (Vallance, 1969, p. 198), and many workers have variously referred to the S-type granitoids as being Benambran, Quidongan, Bowning, and Tabberabberan in age—e.g., Evernden & Richards (1962); Brooks & Leggo (1972); Crook & others (1973); Scheibner (1973, 1976); Talent & others (1975); Vandenberg (1976). Several lines of evidence suggest to us a rather different alternative:

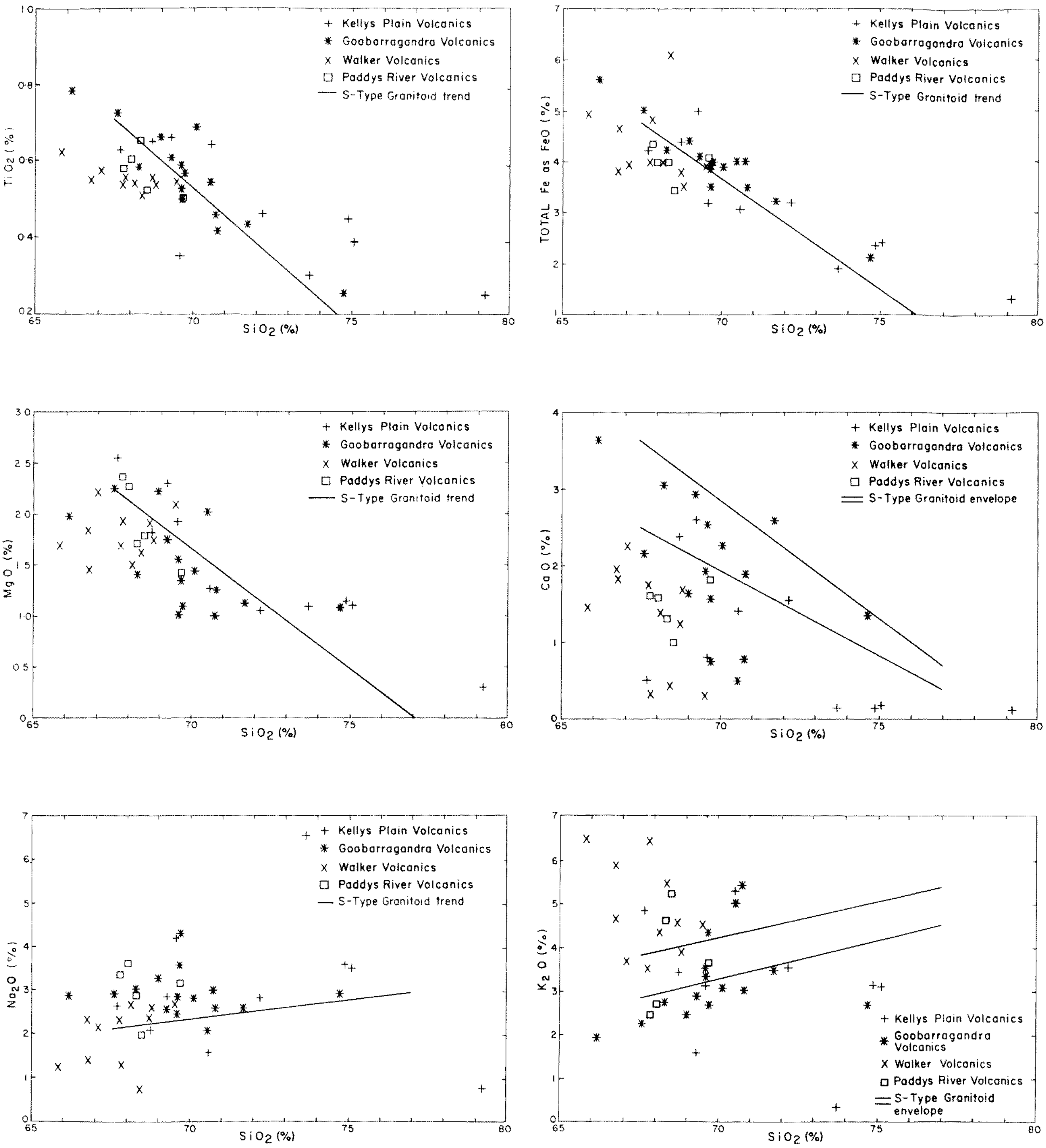
1. Recent work on the metamorphism of the Wagga Metamorphic Belt, west of the mapped area, by Hellman (1976) and L. A. I. Wyborn (1977) has shown that the metamorphism can be explained as a single prograde metamorphic event which outlasted the first period of deformation there (?first Benambran fold episode) but had subsided before the onset of a later and more intense deformation that we interpret as the Bowning fold episode. Further, L. A. I. Wyborn (1977) has shown that the metamorphism affected not only the area west of the Molong Volcanic Arc, but the arc itself and the area east of the arc near Thredbo (JACOBS RIVER). Thus the metamorphism cannot be related to an area of high heat flow in a marginal sea (Wagga Trough), as suggested by Packham & Falvey (1971).

2. There is good evidence for a metamorphic discontinuity beneath the upper Llandoverian to ?lower Ludlovian Peppercorn Formation, and the metamorphosed rocks can be traced southwards into the Wagga Metamorphic Belt. A metamorphic discontinuity probably also exists beneath the Silurian Towanga Formation in the upper Indi River area, in JACOBS RIVER (L. A. I. Wyborn, 1977).

3. A detailed study of S-type granitoids in the Berridale Batholith by Williams (1977), using various methods of isotopic dating, has shown that the more conventional methods of dating (Rb/Sr and K/Ar) yield concordant cooling ages of around 410 to 420 m.y. (according to the decay constants recommended at the IUGS meeting in Sydney in 1976), yet U-Pb dating of monazites from the same samples consistently give ages 10 to 20 m.y. older. Williams (1977) concluded that the older ages give the oldest limit to the age of magma formation; this implies that some granitoids may have taken up to 20 m.y. to form, intrude, and then cool to their strontium and argon retention temperatures.

4. Our correlation of the Bowning fold episode with the intense deformation of the Gingera Batholith and less intense deformation of the Murrumbidgee and Young Batholiths, and a similar correlation of deformation in the Kosciusko Batholith by L. A. I. Wyborn (1977), indicate that these granitoids are actually older than, and not associated with, the Bowning fold episode.

5. Chemical, mineralogical, and isotopic characteristics of the S-type volcanics of Wenlockian to Ludlovian age show that the volcanics represent the extrusive equivalents of the batholiths, so the batholiths must have existed in a magmatic state at depth during these times. A late remelting of the same source material to form the batholiths cannot be sustained, since the widespread occurrence of orthopyroxene in the volcanics indicates that the magmas which produced them were in equilibrium with a relatively anhydrous residue—that is, the anatexis to form the S-type volcanics left a granulite residue. Remelting of this residue would require a high temperature, and would produce a magma chemically different from the S-type batholiths.



All the above evidence indicates that a single but possibly prolonged period of high heat flow that culminated in the Early Silurian was responsible for the generation of S-type magmas. The source was a possible Upper Proterozoic to Cambrian sedimentary layer containing more detrital plagioclase than the Ordovician quartz-rich flysch. The structural environment in the Late Ordovician-early Wenlockian was one of compression, resulting in three deformations which developed progressively eastwards with time (p. 17). Widespread metamorphism and anatexis cannot be related to these localised events, but the compressional regime would not favour the rising of accumulating magma pools, and it was not until the Late Silurian that a favourable structural environment allowed the magmas to rise. At this time a tensional regime resulted in the formation of a series of troughs and highs bounded by block faults in the Lachlan Fold Belt, and tholeiitic magmas were tapped from the upper mantle along major fault lines (D. Wyborn, 1977). S-type felsic volcanics, still retaining anhydrous mafic crystals that were in equilibrium with the melt near its source, were the first magmas to rise, and were soon followed by the granitoids. Those granitoids which rose most quickly retained much of their crystal component, and resulted in the most mafic intrusive bodies, such as the Clear Range, Bendora, McLaughlins Flat, and Callemondah Granodiorites, and the Willoona Tonalite. Later granitoids were progressively more leucocratic. Because the granitoids rose and cooled more slowly than the volcanics, the anhydrous residual mafic crystals in the melt (mostly cordierite, garnet, and orthopyroxene) reacted with the melt plus water liberated from the melt at lower pressures (Tuttle & Bowen,

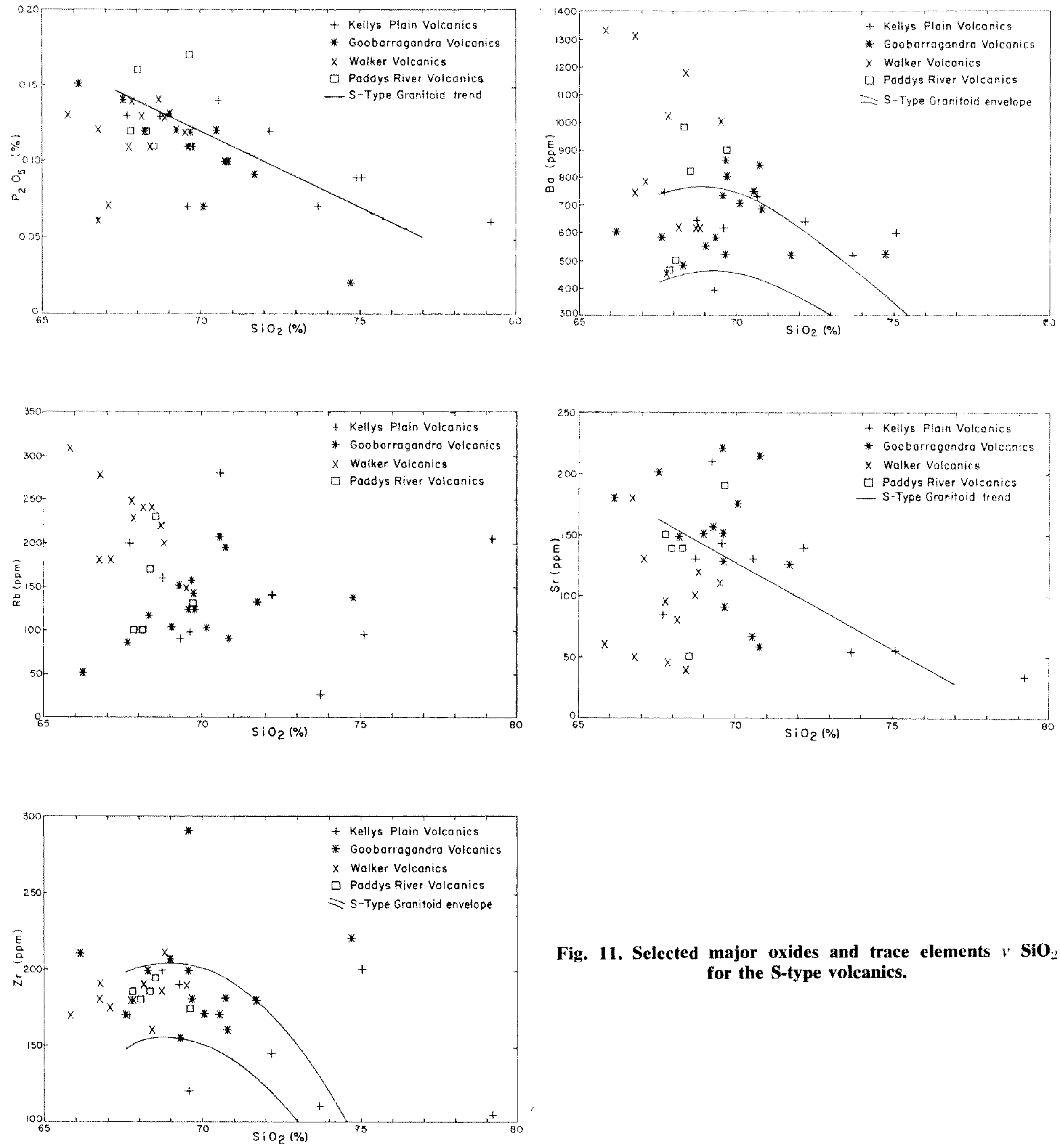


Fig. 11. Selected major oxides and trace elements *v* SiO_2 for the S-type volcanics.

1958) to form biotite. Xenocrysts of cordierite and garnet do occur in some of the mafic granitoids, but orthopyroxene has not yet been found. The Kellys Plain Volcanics, of Early Devonian age, do not fit well into this model as they postdate the Bowning fold episode. Their chemistry, and the presence in them of cordierite, garnet, orthopyroxene, and sillimanite, indicate that they came from the same source as the S-type granitoids, but as they were later they might have been derived from a younger melting event—an event for which we have no evidence. More likely they were still in the magmatic state at the onset of the Bowning fold episode, and this period of compression delayed their extrusion until the Early Devonian.

Comparing this model with a Cainozoic plate tectonic analogue is rather difficult. There is no evidence of subduction-derived melts, but, rather, a bimodal suite

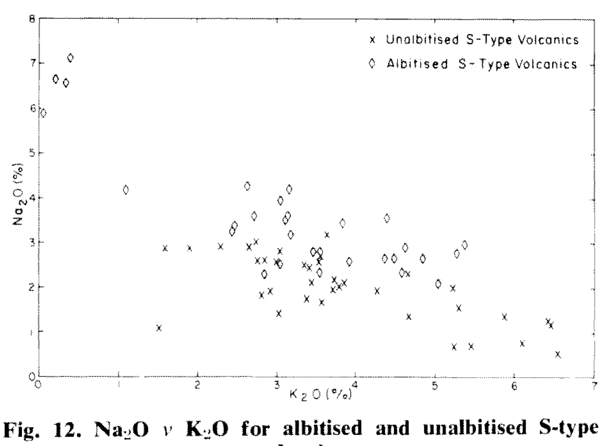
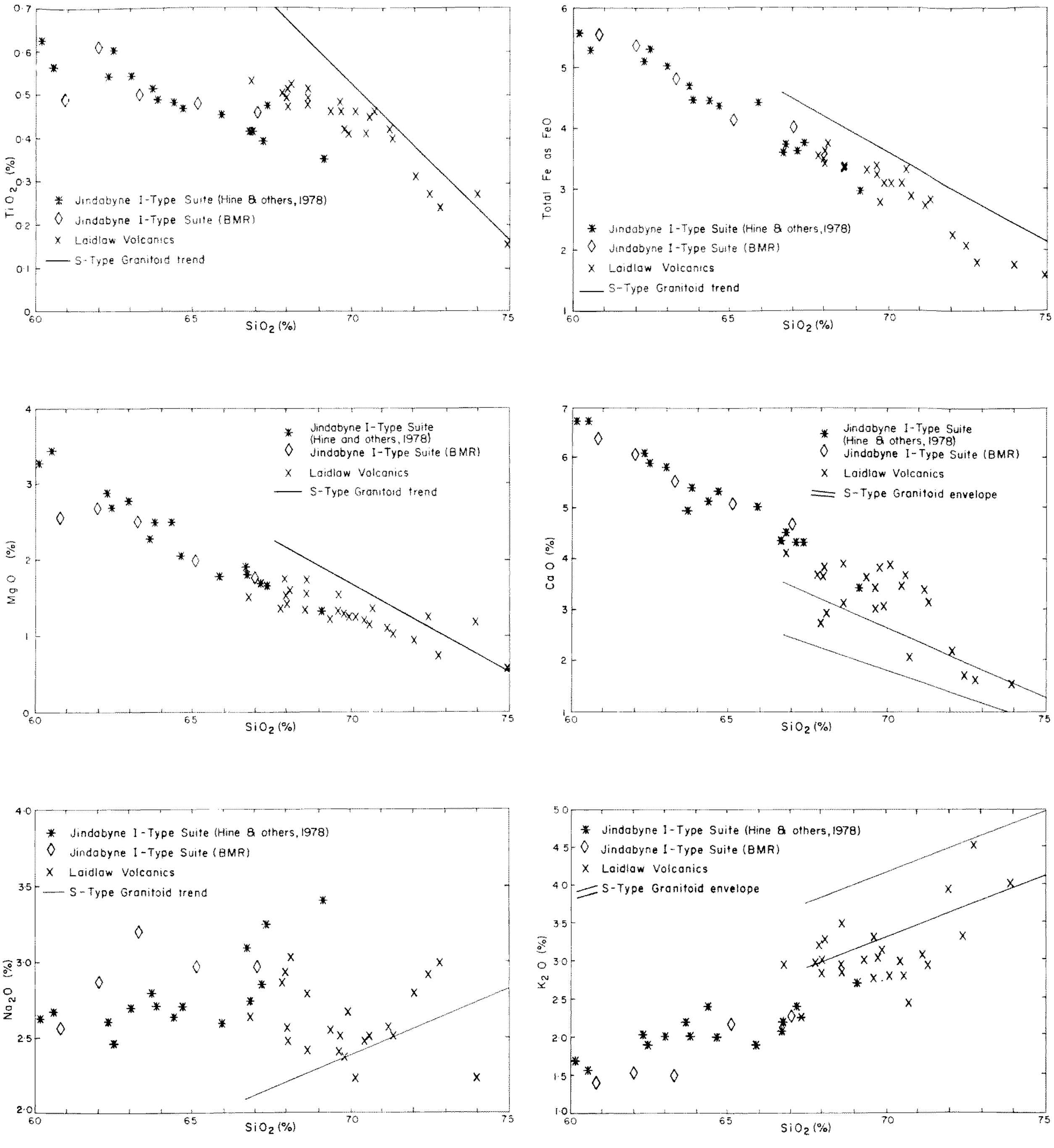


Fig. 12. Na_2O *v* K_2O for albitised and unalbitised S-type volcanics.

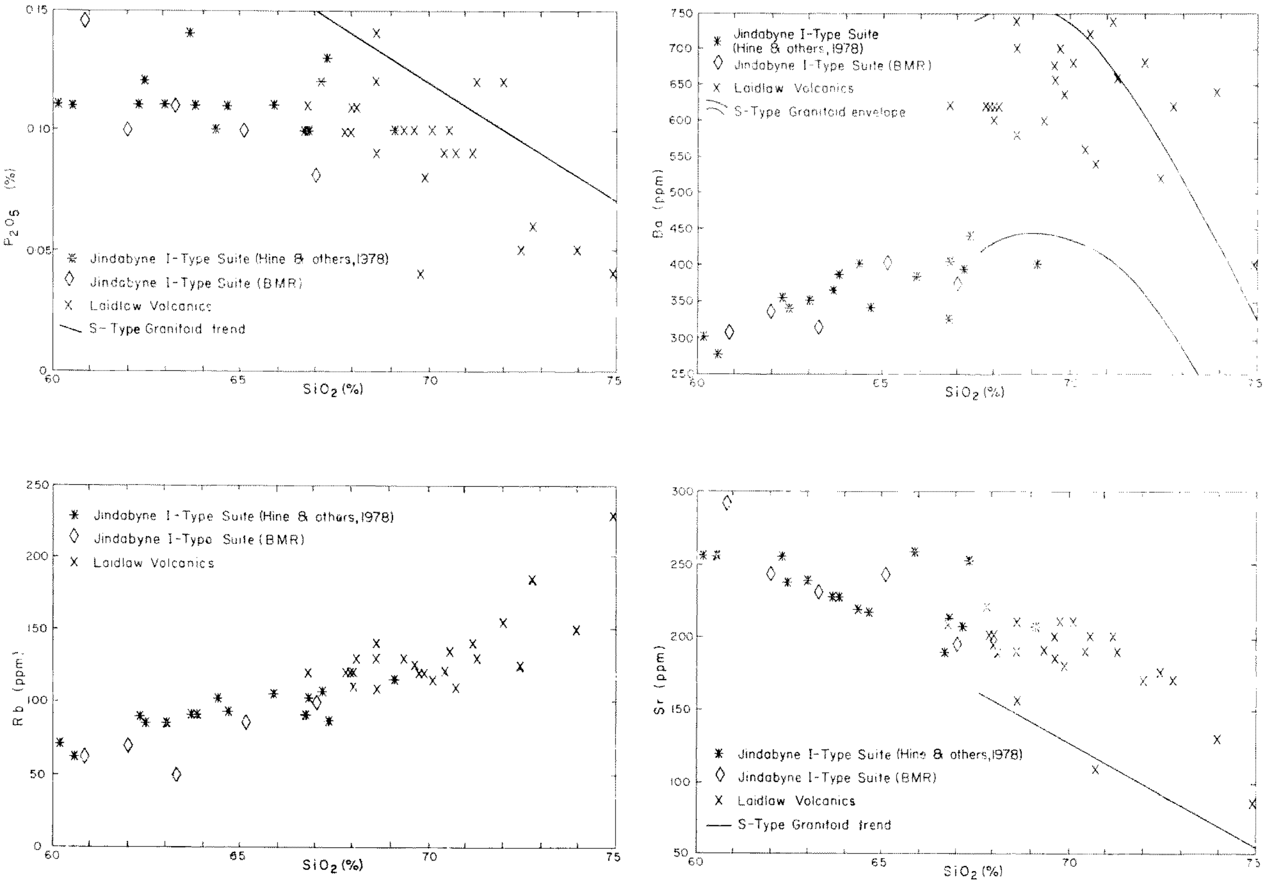


of crustal melts and mantle-derived gabbroic rocks intruded in the Late Silurian. The Basin and Range Province in the Western USA (Atwater, 1970; Proffett, 1977) during the early to middle Cainozoic is probably the closest analogue. The differences in scale and height above or below sea level between the basins and ranges in the USA and the troughs and highs in the Lachlan Fold Belt may have been due to a different basement type underlying the two regions; a thinned crystalline basement underlies the Basin and Range Province, but good evidence of a pre-Ordovician crystalline basement in the Lachlan Fold Belt is still lacking, as the source material of the S-type granitoids is more likely to be a layer of sediments—not crystalline rocks.

SILURIAN I-TYPE GRANITOIDS AND VOLCANICS

We have mapped six I-type granitoid plutons of Silurian age in TANTANGARA and BRINDABELLA. Three of them are petrographically similar and intrude the Goobarragandra Volcanics. They are here termed the Coodravale Suite after the best exposed and most accessible pluton, the Coodravale Granodiorite. The other plutons in the suite are the Kennedy Range and Staravation Point Adamellites. Two analyses, one of the Coodravale Granodiorite (73840347) and one of the Starvation Point Adamellite (71840318), are given in Table A9 (Appendix 2). These plutons are high in silica for I-type granitoids, and are lower in MgO, K_2O, P_2O_5, and Rb, and higher in Na_2O, Fe_2O_3/FeO (Fig. 14), and Zr than S-type granitoids.

The other three I-type plutons—the Bugtown Tonalite, Condor Granodiorite, and tonalite at Ashvale—are similar to I-type granitoids in BERRIDALE which Hine & others (1978) have referred to as the Jindabyne Suite. Analyses of these plutons (Table A9) and Harker diagrams (Fig. 13) confirm their correlation with the



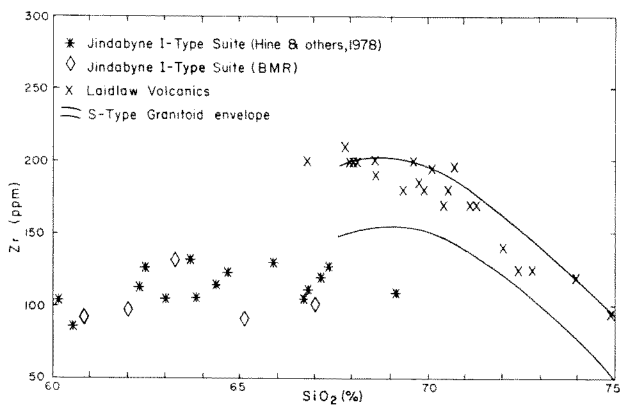


Fig. 13. Selected major oxides and trace elements *v* SiO_2 for I-type granitoids of the Jindabyne Suite, and the Laidlaw Volcanics.

Jindabyne Suite of I-type granitoids, although sodium is a little high, perhaps because of interlaboratory bias. The Jindabyne Suite has lower SiO_2, TiO_2, total Fe, MgO, K_2O, P_2O_5, Ba, Rb, and Zr, and higher CaO and Na_2O than the S-type granitoids; is more oxidised than the S-type granitoids (Fig. 14); and follows a calcalkali trend on an AFM diagram (Fig. 15).

Phenocrysts suggest that the Laidlaw and Uriarra Volcanics are most likely I-type. The Laidlaw Volcanics are commonly quite fresh, and contain phenocrysts of biotite, calcic plagioclase, sanidine, orthopyroxene, and allanite; the Uriarra Volcanics also contain allanite (cf. the Jindabyne Suite, see under *Bugtown Tonalite*, on microfiche; and Hine & others, 1978) and sanidine phenocrysts. Cordierite and garnet, common in the S-type volcanics, are absent from both volcanic units. The Laidlaw Volcanics (Table A10, Appendix 2) are mostly unalbitised, whereas the Uriarra Volcanics (Table A11) are everywhere albitised. The Laidlaw Volcanics are higher in CaO and Sr and lower in Na_2O than the Uriarra Volcanics, but otherwise they share a similar chemistry; differences are due to albitisation of the Uriarra Volcanics. Both units follow a calcalkali trend on an AFM diagram (Fig. 16).

The Ginninderra Porphyry, a high-level stock within the Laidlaw Volcanics, is believed to be the intrusive equivalent of the Laidlaw Volcanics, as it contains orthopyroxene and allanite phenocrysts, but, like the Uriarra Volcanics, has been albitised. Three Ginninderra Porphyry analyses (Table A11, Appendix 2) are

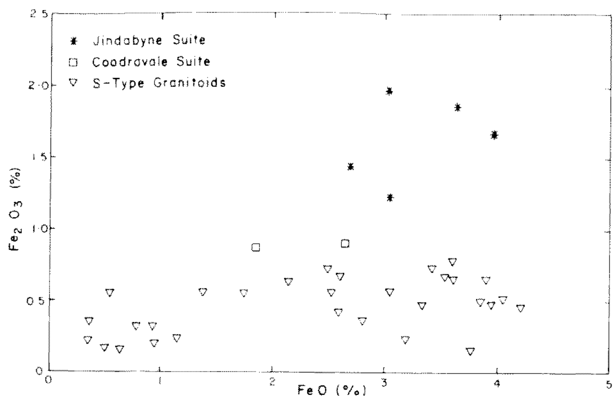


Fig. 14. Fe_2O_3 *v* FeO for the Jindabyne Suite, Coodravale Suite, and S-type granitoids.

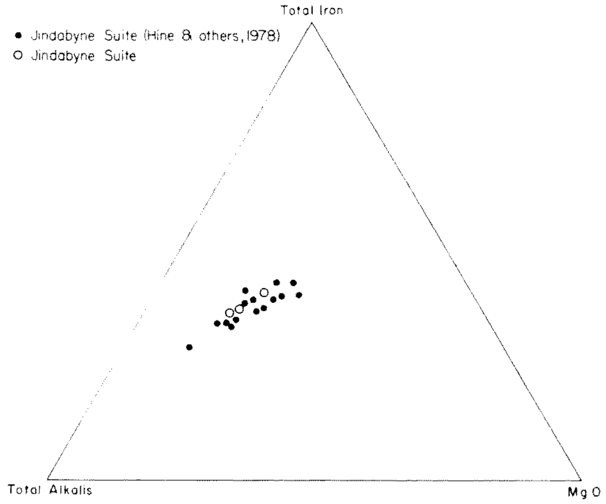


Fig. 15. AFM diagram of the Jindabyne Suite (from data in this Bulletin; and Hine & others, 1978).

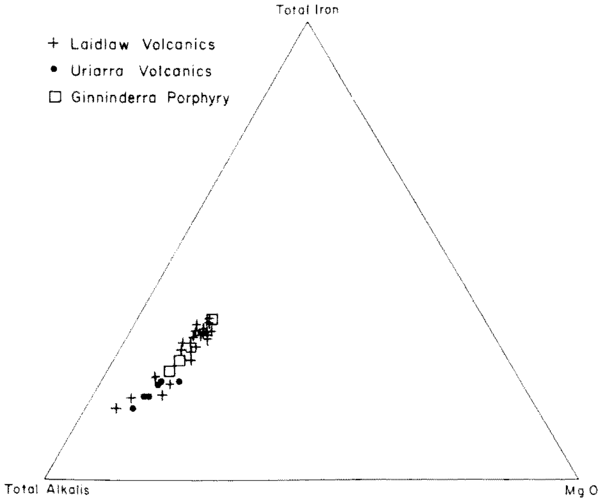


Fig. 16. AFM diagram of the Laidlaw Suite.

almost identical to the Uriarra Volcanics analyses and to two analyses of albitised Laidlaw Volcanics, samples 73840470 and 75840005.

Harker diagrams showing the Laidlaw Volcanics and Jindabyne Suite data (Fig. 13) indicate that:

1. The volcanics are richer in silica than most Jindabyne Suite analyses.

2. Given the silica difference, the Laidlaw Volcanics are similar to the Jindabyne Suite in total Fe, MgO, CaO, Na_2O, P_2O_5, Rb, and Sr.

3. The Laidlaw Volcanics are richer in Ba and Zr, and possibly TiO_2 and K_2O, than the Jindabyne Suite.

4. Compared with the S-type trends, the Laidlaw Volcanics are poorer in TiO_2, total Fe, MgO, P_2O_5, Rb, and possibly K_2O, richer in CaO, Na_2O, and Sr, and similar in Ba and Zr.

5. The chemistry of the Laidlaw Volcanics varies along more linear trends than the more altered S-type volcanics (Fig. 11).

Discussion

Coodravale Suite. The Coodravale Suite of I-type granitoids is confined to the area west of the Long Plain Fault and is part of the Young Batholith. Although analytical data are lacking, the suite does appear to be higher in zirconium than S-type granitoids with the same high silica content. In the S-type granitoids, zirconium is partitioned into the non-melt fraction, indicating that the melt temperature was low (near minimum melt). The high zirconium content in the Coodravale Suite perhaps indicates that the melt was at a high enough temperature to incorporate zirconium, and well above the minimum melt temperature (about 680°C at 2kb—Luth, 1976). As there appears to be little difference in age between the Coodravale Suite and the S-type granitoids in the Young Batholith, we presume that the same melting event in the Early Silurian generated both types.

Jindabyne Suite. Hine & others (1978) have already discussed the chemistry of the Jindabyne Suite I-type granitoids, and suggested a basaltic to andesitic source. As we have shown that one member, the Bugtown Tonalite, is older than the Bowning fold episode and therefore of a similar age to the S-type granitoids, we presume that the same melting event in the Early Silurian generated both types. The Jindabyne Suite granitoids are everywhere younger than adjacent S-type granitoids in BERRIDALE (White & others, 1976a), and in the Murrumbidgee Batholith, where the tonalite of Ashvale intrudes the Westerly and Yaouk Leucogranites. This suggests a deeper source and, hence, a longer time of ascent for the I-type granitoids.

Laidlaw Suite. The relation between the Laidlaw Volcanics and equivalent granitoid rocks is difficult to assess at present. The high Ca, Sr, and Na, and low Mg, Fe, P_2O_5, and Rb, correlate well with the Jindabyne Suite, and this correlation is supported by the presence of allanite in both units. However, hornblende is not present in the Laidlaw Volcanics, but is abundant in the Jindabyne Suite, and Ba and Zr are much higher in the Laidlaw Volcanics. We consider that these differences are sufficient to assign the Laidlaw Volcanics to a separate suite, here named the Laidlaw Suite, in which we also include the Ginninderra Porphyry—the only mapped plutonic equivalent of the suite—and the Uriarra Volcanics.

In some respects the Laidlaw Suite is intermediate in chemistry between I and S-types in the Lachlan Fold Belt. Molecular $Al_2O_3/Na_2O + K_2O + CaO$ is less than 1.1, a feature typical of I-types (Chappell & White, 1974), but the difference between Laidlaw analyses and the S-type trends is not great for any element. The high CaO, Na_2O, and Sr in the Laidlaw Volcanics indicates a more feldspathic source than for that of the S-types; such a source might have been feldspar-rich sediments rather than igneous rock. The initial strontium isotope ratio of the Laidlaw Volcanics (0.708, see p. 37) is intermediate between I and S-types in the Lachlan Fold Belt (Chappell & White, 1976).

LOWER DEVONIAN I-TYPE GRANITOIDS AND VOLCANICS

Owen & Wyborn (1976) gave the name 'high-K I-type suite' to a belt of Lower Devonian plutons that crop out only to the west of the Tantangara Fault in TANTANGARA, and suggested that similar plutons both to the north and south belong to this suite. We here present more complete data on the suite. As Hine & others (1978) pointed out, the naming of a granitoid suite by its high-potassium content might cause confusion in the future, especially as I-type suites appear to be geographically controlled, so we here apply a more appropriate name to it, the Boggy Plain Suite, chosen because the Boggy Plain Adamellite is the most representative pluton of the suite.

Like the Jindabyne Suite and S-type granitoids, the Boggy Plain Suite has a calcalkali trend (Fig. 17), which, however, extends to much lower alkali contents as chemical analyses (Tables A12 to 15, Appendix 2) show that the suite has a much greater silica range—from 48% (sample 73840169, Table A14) to almost 77% (sample 71840465, Table A15). Harker diagrams (Fig. 18) illustrate the chemical variations in the Boggy Plain Suite compared with the S-type granitoid trends. They show that, as well as having a greater silica range, the Boggy Plain Suite has less MgO and P_2O_5; less TiO_2 and total Fe at low silica values, but similar contents at high silica values; similar CaO and K_2O at similar silica values; and more Na_2O, Ba, and Sr at similar silica values. Compared with the Jindabyne Suite the Boggy Plain Suite has higher MgO, K_2O, P_2O_5, Ba, Rb, Sr, and Zr, and lower CaO. Like the Jindabyne Suite, the Boggy Plain Suite is more oxidised than the S-type granitoids (Fig. 19).

The most significant chemical feature of the Boggy Plain Suite is the high content of incompatible elements such as K, P, Ba, Rb, Sr, and Zr. Barium generally increases with increasing silica (Fig. 18). This trend is consistent with a two-component mixing model between melt and residual crystals; it indicates that, unlike the S-type leucogranites, the more silica-rich plutons such as the Gurrangorambla Granophyre, Burrinjuck Adamellite, and Jackson Granite did not form by fractional crystallisation in which the precipitation of early potash feldspar was followed by filter pressing of the residual liquid. However, some crystal-liquid separation would explain why the more felsic parts of the Jackson Granite, Burrinjuck Adamellite, and Boggy Plain Adamellite are depleted in barium.

The Lower Devonian Mountain Creek Volcanics and Rolling Grounds Latite (Tables A16 and A17, Appendix 2) are petrographically similar to plutons of the Boggy Plain Suite, as they contain phenocrysts of clinopyroxene and, in places, orthopyroxene. Both volcanic units are high in incompatible elements such as K, Ba, Sr, Rb, P, and Zr, confirming their similarity to the Boggy Plain Suite, and are therefore believed to be part of the suite.

Selected Harker diagrams (Fig. 20) show that the Mountain Creek Volcanics and Laidlaw Suite are similar in total Fe, but that the Mountain Creek Volcanics are richer in TiO_2 and poorer in MgO; the two volcanic suites show opposing trends for Zr, which increases with increasing SiO_2 in the Mountain Creek Volcanics but decreases (with increasing SiO_2) in the Laidlaw Suite. The positive correlation of Zr with SiO_2 in the Boggy Plain Suite intrusives (Fig. 18) and extrusives (Fig. 20) contrasts with the negative correlation of Zr with SiO_2 in the S-type intrusives (Fig. 9) and indicates that the Zr was incorporated in the melt fraction of the Boggy Plain Suite magmas.

Discussion

The Boggy Plain Suite is a chemically, mineralogically, temporally, and geographically distinct group of I-type granitoids and volcanics. Its silica range is greater than that of the Jindabyne Suite and S-type granitoids and volcanics, and the rocks are enriched in incompatible elements. A two-component mixing model of residual source material (clinopyroxene, orthopyroxene, calcic plagioclase, and minor olivine) plus melt can explain much of their chemical variation, but some individual plutons have undergone fractional crystallisation as well, producing concentrically zoned bodies—such as the Boggy Plain Adamellite—and high-silica aplitic segregations in the Jackson and Burrinjuck plutons. The wide scatter in the data at the low-silica end of the trends is probably due to the accumulation and concentration of pyroxene crystals and aggregates. High zirconium in the melt fraction, relatively flat trends for TiO_2 and total Fe against silica, and large contact aureoles—all indicate temperatures considerably above minimum melt temperatures. The abundance of orthopyroxene and clinopyroxene in the lower-silica rocks indicates a more anhydrous source than the Jindabyne Suite, and a water-undersaturated magma.

The source material for the Boggy Plain Suite must have been of basaltic rather than andesitic composition, relatively anhydrous, and rich in incompatible elements. It had probably never been through a previous melting episode, since that would have left it low in incompatible elements. This suggests either that the melting episode was the same as that which produced the Silurian granitoids, or that the source material is younger than Early Silurian. Initial strontium isotope values between 0.704 and 0.706 for the granitoids (see pp. 37, 39) suggest that the source had aged before it partially melted, so the first alternative is the more likely.

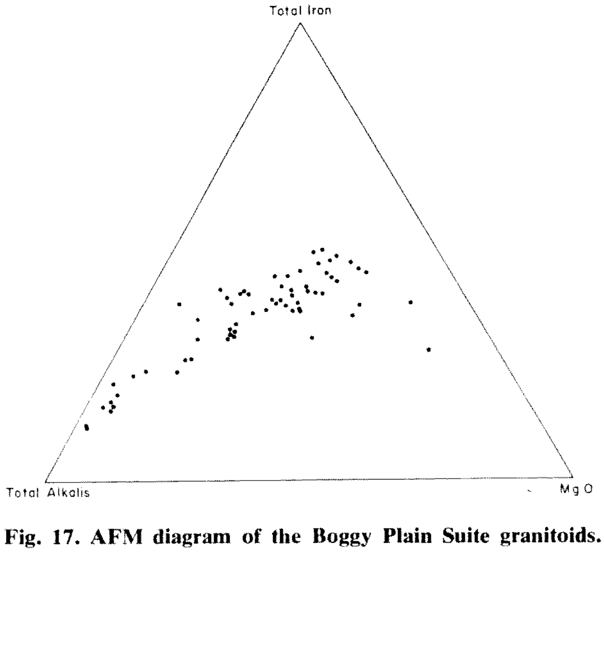


Fig. 17. AFM diagram of the Boggy Plain Suite granitoids.

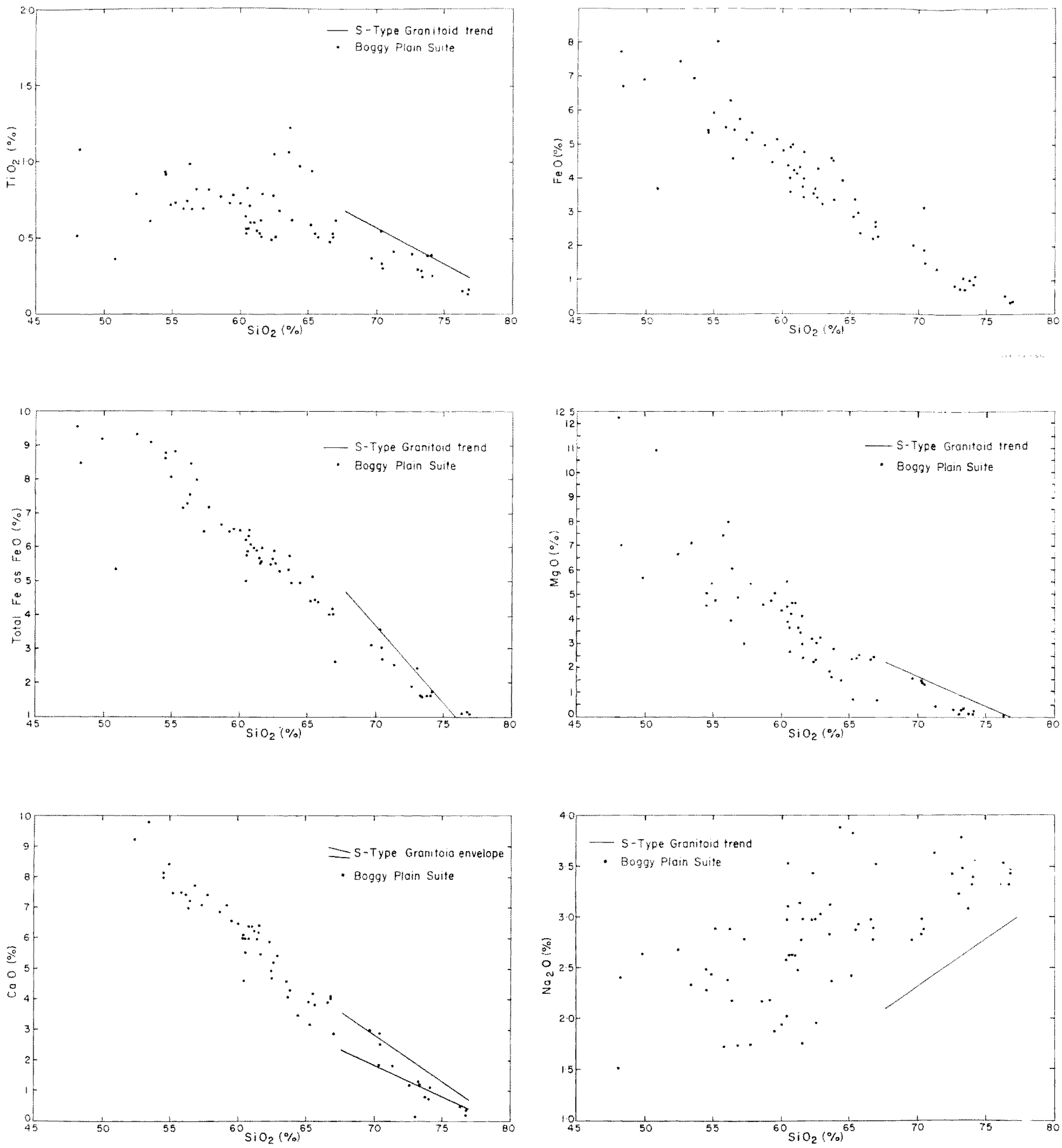
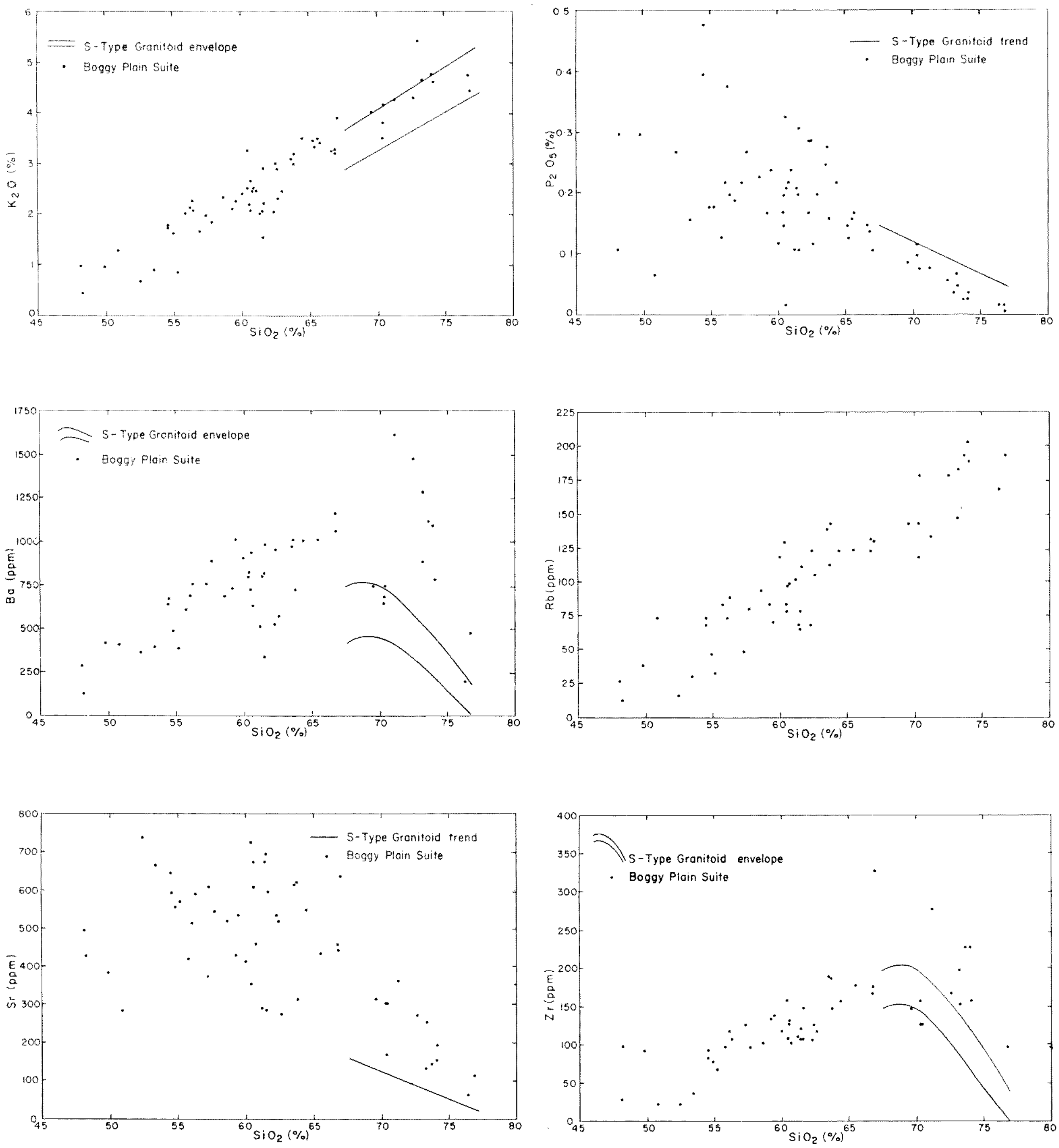


Fig. 18. Selected major oxides and trace elements

Many Lower Devonian high-potassium I-type plutons occupy a meridionally trending belt from Yeoval (300 km north of Canberra) (Gulson, 1972; Gulson, Lovering, Taylor, & White, 1972), past Orange (Crook & Powell, 1976), to Burrinjuck, Cooleman, and south to the upper Tumut River (KOSCIUSKO). This belt roughly coincides with the Ordovician Molong Volcanic Arc, suggesting a genetic relation between the two. As many of the Molong Volcanic Arc basalts are apparently enriched in incompatible elements, a likely source for the Boggy Plain Suite is the high-potassium gabbroic bodies intruded into the lower crust during the Ordovician volcanism.

Upper Silurian basic intrusives

A complex of basic stocks and sheeted dykes of Late Silurian age crops out near the western edge of BRINDABELLA and in northwest TANTANGARA. Farther east, similar dykes crop out locally; they are thought to be Silurian, as those intruding the Walker Volcanics have undergone prehnite-pumpellyite burial metamorphism along with the volcanics. The western complex has been termed the Micalong Swamp Basic Igneous Complex. Analyses from the complex are given in Table A18 (Appendix 2), and variation diagrams in Figure 21.



v **SiO_2 for the Boggy Plain Suite granitoids.**

The complex is highly differentiated, illustrating a well-defined tholeiitic trend (Fig. 22) from magnesium-rich leucogabbros through iron enrichment—of which magnetite-hornblende gabbros are the most enriched—to alkali enrichment. The elements indicate three different types of behaviour during differentiation (decreasing solidification index):

1. continuous depletion of MgO, Al_2O_3, CaO, and the minor elements which readily substitute for magnesium, such as Ni and Cr;

2. TiO_2, MnO, total Fe, P_2O_5, V, Zn, and Sr increase to a maximum and then fall to low values;

3. continuous enrichment of SiO_2, Na_2O, K_2O, Ba, Rb, and Zr.

The trends on variation diagrams for most of these elements are not smooth because of local concentration of cumulate minerals. For example, MgO and total Fe are low (Fig. 21) for samples 73840363 and 74840045, which have high calcic plagioclase contents; conversely, CaO and Al_2O_3 are somewhat high in these samples for the same reason. Again, SiO_2 is low in samples 73840406 and 73840408, in which the magnetite content is high.

Sodium and zirconium gradually increase right through the differentiation series, but SiO_2, K_2O, Rb, and Ba remain low until SI is below 10, when there is a rapid increase. The trends for TiO_2, MnO, total Fe, V, and Zn all reach a maximum at about SI = 25, but

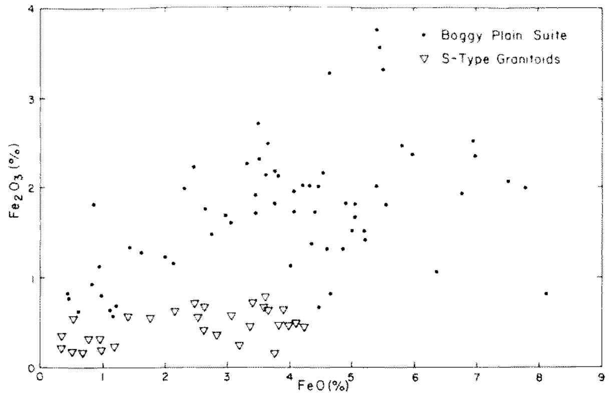


Fig. 19. Fe_2O_3 *v* FeO for the Boggy Plain Suite granitoids and S-type granitoids.

P_2O_5 has an erratic trend and reaches a maximum at SI less than 20. Strontium is highest in the plagioclase cumulates (samples 73840363 and 74840045) and in the rocks highest in iron; as the plagioclase in these iron-rich samples is less calcic and often less abundant than that in the more magnesium-rich rocks, it seems that the plagioclase is more efficient at extracting strontium from the melt when it is of about andesine-labradorite composition. All these trends quite closely follow the computed liquid lines of descent for the Skaergaard pluton (Wager, 1960; Wager & Brown, 1967).

Discussion

The Micalong Swamp Basic Igneous Complex is a classic example of chemical variation produced by fractional crystallisation of a tholeiitic liquid at low pressure. As the samples with highest Mg numbers (65 to 70) contain accumulated plagioclase crystals, the parent liquid was probably not a direct partial melt from the upper mantle, but had lost high-magnesian olivine before reaching the final level of emplacement.

The presence of hornblende and ferrohastingsite in the middle and late stages of fractionation, rather than ferroaugite and hedenbergite, indicates that the magma was more hydrated than the Skaergaard, Bushveld, or Stillwater plutons (Wager & Brown, 1967). The high water content of the magma may explain the high anorthite component (up to An_{90}) in the plagioclase, as plagioclase-melt equilibria are sensitive to water pressure (Drake, 1976), and Yoder (1969) has shown that more-calcic plagioclase crystallises from a melt at higher water pressures. In the three relatively anhydrous plutons mentioned above, plagioclase is rarely more calcic than An_{75}.

D. Wyborn (1977) has suggested that the widespread availability in the southern Lachlan Fold Belt of a middle to Late Silurian low-potassium tholeiitic magma (such as that which formed the Micalong Swamp Basic Igneous Complex), and the intrusion of this magma to form meridional parallel and sheeted dyke complexes, is evidence of a period of crustal extension at the same time as the upwelling of crustal melts to form the Silurian felsic volcanics and batholiths. The Micalong Swamp Basic Igneous Complex is particularly useful for demonstrating this suggestion, as meridional basic dyke swarms intrude the Goobarragandra Volcanics and are intruded by plutons of the Young Batholith.

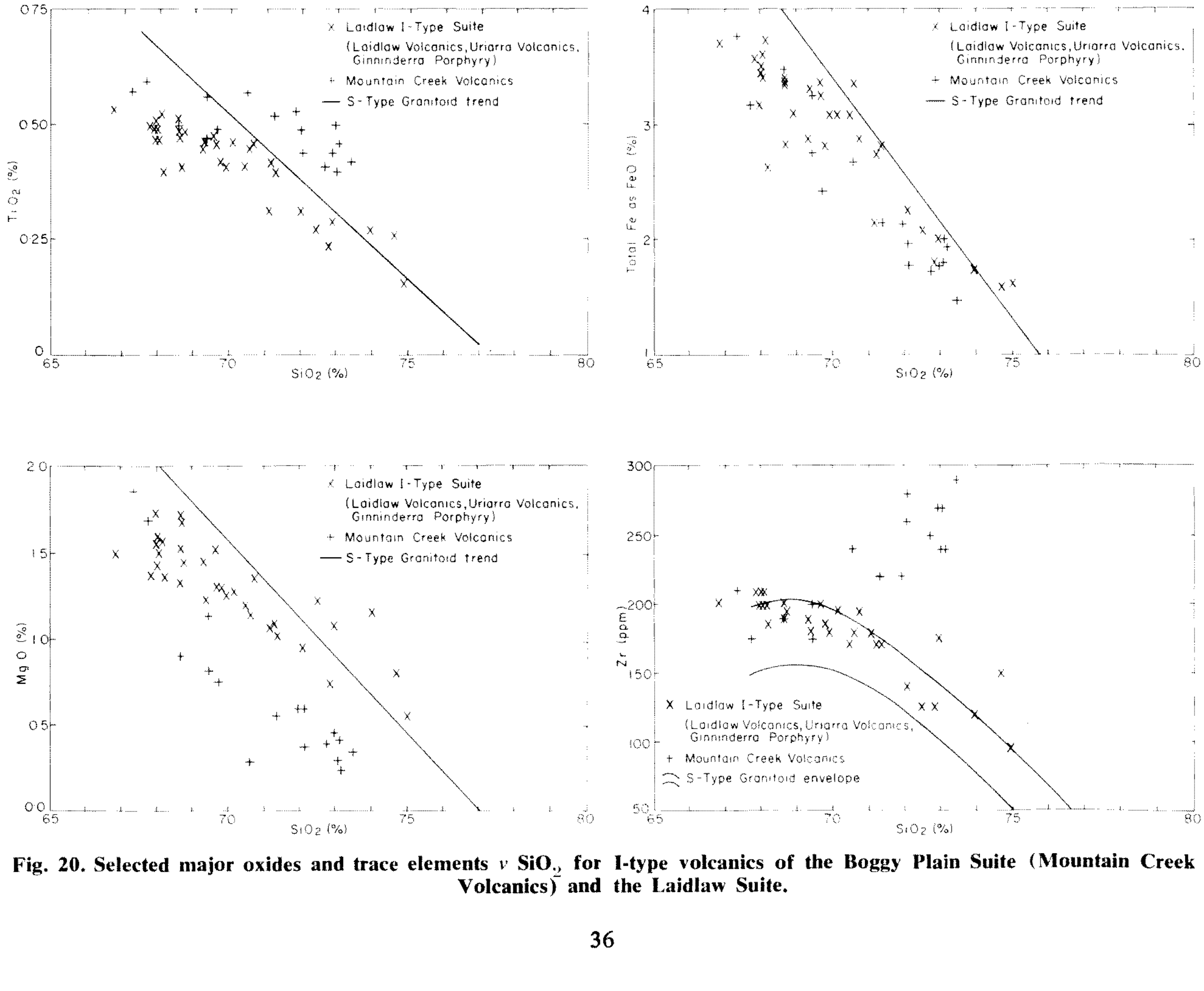


Fig. 20. Selected major oxides and trace elements *v* SiO_2 for I-type volcanics of the Boggy Plain Suite (Mountain Creek Volcanics) and the Laidlaw Suite.

GEOCHRONOLOGY

The Australian Mineral Development Laboratories (AMDEL) did all the isotopic work reported here. They used the decay constants that were recommended at the 25th International Geological Congress, in Sydney (Steiger & Jager, 1977).

Although the main aim of any geochronological work is to date geological events, one of the aims of our study was to date samples of igneous bodies which have good stratigraphic control, so that we might relate some of the lower Palaeozoic stages to an isotopic time scale derived from the rocks that AMDEL dated for us. As the ages that geochronologists have assigned to many of the boundaries between the lower Palaeozoic stages are either poorly defined or mutually conflicting (e.g., Lanphere, Churkin, & Eberlein, 1977; Gale, Beckinsale, & Wadge, 1979), this work might help to resolve the ages of some of them.

For convenience the isotopic results are discussed in four sections: Ordovician, Silurian, Devonian, and Tertiary.

Ordovician results

Hornblende from a pyroxene hornblendite intrusion at grid reference 312111 (KOSCIUSKO) yielded a K/Ar age of 455 ± 10 m.y. This intrusion, the Doubtful River Gabbro, is believed to be related to the Nine Mile Volcanics of Gisbornian age. It intrudes the upper Darriwilian to ?upper Gisbornian Temperance Formation, and field evidence suggests that it is a sill which intruded the sediments when they were only partly lithified (see under *Intrusions related to the Nine Mile Volcanics* on microfiche). Although the sample is from a greenschist facies terrain the hornblende shows little or no alteration and we believe that 455 ± 10 m.y. is a measure of the age of intrusion and not some later event.

A sample of olivine monzonite porphyry from the Nine Mile Volcanics (sample 71840490 from grid ref. 479610) was measured for isotopic abundances of rubidium and strontium. It has a present-day Sr^{87}/Sr^{86} ratio of 0.70620 ± 0.0004 (2δ). As the rock is known to be of Gisbornian age, its initial ratio—allowing for an error in the age of the Gisbornian of ± 20 m.y.—was calculated as 0.7046 ± 0.0004. This initial ratio is somewhat high for the rock to be derived from a homogeneous mantle. This high ratio may be due to alteration, but it may also suggest that the magmatic source of the Nine Mile Volcanics had an earlier history and was originally enriched in Rb^{87} compared with normal mantle material. This second reason for high initial ratios has been advocated for Cainozoic volcanics in the Andes (James, Brooks, & Cuyubamba, 1976) and Papua New Guinea (Johnson & others, 1978b).

Silurian results

Micalong Swamp Basic Igneous Complex

An attempt to date the Micalong Swamp Basic Igneous Complex by a whole-rock Rb/Sr isochron failed because of a lack of spread in the Rb/Sr ratios. However, the spread was great enough to give a reasonably accurate initial Sr^{87}/Sr^{86} ratio of 0.7050 ± 0.0010.

Hornblende from a magnetite gabbro at grid reference 473112 gave a K/Ar age of 430 ± 9 m.y., which is a little older than the stratigraphic control of the complex indicates.

Felsic igneous rocks

Goobarragandra Volcanics. Nine samples of the Goobarragandra Volcanics, collected from where the volcanics conformably underlie a sequence of sediments interbedded with the Ludlovian Yarrangobilly Limestone close to the TANTANGARA/YARRANGOBILLY border, were plotted on a Rb/Sr whole-rock isochron, which yielded an age of 429 ± 16 m.y. and initial ratio of 0.7095 ± 0.0009. A porphyry dyke from within the Goobarragandra Volcanics (grid ref. 410653) was plotted on a Rb/Sr whole-rock/biotite isochron, which yielded an age of 417 ± 8 m.y. and initial ratio of 0.7096. The biotite from the same sample yielded a K/Ar age of 429 ± 9 m.y. This porphyry dyke is similar in mineralogy and chemistry to the Goobarragandra Volcanics and is probably a feeder dyke to volcanics higher in the pile. Its age is not significantly different from that derived from the whole-rock isochron of the Goobarragandra Volcanics, but there appears to be some discrepancy between its Rb/Sr age and its K/Ar age determined from biotite in the same sample.

Laidlaw Volcanics. A sample from grid reference 818032 plotted on a Rb/Sr whole-rock/biotite isochron yielded an age of 418 ± 6 m.y. and initial ratio of 0.7081. The biotite from the same sample yielded a K/Ar age of 425 ± 6 m.y. As the Laidlaw Volcanics are stratigraphically well placed at early Ludlovian an accurate date of their formation would place a lower limit on the age of the Silurian-Devonian boundary. To this end, further work on the isotopic age of the Laidlaw Volcanics is in preparation in conjunction with the Research School of Earth Sciences, ANU.

McLaughlins Flat Granodiorite. A sample from grid reference 575146 (BERRIDALE) plotted on a Rb/Sr whole-rock/biotite isochron yielded an age of 412 ± 8 m.y. and initial ratio of 0.7134. The biotite from the same sample yielded a K/Ar age of 422 ± 8 m.y.

Tonalite at Ashvale. Biotite from a sample of hornblende-biotite tonalite from grid reference 689169 yielded a K/Ar age of 414 ± 6 m.y., which is somewhat older than the two Rb/Sr dates of 408 ± 4 m.y. and 405 ± 4 m.y. for the adjacent Westerly Leucogranite (Roddick & Compston, 1976). The isotopic ages for these two intrusions are incompatible, as the tonalite intrudes the leucogranite.

Devonian results

Boggy Plain Adamellite

A whole-rock Rb/Sr isochron through six samples yielded an age of 448 ± 130 m.y. and initial ratio 0.7042 ± 0.0010. The samples all came from Boggy Plain. Two samples, one from Boggy Plain (sample 73840175, grid ref. 440289) and one from Rocky Plain (sample 73840170, grid ref. 386263), were dated by K/Ar and Rb/Sr techniques on biotite and hornblende concentrates; the results are shown below:

Sample	*K/Ar (hornblende)*	*K/Ar (biotite)*	*Rb/Sr (biotite)*
73840175	417 ± 10 m.y.	415 ± 10 m.y.	407 ± 5 m.y.
73840170	390 ± 15 m.y.	417 ± 10 m.y.	406 ± 5 m.y.

The hornblende in sample 73840170 appears to have lost argon.

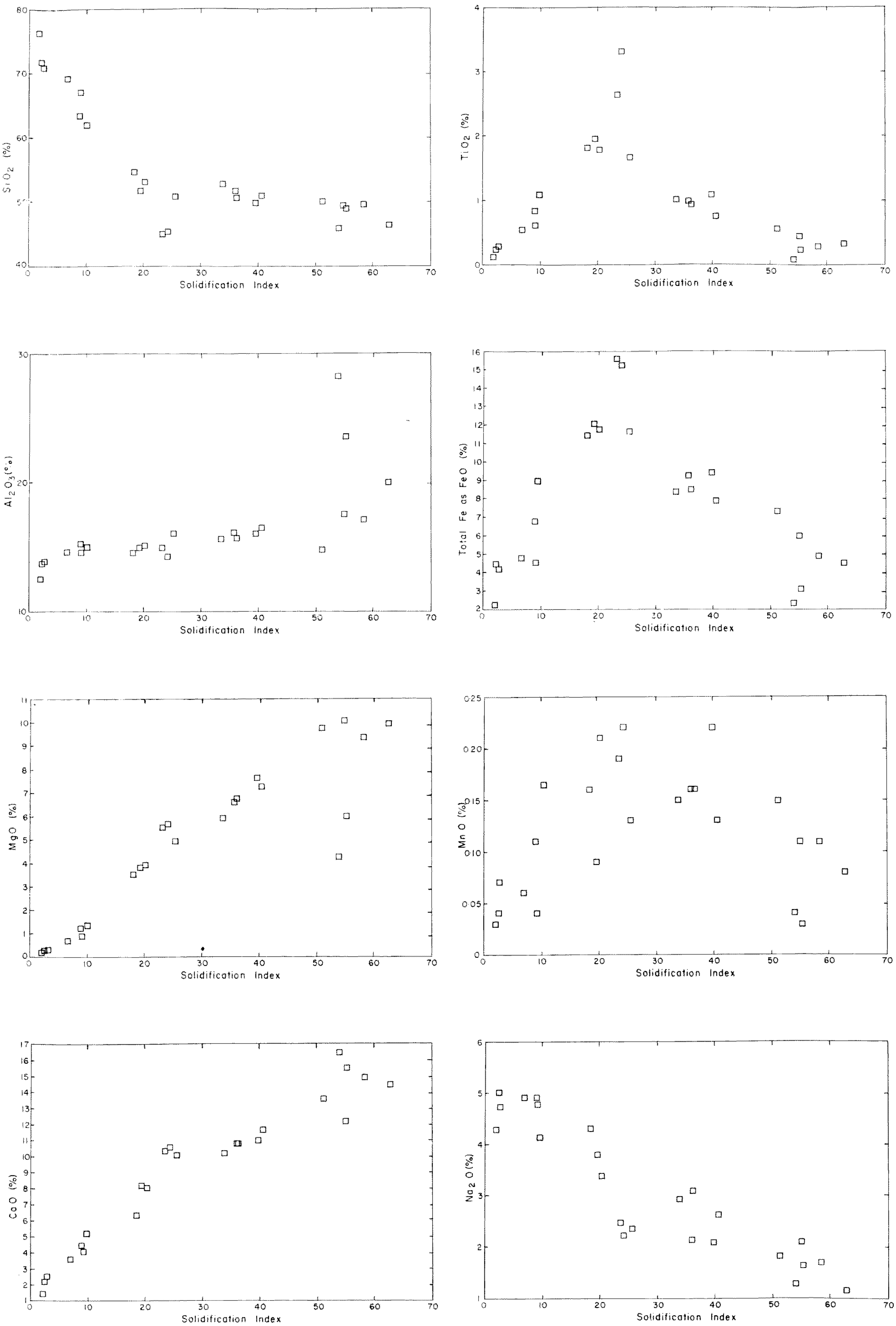


Fig. 21. Selected major oxides and trace elements *v* solidification

Burrinjuck Adamellite

Biotite from sample 73840385 (grid ref. 418245) yielded K/Ar and Rb/Sr dates of 415 ± 8 and 399 ± 8 m.y. respectively. A whole-rock/biotite Rb/Sr isochron gave an initial ratio of 0.7051.

Jackson Granite

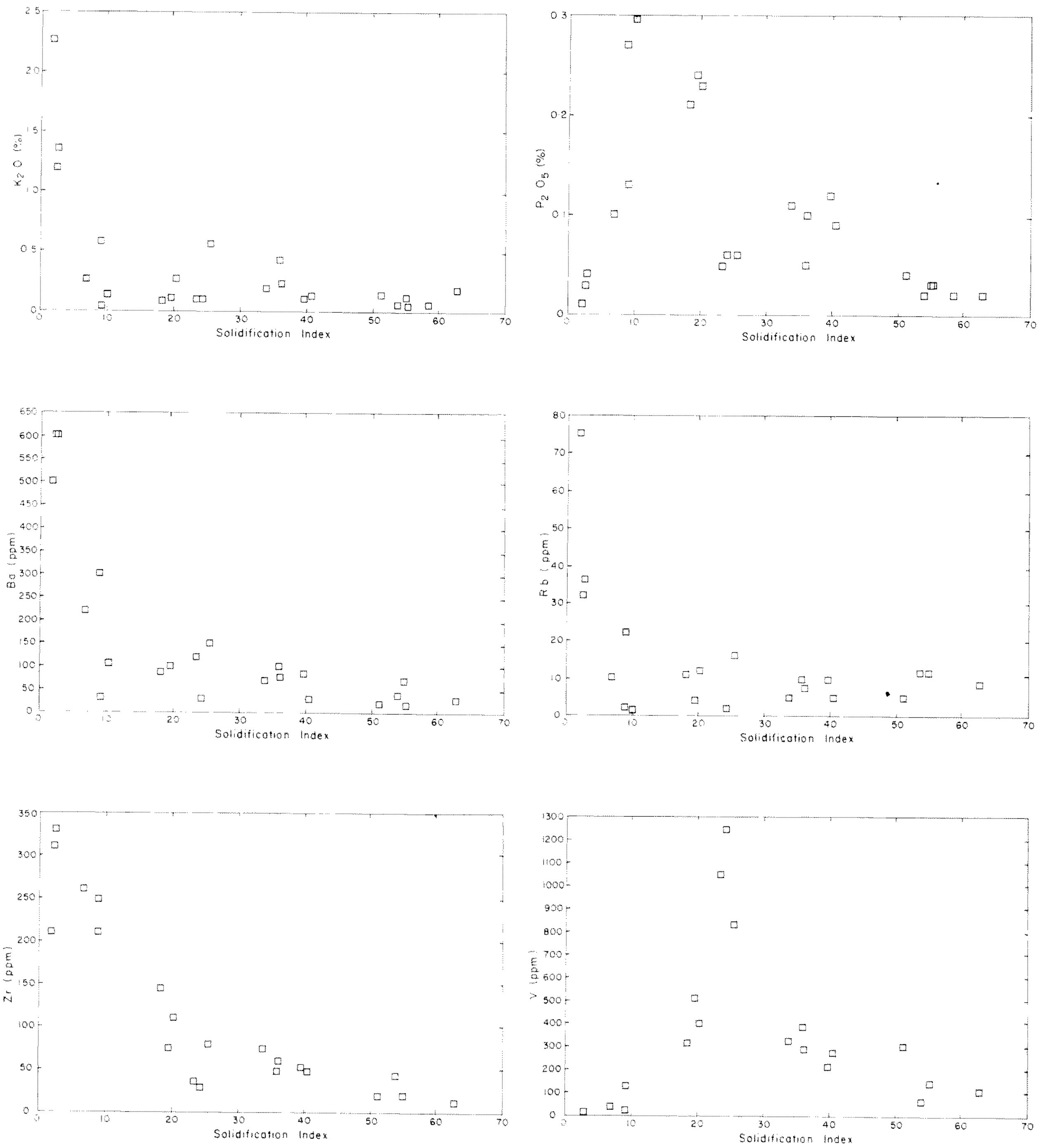
Biotite from sample 71840365 (grid ref. 535553) yielded K/Ar and Rb/Sr dates of 413 ± 8 and 324 ± 6 m.y. respectively. A whole-rock/biotite Rb/Sr isochron gave an initial ratio of 0.7063.

Tertiary results

K/Ar ages for Tertiary basalts are given below:

Sample	*Grid reference*	*Location*	*Age*
72840216	453636	Peppercorn Hill	23.2 ± 0.6 m.y.
75840035	787187	Near Shannons Flat	15.2 ± 0.3 m.y.
75840035A	771209	Near Shannons Flat	18.2 ± 0.3 m.y.
75840035B	785192	Near Shannons Flat	18.0 ± 0.4 m.y.

The dates indicate that all samples belong to the Snowy Mountains Province of Wellman & McDougall (1974), though sample 75840035 has probably yielded an erroneously young age.



index for the Micalong Swamp Basic Igneous Complex.

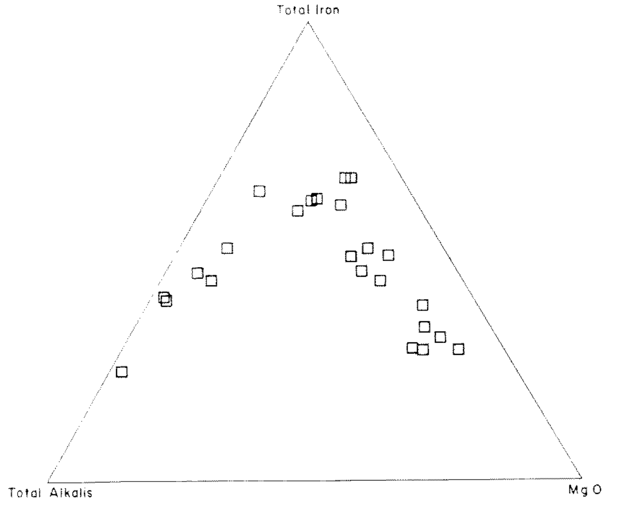


Fig. 22. AFM diagram of the Micalong Swamp Basic Igneous Complex.

Discussion on the Palaeozoic results

Although a reasonable time scale can be constructed from the Palaeozoic results there remains a problem of correlating K/Ar dates with Rb/Sr dates on the same sample. There appears to be a systematic error, as the K/Ar dates are consistently older than the Rb/Sr dates by 7 to 16 million years (Table 3).

Several lines of evidence suggest that the K/Ar ages are too old:

1. The Rb/Sr results for the Boggy Plain Adamellite determined at AMDEL are consistent with results for the same pluton determined by W. Compston at ANU (see Wyborn, 1977).

2. K/Ar work carried out at ANU (I. McDougall, written communication 1978) on the Laidlaw Volcanics yielded a biotite age 5 million years younger than the AMDEL K/Ar age for a sample from the same locality.

3. The K/Ar age of 414 m.y. for the tonalite at Ashvale conflicts with the younger age for the Westerly Leucogranite given by Roddick & Compston (1976).

4. The K/Ar age of 430 m.y. for the Upper Silurian Micalong Swamp Basic Igneous Complex is older than its stratigraphic control indicates.

The most reliable time scale, therefore, can be constructed using the Rb/Sr dates, and is shown below with suggested ages for the Ordovician/Silurian and Silurian/Devonian boundaries:

TABLE 3. K/Ar AGES COMPARED WITH Rb/Sr AGES FOR THE SAME SAMPLES OF UPPER SILURIAN AND LOWER DEVONIAN IGNEOUS ROCKS

Rock unit	*Rb/Sr age m.y.*	*K/Ar age m.y.*	*Difference m.y.*
Laidlaw Volcanics	418	425	+7
Dyke in Goobarragandra Volcanics	417	429	+12
McLaughlins Flat Granodiorite	412	422	+10
Boggy Plain Adamellite	407	415 (biotite)	+8
		417 (hornblende)	+10
Boggy Plain Adamellite	406	417 (biotite)	+11
Burrinjuck Adamellite	399	415	+16

TABLE 4. SUGGESTED TIME SCALE FOR UPPER ORDOVICIAN TO LOWER DEVONIAN STAGES

DEVONIAN	LOCHKOVIAN	< Burrinjuck Adamellite ≃ 400 m.y. < Boggy Plain Adamellite 406 m.y.
		410 m.y.
SILURIAN	PRIDOLIAN	
		< Shannons Flat Adamellite 414 m.y. (Roddick & Compston, 1976)
	LUDLOVIAN	< Laidlaw Volcanics 418 m.y.
	WENLOCKIAN	< Goobarragandra Volcanics ≃ 429 m.y.
	LLANDOVERIAN	
		436 ± 1 m.y. (Lanphere & others, 1977)
ORDOVICIAN	BOLINDIAN	
	EASTONIAN	
	GISBORNIAN	< Doubtful River Gabbro ≃ 450 m.y.
	DARRIWILIAN	

ECONOMIC GEOLOGY

Known mineral deposits in TANTANGARA and BRINDABELLA are typical of much of the Lachlan Fold Belt: they are small and mostly uneconomic; only gold has ever been of economic importance. Gilligan (1975a, b) has recently listed and briefly described the mineral deposits in the Canberra 1:250 000 Sheet area, so our account describes only the larger deposits in BRINDABELLA and TANTANGARA.

METALLIFEROUS MINERAL DEPOSITS

At the *Black Andrew mine* (grid ref. 434206, BRINDABELLA) a tungsten-bismuth deposit was worked intermittently from about 1914 to 1944, though the main period of production was from 1942 to 1944. The grade of the deposit was consistently low, and Owen (1944) reported that a total of only 5.5 tonnes of concentrate was obtained from 1291 tonnes of ore; Gilligan (1975a) listed the total production as 1294 kg of bismuth and 3658 kg of tungstic oxide (WO_3). Mineralisation developed in a quartz vein, trending northwest and dipping about 60°S, close to its intersection with a minor north-trending fault. The main mineral present is wolframite, with quartz as gangue, and minor fluorite, chalcopyrite, pyrite, bismuthinite, molybdenite, arsenopyrite, galena, and scheelite (Gilligan, 1975a). Although the quartz vein has not been worked out, the low grade of the ore indicates that the deposit is uneconomic. The deposit appears to be related to, and is probably a late-stage hydrothermal feature of, the Burrinjuck Adamellite, which—like the Black Andrew deposit—contains fluorite as an accessory mineral.

The *Mount Blundell base-metal prospect* (grid ref. 682933 to 679928, BRINDABELLA) is a lead-zinc-silver-gold prospect worked briefly in the late 1890s and again in the 1920s. Mineralisation occurs over a north-south strike length of about 500 m, and is considered to be stratabound in its host rock—a tuffaceous siltstone which is part of the Mountain Creek Volcanics. It appears to be concentrated where major cross-fractures cut the mineralised zone, and at these localities extensive gossan has developed. Samples of gossan analysed by BMR (Carter, 1970) gave values of up to 2% lead and 0.73% zinc. Jaquet (1897) quoted assays of ore at up to 13.4% lead, 15.34 g/tonne gold, and up to 3670 g/tonne silver, but noted that results were variable, particularly for silver. The deposit is unlikely to be large or of a high grade, since the Mountain Creek Volcanics are essentially a subaerial sequence, an unfavourable environment for such deposits in felsic volcanics.

Two mineral deposits are present in the lower part of Paddys River, near its junction with the Cotter River. The lower one (grid ref. 763880) is the *Congwarra copper lode* (after Gilligan, 1975a), and the upper one (grid ref. 773863) is the *Paddys River iron prospect;* previously Smith (1963) had termed them the Half-Mile and Two-Mile Deposits.

The *Congwarra copper lode* is formed mainly of magnetite oxidised in part to limonite, with relatively minor galena, sphalerite, chalcopyrite, pyrite, arsenopyrite, and gold. It was first prospected in 1895 (Smith, 1963), when 61 tonnes of ore were raised, and prospecting continued until 1908, and again in 1946. Samples taken in 1946 contained up to 3.6% Pb, 7.7% Zn, 0.9% Cu, and 318 g/tonne Ag (Smith, 1963). Gilligan (1975a) reported assays, presumably done in the 1890s, averaging 2.9% Cu, 3.4% Pb, and 1.1% Zn. The average grade from the data listed by Smith is considerably more than Gilligan's figures, particularly for zinc. The deposit is estimated to contain upwards of a million tonnes of magnetite, and, if the average grades given by Smith are used, about 50 000 tonnes or more of sulphide may be present.

The *Paddys River iron prospect* covers an area about 200 m by 90 m. It is formed mainly of magnetite, with some possible hematite, and contains only a trace of sulphides. Jaquet (1901) estimated reserves at a minimum of 1 000 000 tonnes of magnetite, but Smith (1963) revised the estimate to about 600 000 tonnes.

Both deposits are within the Paddys River Volcanics at their contact with the Shannons Flat Adamellite, and appear to have originated by metasomatic replacement of limestone lenses within the volcanics. At the Congwarra copper lode, limestone crops out next to the deposit, and the calcium-iron pyroxene mineral hedenbergite is common. In addition, at another small deposit farther south (grid ref. 777851), metasomatism is only partial, and marble and magnetite occur together.

The *Brindabella alluvial gold workings* (grid ref. 566726) were never very profitable, although a large amount of money was spent on the project. Work began in 1881 and continued intermittently until 1914. A large open cut worked by sluicing was excavated in river gravels in an old terrace of the Goodradigbee River. Extensive races were built to bring water from the Goodradigbee River 3.5 km upstream; they included the short tunnel at grid reference 563748. The total recorded production from the claim is only 2924 g of gold.

The *Kiandra goldfields* at the time of their discovery were among the richest in Australia, and caused a major goldrush. The field was discovered in November 1859, and the population rapidly rose to exceed 10 000 by April 1860, but only 3000 stayed over the winter; by the end of the year the easily won gold had been worked out, and the population had fallen to about 250 by March 1861. According to official figures, the total production of gold from 1859 to the present is 5350 kg, but it probably exceeds 6000 kg because much of the early production was not recorded. The history of the goldfields has been documented in detail by Andrews (1901) and Moye (1959).

The gold was initially found in and worked from Holocene alluvium, but most of the gold was won from Tertiary gravels preserved under the basalt capping of many hills around Kiandra. Many of the workings, and all the rich ones, are outside TANTANGARA; those within the Sheet area are Basalt Claim (grid ref. 355250), which yielded poor returns, and the Six Mile workings (grid ref. 361357), which yielded good returns for a short time in 1860. Elsewhere in the Sheet area much prospecting was done in the 1860s, generally with limited or no success.

The main sulphide deposit in TANTANGARA is at *Mount Black mine,* about 200 m west of Spencers Hut on Cooleman Plain (grid ref. 522556). Two shafts sunk to depths of 13 m and 7 m in 1939, and a short horizontal drive extended from the lower shaft, proved an orebody of limited extent.

Ashley & Creelman (1976) considered that the deposit, which occurs in the Cooleman Limestone immediately below its contact with the overlying Blue Waterhole Formation, developed in a joint-controlled collapse breccia zone, which they interpret as a palaeokarst structure. Limestone fragments in the breccia appear to have been replaced by a variety of minerals, including quartz, sphalerite, galena, and minor chalcopyrite, pyrite, marcasite, tetrahedrite, arsenopyrite, and mackinawite. Ashley & Creelman (1976), and also Gilligan (1973), have recognised many similarities between the Mount Black deposit and Mississippi Valley-type ore deposits.

A shaft was sunk in the early 1900s into an extensive *gossan at the southern end of Smiths Range* (grid ref. 483363; T. Taylor, Currango homestead, personal communication 1972). The shaft, which is about 30 m deep, is still in existence, though in a dangerous condition. It apparently failed to find an economic orebody. Evidence from the adjacent tip indicates that the main sulphide mineral was pyrite, with minor galena, sphalerite, chalcopyrite, and marcasite. The host rock is rhyodacite tuff, some of which may be reworked waterlaid tuff, and the mineralisation apparently occurs in veins with quartz as gangue mineral.

The *Mount Jackson magnetite deposit* is in a joint which extends from within the Jackson Granite into the Mountain Creek Volcanics just north of Jackson Trig at grid reference 537619. The mineralisation occurs over a total length of 1000 m and is up to 20 m wide. Samples that we collected from the deposit have a simple mineralogy of either one or two major phases and very small amounts of other phases. Assemblages present are:

—monomineralic (a) magnetite
(b) hydrogrossularite
(c) chlorite
(d) epidote

—two-phase assemblages (a) magnetite-quartz
(b) magnetite-hydrogrossularite
(c) quartz-chlorite
(d) quartz-epidote

Analyses of several samples for trace elements yielded high values of Zn, Bi, W, and Sn, and low values of Ni, V, and Ti; Owen & others (1974b) have listed the full results.

The Jackson Granite is a leucocratic rock low in MgO, FeO, and CaO. These oxides, together with Zn, Bi, W, and Sn, probably could not be accommodated in the granite, so were expelled with a fluid phase when the granite magma crystallised. The Jackson Granite is a high-level granite that crystallised under very low load pressures, so it is unlikely that the magnetite was caused to crystallise by a large decrease in pressure. Rather, precipitation was probably caused by a large decrease in temperature, together with wallrock reactions (chloritisation and epidotisation) decreasing the activity of elements in solution. The iron, magnesium, calcium, and various trace elements may have been original constituents of the hydrous magma—yet they may have been the residues of partly assimilated xenoliths, which are common in parts of the Jackson Granite.

East of Seventeen Flat a magnetite-goethite deposit occurs along the Mount Black Fault from between grid references 549536 and 558508—a strike length of 3000 m. The deposit has not been studied in detail, but it may have formed by a similar process to the Mount Jackson deposit. It forms a pronounced aeromagnetic anomaly which is displaced about 400 m to the west of the outcrop of the deposit, suggesting a westward dip.

The total tonnage of magnetite in the two deposits is estimated as several million tonnes, but as both are difficult of access they would be uneconomic to mine. Exploitation is also precluded because the deposits are in a highly scenic area of the Kosciusko National Park.

Genetic associations

Mineralisation in TANTANGARA and BRINDABELLA may be grouped into four genetic associations.

1. Lower Devonian I-type granitoid association

The Black Andrew tungsten-bismuth deposit and the Mount Jackson and Seventeen Flat magnetite deposits are probably the result of late-stage hydrothermal activity from a leucocratic I-type granitoid of the Boggy Plain Suite. All of them were deposited in veins.

The prospects of finding further deposits of this association are considered to be remote. The magnetite deposits tend to form obvious outcrops, easily located by fieldwork, and the present detailed mapping failed to find additional deposits. Large tungsten-bismuth deposits of the Black Andrew type are not evident, at least in BRINDABELLA, where a stream-sediment geochemical study (Shackleton, 1976) yielded no related geochemical anomaly near the Burrinjuck Adamellite.

2. Upper Silurian S-type granitoid association

Mineral deposits in the Paddys River valley are similar genetically to the deposits of the first association, as both are derived from late-stage fluids in a granite, but the Paddys River deposits are derived from an S-type granite, the Shannons Flat Adamellite, and have formed by metasomatic replacement of limestone lenses rather than deposition in veins. Again, the prospects of finding further deposits of this association are considered to be remote.

3. Silurian limestone/lead-zinc association

Both Gilligan (1973) and Ashley & Creelman (1976) have argued that the Mount Black deposit, on Cooleman Plain, may be a Mississippi Valley-type deposit—that is, it originated from connate brines expelled during diagenesis of marine sediments and redeposited in a suitable environment in the Cooleman Limestone. Ashley & Creelman listed several features of the Mount Black deposit which are characteristic of Mississippi Valley-type deposits, but they also listed other features which are atypical: the presence of quartz as a gangue mineral, the lack of dolomitisation, the lack of barite and fluorite, and the proximity of igneous rocks. These features may indicate hydrothermal modification of the Mount Black deposit; indeed, the Jackson Granite, which crops out within a kilometre of the mine, is enriched in lead compared with similar granitoids in the region.

4. Silurian-Devonian acid volcanic association

Mineralisation associated with Silurian and Devonian acid volcanism consists mainly of stratabound, vein, and stockwork deposits; examples are at Smiths Range and Mount Blundell. East of Canberra, at Captains Flat and Woodlawn, the Silurian acid volcanics are host to massive stratabound sulphide deposits of Kuroko-type, which are absent from TANTANGARA and BRINDABELLA. This is because Kuroko-type deposits appear to develop only in a submarine environment, and most of the acid volcanics in TANTANGARA and BRINDABELLA erupted in a subaerial environment, where vein and stockwork deposits of limited extent are likely to form rather than massive stratabound sulphides. The prospects of finding economic sulphide deposits in the two Sheet areas are therefore considered remote.

NON-METALLIFEROUS MINERAL DEPOSITS

Small sand and gravel deposits in alluvium are common along the Murrumbidgee River, but are rare on most other rivers and creeks. The main exception is on the Eucumbene River near Providence Portal, where SMHA removed gravel before the area was flooded by Lake Eucumbene.

Sand and gravel is at present being won from two areas in BRINDABELLA (at grid refs. 794988 and 733110), though neither has reserves that are likely to last more than five to ten years. Gravel is also worked intermittently near Bolairo (grid ref. 666162) in TANTANGARA when local demand warrants it. Small amounts of river sand have also been obtained at Cusacks Crossing (grid ref. 768027) after major floods of the Murrumbidgee River.

Material for surfacing dirt roads in the two Sheet areas has been taken from many small local quarries, but the only substantial deposit—weathered granite from the Shannons Flat Adamellite—is at Murrays Corner (grid. ref. 770850). Crushed rock aggregate is not being produced in either of the Sheet areas because large markets are too distant, though a large quarry was developed at Traces Knob (grid. ref. 488366), near Tantangara Dam, to supply aggregate for the construction of the dam. Close to Canberra suitable material for crushed rock aggregate is available from the Laidlaw Volcanics around Surveyors Hill (grid ref. 802056) and nearby hills northwest of Belconnen.

Limestone has not been quarried in either of the Sheet areas, except for ornamental stone from a small quarry in the Taemas Limestone at grid reference 686240. Large resources are present in the Cooleman Limestone on Cooleman Plain, and in the Taemas Limestone at Taemas Bridge and Wee Jasper. Those on Cooleman Plain are remote from any market and are in a particularly scenic area of the Kosciusko National Park, so are economically and environmentally unsuitable for quarrying. The Wee Jasper and Taemas Bridge deposits are more favourably located. Both are probably uneconomic at present, though this may change as demand for cement increases and the large Bungonia quarries east of Goulburn become worked out. The Wee Jasper deposit has a greater thickness of suitable massive limestone, mainly in the upper half of the Taemas Limestone, though again environmental considerations would play an important part in any decision to quarry it.

GEOLOGICAL HISTORY

The pre-middle Ordovician history of TANTANGARA and BRINDABELLA is unknown and highly speculative, since the oldest unit exposed is the Boltons beds, an unfossiliferous quartz-rich distal flysch sequence of presumed middle Ordovician age. Scheibner (1973) and Crook & others (1973) have both postulated that the southeast Lachlan Fold Belt is underlain by ocean-floor tholeiitic basalt, of presumed Cambrian or Early Ordovician age, that passes up into chert and quartz-rich flysch. In contrast, White & others (1976b) have suggested that the Lachlan Fold Belt west of Canberra is underlain by a thick block of continental crust, possibly crystalline shield, whose eastern margin is marked by the eastern limit of S-type granitoids. There is little evidence to support either theory at present. Our own work has not provided clear evidence for the early history of the Lachlan Fold Belt; crustal geophysical work may have to be done before the pre-middle Ordovician geology in the belt can be explained.

By the middle Ordovician the region was receiving large amounts of quartz-rich, mainly distal flysch (Boltons beds) thought to have been deposited in the outer part of a large submarine fan. This fan must have been about as large as the Bengal Fan (about 3000 by 1000 km; Curray & Moore, 1971). It is thought to have been derived from the south, since Ordovician sedimentary rocks in Tasmania are shallow-water deposits, and, if the reconstruction of Griffiths (1974) is correct, northern Victoria Land, Antarctica, could have provided a suitable source for the flysch.

Late in the middle Ordovician, basic volcanic activity commenced, producing rocks which now crop out in an elongate north-northeasterly trending zone between the Victorian border in the headwaters of the Murray River, and Peppercorn Plain (grid ref. 455605) in TANTANGARA, a distance of about 150 km. This activity was almost certainly continuous northwards into central New South Wales, where similar volcanic activity commenced in the Early Ordovician. This volcanic belt was termed the Molong Volcanic Rise by Scheibner (1973) and the Macquarie Volcanic Belt by Webby (1976). We use the name Molong Volcanic Arc, since it has many of the characteristics of modern-day volcanic arcs. Scheibner (1976, p. 162) explained that he used the term 'Rise' instead of 'Arc' only because much of the volcanism was submarine rather than subaerial, a distinction we consider unnecessary.

The Molong Volcanic Arc divided the pre-existing large deep ocean basin into two: to the west the Wagga Marginal Basin (Scheibner, 1973), and to the east the Monaro Slope and Basin (Scheibner, 1973). Both continued to receive quartz-rich distal flysch while volcanic activity continued along the intervening volcanic arc.

Two types of basic volcanism developed: one similar to modern island-arc tholeiitic basalts (Gooandra Volcanics); the other similar to present-day shoshonitic lavas (Nine Mile Volcanics). The tholeiitic rocks are considered to be the older though evidence is circumstantial. Similar rocks in some present-day island-arc settings are related to concurrent subduction zones, but, as discussed above (pp. 24-26), the presence of a subduction zone in the region during the middle to Late Ordovician cannot be postulated with any confidence.

An extensive archipelagic apron consisting of chert, reworked tuff, and slide breccia (Temperance Formation) developed around the volcanic centres, and passed laterally into the quartz-rich flysch being deposited in the basins on either side of the arc. Much of the volcanic arc appears to have been submarine, but coralline limestone accumulated briefly in shallow water in the Peppercorn area, and some of the lavas in the same area are considered to be subaerial.

Volcanic activity is considered to have ceased by the end of the Gisbornian, the age of graptolites from near the top of the volcanics in the Tumut Ponds area (KOSCIUSKO). Distal quartz-rich flysch deposition in the Wagga Marginal Basin, and in the Monaro Slope and Basin (Nungar beds), continued well into the Eastonian. The extinct Molong Volcanic Arc appears to have contributed little, if at all, to the detritus, suggesting that it remained a mainly submarine topographic feature. By the late Eastonian extensive proximal quartz-rich flysch deposits (Adaminaby beds) covered the area. The change in style of deposition may have been either a progradation of the pre-existing fan complex northwards, or derivation of the sediments from a more local source as a result of early movements of the first Benambran fold episode in northeast Victoria; some support for a local source comes from the presence of an inner fan facies around Corin Dam, in TANTANGARA.

In the late Bolindian the first Benambran fold episode deformed the Ordovician sediments and volcanics. The effects of this episode appear to have been slight in the east, but became increasingly significant to the west, where the Molong Volcanic Arc was exposed and eroded, and where considerable movement on the Kiandra Fault must have taken place (p. 14). The first Benambran fold episode also caused the development in the early Llandoverian of a small trough, which we have called the Tantangara Trough, whose western boundary against the now uplifted and folded Wagga Marginal Basin probably coincided with the Kiandra Fault. Evidence for the exact position of the eastern boundary of this trough is lacking, but an early Llandoverian disconformity or slow rate of sedimentation in the Bredbo area (Hill, 1975), in MICHELAGO, implies that the boundary cannot have been as far east as there.

A series of submarine fans developed on the western margin of the Tantangara Trough, and fed into it quartz-rich flysch (Tantangara Formation) derived from the uplifted Wagga Marginal Basin; the deposits are progressively more distal eastwards. As implied earlier, the Bredbo area appears to have been an area of non-deposition in the early Llandoverian; apparently the first Benambran fold episode had cut off the supply of sediment from the south, and the Tantangara Trough restricted the supply of sediment from the west.

In the middle Llandoverian, the second Benambran fold episode destroyed the Tantangara Trough. This episode folded the sediments of the trough into closely spaced but not isoclinal meridional folds. Its effects became less intense westwards, and only minor tilting is evident east of the Cotter River.

Sometime during the early to middle Llandoverian a high heat flow must have developed within the crust, since regional metamorphism occurred over all of the southern Lachlan Fold Belt, affecting mainly deeper buried rocks. The peak of this event can be dated quite precisely in TANTANGARA, since it followed movement on the Kiandra Fault but preceded deposition of the unmetamorphosed upper Llandoverian shelf sediments (Peppercorn Formation). Large-scale anatexis in the lower crust accompanied this regional metamorphism, resulting in vast amounts of felsic magma being formed.

By the late Llandoverian much of the eastern part of TANTANGARA and BRINDABELLA formed a shallow-marine shelf, which later extended to include the Yass-Canberra and Bredbo areas. This feature has received a variety of names, including Canberra Rise and Canberra-Yass Rise (Scheibner, 1973), Yass Shelf (Brown & others, 1968), Molong Geanticline (Packham, 1969), and Molong High (Talent & others, 1975); we have referred to it as the Canberra-Yass Shelf. Sedimentation on this shelf commenced with basal conglomerate, passing upwards in the Cotter valley into mature quartz sandstone (Tidbinbilla Formation) and in the Cooleman area into fine siltstone (Peppercorn Formation). Eastwards, possibly near the eastern edge of BRINDABELLA and TANTANGARA, the shelf passed into a trough in which proximal quartz-rich flysch sediments accumulated in the Canberra-Bredbo area. Westwards, a land mass separated the Canberra-Yass Shelf from the newly developed Tumut Trough (Lightner, 1977), and shed sediments into both. Previous authors have considered this Silurian trough in the Tumut area to be the southern extension of the Cowra Trough (Talent & others, 1975), but Lightner (1977) has demonstrated that they are separate troughs arranged en echelon; we have accepted Lightner's conclusions.

Shelf sedimentation in the Cooleman-Tantangara area continued virtually uninterruptedly until the close of the Silurian; carbonate sediments were a major component (Cooleman Plains Group), and acid volcanic activity was absent. Farther east, in the early Wenlockian, the Quidongan fold episode caused minor uplift of the eastern edge of the Canberra-Yass Shelf, and greater uplift (though still with only gentle folding) of the Yass-Canberra-Bredbo area, which then became part of the Canberra-Yass Shelf. Shallow marine sedimentation persisted briefly in the Canberra area, but was largely replaced during the late Wenlockian by widespread felsic volcanism—mostly erupting ignimbrites—in a subaerial environment that was locally inundated by the sea.

These felsic volcanics were derived from the magma generated in the Llandoverian by anatexis in the lower crust. At that time, a compressive regime prevented the magma from rising into the upper crust, but by the late Wenlockian a tensional regime had developed, allowing vast amounts of felsic magma to rise. On the Canberra-Yass Shelf, the S-type magmas were the first to reach the surface (Paddys River and Walker Volcanics), and were followed in the early Ludlovian by I-type volcanics (Uriarra and Laidlaw Volcanics). In the west, only S-type volcanics erupted (Goobarragandra Volcanics); they probably continued into the Ludlovian.

In many places the rising felsic magmas intruded their comagmatic volcanic piles (as the Murrumbidgee, Young, and Gingera Batholiths). In the west, tholeiitic magmas (Micalong Swamp Basic Igneous Complex) derived by melting in the uppermost part of the mantle intruded at about the same time as the granitoids of the Young Batholith. The intrusion of S-type granitoids was closely followed by I-type granitoids, which—being derived from deeper crustal levels—took longer to rise.

Volcanism ceased in the Canberra-Uriarra area in the early Ludlovian, and this part of the Canberra-Yass Shelf may well have been land for much of the remainder of the Silurian, though the sea may have extended briefly southwards from the Yass Basin, where a marine environment persisted throughout the Ludlovian and Pridolian. At times in the Ludlovian the sea also extended southwards roughly along the present line of the Goodradigbee River to the Cooleman area.

The Bowning fold episode, which in the type area in YASS has been dated as earliest Devonian (Link, 1970), temporarily arrested marine sedimentation in the two Sheet areas. Locally in TANTANGARA and BRINDABELLA it caused intense isoclinal folding, particularly in the Brindabella Range and southwards to the west of Adaminaby. To the east and west of this zone, deformation was less intense, resulting in broad open folds.

Soon after the Bowning fold episode, the eruption of S-type subaerial acid volcanics (Kellys Plain Volcanics) in the Cooleman-Tantangara area marked the final stage of the Silurian-Devonian volcanic cycle. These S-type volcanics were then partly eroded, but not folded, before being covered by volcanics erupted from two large Devonian stratovolcanoes centred in the Cooleman area and near Mount Coree (Mountain Creek Volcanics). Concurrent with this volcanic activity a large number of comagmatic granitoid intrusions (Boggy Plain Suite) were emplaced in a belt from the upper Tumut River (KOSCIUSKO) in the south to the Yeoval Batholith in the north, a distance of 400 km. The spatial relation of this belt of intrusions and volcanics with the Ordovician Molong Volcanic Arc suggests that they are genetically related. The Boggy Plain Suite is considered to have derived its characteristic chemistry from the incorporation into the magma of large amounts of high-potassium basic intrusive rocks which underlay the pre-existing arc.

During the later stages of the eruption of the volcanics from the Mount Coree centre a restricted marine or brackish-water environment developed on the northern edge of BRINDABELLA, resulting in the deposition of anaerobic black mud (Kirawin Formation). Soon after volcanism ceased, this northern area was covered by a sheet of coarse sand and silt (Sugarloaf Creek Formation) derived from the erosion of the Mountain Creek Volcanics to the south, and of the Silurian acid volcanics, granitoids, and Ordovician flysch to the east. Much of the Sugarloaf Creek Formation in the west appears to have been deposited by mudflows originating on the sides of the volcano, but eastward more normal fluviatile sedimentation took place.

In the later part of the Early Devonian, an open sea extended across the northern edge of BRINDABELLA, and a subtidal to supratidal carbonate sequence (Cavan Limestone) was deposited—presumably on the edge of a landmass lying to the south and west—over the site of the earlier Devonian stratovolcano near Mount Coree. Following a brief resumption of brackish-water clastic sedimentation (Majurgong Formation), a return to a normal marine environment favoured the deposition of a mainly subtidal carbonate sequence (Taemas Limestone) in which bioherms developed in the Wee Jasper area. The full areal extent of this marine incursion is uncertain: a marine Devonian sequence of similar age at Ravine, west of TANTANGARA, may have been connected to the Wee Jasper sequence across the western half of BRINDABELLA and TANTANGARA; and the sea probably extended east towards Canberra, and northeast to Tarago and Lake Bathurst, but subsequent erosion has destroyed any evidence of sedimentation there.

Movements correlated with the Tabberabberan fold episode brought this marine incursion to a close at the end of the Early Devonian. The effects of this event in TANTANGARA and BRINDABELLA were slight, resulting only in minor uplift, regression of the sea, and minor erosion. Elsewhere in the southeast Lachlan Fold Belt, however, the effects must have been more marked since in the early part of the Middle Devonian a thick red-bed sequence of conglomerate, sandstone, and siltstone was deposited in the Wee Jasper area (Hatchery Creek Conglomerate), where—in a fluviatile environment that was intermittently flooded—ephemeral lakes supported a fish fauna.

The Hatchery Creek Conglomerate, the youngest Palaeozoic unit in the two Sheet areas was deformed by a major fold episode which, by comparison with areas such as the Hill End Trough, is correlated with the Carboniferous Kanimblan fold episode (Powell & others, 1976). This fold episode resulted in large thrust movements and extensive cleavage development along the Long Plain Fault in TANTANGARA and BRINDABELLA, and, probably, wrench faulting along the Mount Black and Boggy Plain Faults in TANTANGARA.

The history of the two Sheet areas through the late Palaeozoic and Mesozoic is unknown, as no rocks of this age are preserved, but both were probably part of a landmass, since by the Late Cretaceous a peneplain was well developed throughout southeastern Australia. In the Tertiary the two Sheet areas were uplifted, first during the pre-Miocene, and later during the post-Miocene. During the first uplift, the Kiandra Uplift, extensive basalts erupted in the Cooma area, southeast of TANTANGARA, and, between the two uplifts, further basalt buried lacustrine deposits on the western edge of the two Sheet areas, from Kiandra to Wee Jasper. The second uplift, the Kosciusko Uplift, has continued to the present day (Cleary & others, 1964).

During the Pleistocene Ice Age, extensive slope-masking colluvial deposits accumulated in a periglacial environment. Since then, small alluvial deposits have been accumulating along many of the watercourses.

REFERENCES

ADAMSON, C. L., 1951—Reconnaissance geology of the Snowy Mountains area, Progress Report No. 4, Adaminaby. *Department of Mines, New South Wales* (unpublished).

ADAMSON, C. L., 1955—Reconnaissance geology of the Snowy Mountains area, Progress Report No. 4, Adaminaby. *Department of Mines, New South Wales, Annual Report for 1951*, 78-86.

ADAMSON, C. L., 1956—Geological investigations, Adaminaby Dam, Eaglehawk site. *Department of Mines, New South Wales, Annual Report for 1952*, 141-6.

ADAMSON, C. L., 1960—Reconnaissance geology of the Snowy Mountains area, Progress Report No. 16, Tumut. *Department of Mines, New South Wales, Technical Report* 5 (1957), 138-54.

ALDRIDGE, R. J., 1972—Llanodovery conodonts from the Welsh Borderland. *British Museum of Natural History (Geology), Bulletin* 22, 125-231.

ALLEN, J. R. L., 1965—A review of the origin and characteristics of recent alluvial sediments. *Sedimentology* 5, 89-191.

ANDREWS, E. C., 1901—Report on the Kiandra lead. *Geological Survey of New South Wales, Mineral Resources* 10.

ASHLEY, P. M., 1973—Ultramafic and associated rocks near Tumut, New South Wales. *Ph.D. Thesis, Macquarie University* (unpublished).

ASHLEY, P. M., & BASDEN, H., 1973—Revision of nomenclature of granitic intrusions at Burrinjuck, Young, and Cowra. *Geological Survey of New South Wales, Record* 15, 213-20.

ASHLEY, P. M., & CHENHALL, B. E., 1976—Mylonitic rocks in the Young Granodiorite, southern New South Wales. *Journal and Proceedings of the Royal Society of New South Wales*, 98, 239-62.

ASHLEY, P. M., CHENHALL, B. E., CREMER, P. L., & IRVING, A. J., 1971—The geology of the Coolac Serpentinite and adjacent rocks east of Tumut. *Journal and Proceedings of the Royal Society of New South Wales*, 104, 11-29.

ASHLEY, P. M., & CREELMAN, R. A., 1976—The Mount Black lead-zinc deposit, a probable Mississippi Valley-type sulphide occurrence at Cooleman Plains, southern New South Wales. *Journal of the Geological Society of Australia* 22, 423-34.

ATKINS, F. B., 1969—Pyroxenes of the Bushveld intrusion, South Africa. *Journal of Petrology*, 10, 222-49.

ATWATER, T., 1970—Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. *Bulletin of the Geological Society of America*, 81, 3513-36.

BAGNOLD, R. A., 1956—The flow of cohesionless grains in fluids. *Philosophical Transactions of the Royal Society of London, Series A*, 249, 235-97.

BANNO, S., 1964—Petrologic studies on Sanbagawa crystalline schists in the Bessi-Inc District, Central Sikoko, Japan. *Faculty of Science, Tokyo University, Journal* 15, 203-319.

BARKAS, J. P., 1976—Early Devonian igneous activity and some stratigraphic correlations in the Tumut region, New South Wales. *Proceedings of the Linnean Society of New South Wales*, 101, 13-26.

BARRON, B. J., 1976—Recognition of the original volcanic suite in altered mafic volcanic rocks at Sofala, New South Wales. *American Journal of Science*, 276, 604-36.

BARRON, B. J., & BARRON, L. M., 1976—A model for greenschist facies equilibria in altered mafic volcanic rocks at Sofala, New South Wales. *American Journal of Science*, 276, 637-69.

BASDEN, H., 1974—Preliminary report on the geology of the Cootamundra 1:100 000 Sheet. *Geological Survey of New South Wales, Quarterly Notes*, 15.

BEIN, J., 1968—Geology of the Tantangara area, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

BELOUSSOV, A. F., 1971—Statistical characteristics of the behaviour of K in basaltoids during greenschist facies metamorphism. *Geochemistry International*, 8, 517-23.

BERENTS, H. W., 1977—Geology of the Neville-Barry region, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

BEST, J. G., D'ADDARIO, G. W., WALPOLE, B. P., & ROSE, G., 1964—Canberra, Australian Capital Territory and New South Wales—1:250 000 Geological Series Sheet SI/55-16. *Bureau of Mineral Resources, Australia, Canberra* (2nd Edition).

BIRCH, W. D., & GLEADOW, A. J. W., 1974—The genesis of garnet and cordierite in acid volcanic rocks: evidence from the Cerberean Cauldron, central Victoria, Australia. *Contributions to Mineralogy and Petrology*, 45, 1-13.

BISHOP, D. G., 1972—Progressive metamorphism from prehnite-pumpellyite to greenschist facies in the Dansey Pass area, Otago, New Zealand. *Bulletin of the Geological Society of America*, 83, 3177-98.

BLAKE, D. H., & EWART, A., 1974—Petrography and geochemistry of the Cape Hoskins volcanoes, New Britain, Papua New Guinea. *Journal of the Geological Society of Australia*, 21, 319-31.

BOESEN, R. S., 1964—The clinopyroxenes of the monzonitic complex at Mount Dromedary, New South Wales. *American Mineralogist*, 49, 1435-57.

BOFINGER, V. M., COMPSTON, W., & GULSON, B. L., 1970—A Rb-Sr study of the Lower Silurian State Circle Shale, Canberra, Australia. *Geochimica et Cosmochimica Acta*, 34, 433-45.

BOUGAULT, H., & HEKINIAN, R., 1974—Rift valley in the Atlantic Ocean near 36°50'N: petrology and geochemistry of basaltic rocks. *Earth and Planetary Science Letters*, 24, 249-61.

BOUMA, A. H., 1962—SEDIMENTOLOGY OF SOME FLYSCH DEPOSITS: A GRAPHIC APPROACH TO FACIES INTERPRETATION. *Elsevier, Amsterdam*.

BROOKS, C., & LEGGO, M. D., 1972—The local chronology and regional implications of a Rb-Sr investigation of granitic rocks from the Corryong district, southeastern Australia. *Journal of the Geological Society of Australia*, 19, 1-19.

BROWN, D. A., 1964—Excursion notes on the geology of the Yass district, NSW. *In* Geological excursions, Canberra district. *Bureau of Mineral Resources, Australia, Canberra, for 37th Australian and New Zealand Association for the Advancement of Science Congress, Canberra 1964*, 13-20.

BROWN, D. A., CAMPBELL, K. S. W., & CROOK, K. A. W., 1968—THE GEOLOGICAL EVOLUTION OF AUSTRALIA AND NEW ZEALAND. *Pergamon Press, Oxford*.

BROWN, G. M., 1957—Pyroxenes from the early and middle stages of fractionation of the Skaergaard intrusion, east Greenland. *Mineralogical Magazine*, 31, 511-43.

BROWN, I. A., 1941—The stratigraphy and structure of the Silurian and Devonian rocks of Yass-Bowning district, NSW. *Journal of the Royal Society of New South Wales*, 74, 312-41.

BROWNE, I. A., 1959—Stratigraphy and structure of the Devonian rocks of the Taemas and Cavan areas, Murrumbidgee River, south of Yass, NSW. *Journal and Proceedings of the Royal Society of New South Wales*, 92, 115-28.

BROWNE, W. R., 1914—The geology of the Cooma district, NSW. Part 1. *Journal and Proceedings of the Royal Society of New South Wales*, 48, 172-222.

BROWNE, W. R., 1929—An outline of the history of igneous action in New South Wales till the close of the Palaeozoic era. *Proceedings of the Linnean Society of New South Wales*, 54, 9-39.

BROWNE, W. R., 1931—Notes on bathyliths and some of their implications. *Journal and Proceedings of the Royal Society of New South Wales*, 65, 112-44.

BROWNE, W. R., 1944—The geology of the Cooma district, NSW. Part II: The country between Bunyon and Colinton. *Journal and Proceedings of the Royal Society of New South Wales*, 77, 156-72.

BROWNE, W. R., 1969—Geomorphology. *In* Packham, G. H. (Editor)—The geology of New South Wales. *Journal of the Geological Society of Australia*, 16, 559-69.

BROWNE, W. R., 1973—Grey billy and its associates in eastern Australia. *Proceedings of the Linnean Society of New South Wales*, 97, 98-129.

BROWNE, W. R., & GREIG, W. A., 1923—On an olivine-bearing quartz-monzonite from Kiandra, NSW. *Journal and Proceedings of the Royal Society of New South Wales*, 56, 260-77.

BRYAN, W. B., THOMPSON, G., FREY, F. A., & DICKEY, J. S., 1976—Inferred geologic settings and differentiation in basalts from the Deep Sea Drilling Project. *Journal of Geophysical Research*, 81, 4285-304.

BULL, W. B., 1964—Alluvial fans and near surface subsidence in western Fresno County, California. *United States Geological Survey, Professional Paper* 437A, 1-71.

BURBIDGE, N. T., & GRAY, M., 1970—FLORA OF THE A.C.T. *Australian National University Press, Canberra.*

CANN, J. R., 1969—Spilites from the Carlsberg Ridge, Indian Ocean. *Journal of Petrology*, 10, 1-19.

CARMICHAEL, I. S. E., TURNER, F. J., & VERHOOGEN, J., 1974—IGNEOUS PETROLOGY. *McGraw-Hill Inc, New York.*

CARTER, E. K., 1970—Mount Blundell mineral deposit, A.C.T.-N.S.W. *Bureau of Mineral Resources, Australia, Record* 1970/102 (unpublished).

CHAPPELL, B. W., 1966—Petrogenesis of the granites at Moonbi, N.S.W. *Ph.D. Thesis, Australian National University* (unpublished).

CHAPPELL, B. W., & WHITE, A. J. R., 1974—Two contrasting granite types. *Pacific Geology*, 8, 173-74.

CHAPPELL, B. W., & WHITE, A. J. R., 1976—Plutonic rocks of the Lachlan Mobile Zone. *25th International Geological Congress, Excursion Guide* 13C.

CHATTERTON, B. D. E., 1973—Brachiopods of the Murrumbidgee Group, Taemas, New South Wales. *Bureau of Mineral Resources, Australia, Bulletin* 137.

CLARK, J. M., 1974—Geology and geochemistry northeast of Coolac, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

CLARKE, W. B., 1860—RESEARCHES IN THE SOUTHERN GOLD-FIELDS OF NEW SOUTH WALES. *Reading and Wellbank, Sydney.*

CLEARY, J. R., DOYLE, H. A., & MOYE, D. G., 1964—Seismic activity in the Snowy Mountains region and its relationship to geological structures. *Journal of the Geological Society of Australia*, 11, 89-106.

COOKE, J. A., 1975—The geology of an area north of Boorowa. *B. Sc. (Honours) Thesis, Australian National University* (unpublished).

COOKSON, I. C., 1945—Pollen content of Tertiary deposits. *Australian Journal of Science*, 7, 149-50.

COOKSON, I. C., 1946—Pollens of *Nothofagus* Blume from Tertiary deposits in Australia. *Proceedings of the Linnean Society of New South Wales*, 71, 49-63.

COOKSON, I. C., 1947—Fossil fungi from Tertiary deposits in the southern hemisphere. Part 1. *Proceedings of the Linnean Society of New South Wales*, 72, 207-14.

COOKSON, I. C., 1950—Fossil pollen grains of proteaceous type from Tertiary deposits in Australia. *Australian Journal of Scientific Research, Series B*, 3, 166-77.

COOKSON, I. C., 1953—The identity of the sporomorph *Phyllocladidites* with *Dacrydium*, and its distribution in southern Tertiary deposits. *Australian Journal of Botany*, 1, 64-70.

COOKSON, I. C., 1954a—The Cainozoic occurrence of *Acacia* in Australia. *Australian Journal of Botany*, 2, 52-9.

COOKSON, I. C., 1954b—A palynological examination of No. 1 bore, Birregurra, Victoria. *Proceedings of the Royal Society of Victoria*, 66, 119-28.

COSTIN, A. B., 1954—A STUDY OF THE ECOSYSTEMS OF THE MONARO REGION OF N.S.W. *Soil Conservation Service of New South Wales, Sydney.*

CRAMSIE, J., POGSON, D. J., & BAKER, C. J., 1975—Yass 1:100 000 Geological Sheet. *Geological Survey of New South Wales, Sydney.*

CRAMSIE, J., POGSON, D. J., & BAKER, C. J., 1978—Geology of the Yass 1:100 000 Sheet. *Geological Survey of New South Wales, Sydney.*

CRANDELL, D. R., 1971—Post-glacial lahars from Mount Rainier volcano, Washington. *United States Geological Survey, Professional Paper* 677.

CROOK, K. A. W., BEIN, J., HUGHES, R. J., & SCOTT, P. A., 1973—Ordovician and Silurian history of the south-eastern part of the Lachlan Geosyncline. *Journal of the Geological Society of Australia* 20, 113-38.

CROOK, K. A. W., & POWELL, C. McA., 1976—The evolution of the southeastern part of the Tasman Geosyncline. *25th International Geological Congress, Excursion Guide* 17A.

CURRAY, J. R., & MOORE, D. G., 1971—Growth of the Bengal Deep-Sea Fan, and denudation in the Himalayas. *Bulletin of the Geological Society of America*, 82, 563-72.

DAVID, T. W. E., 1914—The geology of the Commonwealth. *In* FEDERAL HANDBOOK ON AUSTRALIA. *Government Printer, Melbourne*, 241-325.

DAVID, T. W. E., 1932—EXPLANATORY NOTES TO ACCOMPANY A NEW GEOLOGICAL MAP OF THE COMMONWEALTH OF AUSTRALIA. *Commonwealth Council of Scientific and Industrial Research, Sydney.*

DAVID, T. W. E., edited by BROWNE, W. R., 1950—THE GEOLOGY OF THE COMMONWEALTH OF AUSTRALIA. *Arnold & Co., London.*

DE KONINCK, L. G., 1876—Recherches sur les fossiles Paleozoiques de la Nouvelle-Galles du Sud (Australie). *Societé Royale des Sciences Liège, Memoire, Série 2*, 2, 1-40. (Translated by David, T. W. E. & Dunn, W. S. in 1898 and published as *Geological Survey of New South Wales, Memoir Palaeontology* 6.)

DICKINSON, W. R., 1962—Petrology and diagenesis of Jurassic andesitic strata in central Oregon. *American Journal of Science* 260, 481-500.

DRAKE, M. J., 1976—Plagioclase-melt equilibria. *Geochimica et Cosmochimica Acta*, 40, 457-65.

DZULYNSKI, S., & SANDERS, J. E., 1962—Current marks on firm mud bottoms. *Transactions of the Connecticut Academy of Arts and Science*, 42, 57-96.

EDGELL, H. S., 1949—Geology of the Burrinjuck-Wee Jasper district. *B.Sc. (Honours) Thesis, University of Sydney* (unpublished).

EVANS, B. W., 1965—Application of a reaction-rate method to the breakdown equilibria of muscovite and muscovite plus quartz. *American Journal of Science*, 263, 647-67.

EVERNDEN, J. F., & RICHARDS, J. R., 1962—Potassium-argon ages in eastern Australia. *Journal of the Geological Society of Australia*, 9, 1-50.

EWART, A., BRYAN, W. B., & GILL, J. B., 1973—Mineralogy and geochemistry of the younger volcanic islands of Tonga, southwest Pacific. *Journal of Petrology*, 14, 429-65.

FAIRBRIDGE, R., 1953—AUSTRALIAN STRATIGRAPHY, 2nd edition. *University of Western Australia Press, Perth.*

FAIRBRIDGE, R. W., FITZPATRICK, B., GOLDFLAM, L., & MCPHEE, I., 1951—Report of geological survey of the Boltons Hill-"M" bend area of the Happy Jacks River on the Adaminaby-Tumut tunnel line. *Snowy Mountains Hydro-electric Authority, Cooma, New South Wales* (unpublished).

FINGER, L. W., 1972—The uncertainty in the calculated ferric iron content of a microprobe analysis. *Carnegie Institution of Washington Yearbook* 71, 600-3.

FLOYD, P. A., & WINCHESTER, J. A., 1975—Magma type and tectonic setting discrimination using immobile elements. *Earth and Planetary Science Letters*, 27, 211-18.

FOLK, R. L., 1968—PETROLOGY OF SEDIMENTARY ROCKS. *Hemphill's, University of Texas.*

FRANKLIN, B. J., 1975—The geology of the North Mooney Complex. *Ph.D. Thesis, University of New South Wales* (unpublished).

FREY, F. A., BRYAN, W. B., THOMPSON, G., 1974—Atlantic Ocean floor; geochemistry and petrology of basalts from legs 2 and 3 of the Deep Sea Drilling Project. *Journal of Geophysical Research*, 79, 5507-27.

FUCHTBAUER, H., 1974—SEDIMENTARY PETROLOGY. PART 2: SEDIMENTS AND SEDIMENTARY ROCKS. *John Wiley & Sons Inc., New York.*

GALE, N. H., BECKINSALE, R. D., & WADGE, A. J., 1979—A Rb/Sr whole rock isochron for the Stockdale Rhyolite of the English Lake District and a revised mid-Palaeozoic time-scale. *Journal of the Geological Society of London* 136, 235-42.

GILL, E. D., & SHARP, K. R., 1957—The Tertiary rocks of the Snowy Mountains, eastern Australia. *Journal of the Geological Society of Australia*, 4, 21-40.

GILL, J. B., 1970—Geochemistry of Viti Levu, Fiji, and its evolution as an island arc. *Contributions to Mineralogy and Petrology*, 27, 179-203.

GILLIGAN, L. B., 1973—Possible Mississippi Valley-type deposits at Cooleman, southeastern New South Wales. *Geological Survey of New South Wales, Quarterly Notes*, 10, 1-10.

GILLIGAN, L. B., 1975a—Part 1. Mine data sheets to accompany metallogenic map, Canberra 1:250 000 Sheet. *Geological Survey of New South Wales, Sydney.*

GILLIGAN, L. B., 1975b—Cowra-Yass Synclinorial Zone. *In* MARKHAM, N. L., & BASDEN, H. (Editors)—THE MINERAL DEPOSITS OF NEW SOUTH WALES. *Geological Survey of New South Wales, Sydney.*

GREEN, R., 1961—Palaeomagnetism of some Devonian rock formations in Australia. *Tellus*, 13, 119-24.

GREEN, T. H., 1976—Experimental generation of cordierite or garnet-bearing granitic liquids from a pelitic composition. *Geology*, 4, 85-8.

GRIFFITHS, J. R., 1974—Revised continental fit of Australia and Antarctica. *Nature*, 249, 336-8.

GULSON, B. L., 1972—The high-K diorites and associated rocks of the Yeoval Diorite Complex, NSW. *Contributions to Mineralogy and Petrology*, 35, 173-92.

GULSON, B. L., LOVERING, J. F., TAYLOR, S. R., & WHITE, A. J. R., 1972—High-K diorites, their place in the calc-alkaline association and relationship to andesites. *Lithos*, 5, 269-79.

HALL, L. R., 1949—Geology of the Eucumbene-Tumut region. *Department of Mines, New South Wales, Report* (unpublished).

HALL, L. R., & LLOYD, J. C., 1954—Geology of the Snowy Mountains area, Progress Report No. 1—Toolong. *Department of Mines, New South Wales, Annual Report for 1950*, 96-104.

HALL, L. R., ROSE, G., & POGSON, D. J., 1967—Bega, New South Wales—1:250 000 Geological Series Sheet SJ/55-4. *Geological Survey of New South Wales, Sydney.*

HARPER, L. F., 1909—The geology of the Murrumbidgee district near Yass, N.S.W. *Geological Survey of New South Wales, Record* 9(1), 1-54.

HELLMAN, P. L., 1976—Structural analysis of the Albury district, N.S.W. *Journal and Proceedings of the Royal Society of New South Wales*, 109, 103-13.

HENDERSON, G. A. M., 1975—Engineering geological notes on the Gooromon Ponds area, N.S.W. *Bureau of Mineral Resources, Australia, Record* 1975/111 (unpublished).

HENSEN, B. J., & GREEN, D. H., 1972—Experimental study of the stability of cordierite and garnet in pelitic compositions at high pressures and temperatures. II: Compositions without excess alumino-silicates *Contributions to Mineralogy and Petrology*, 35, 331-54.

HESS, H. H., 1960—Stillwater igneous complex, Montana. *Geological Society of America, Memoir* 80.

HILL, D., 1940—The lower Middle Devonian rugose corals of the Murrumbidgee and Goodradigbee Rivers, NSW. *Journal and Proceedings of the Royal Society of New South Wales*, 74, 247-76.

HILL, D., 1954—Coral faunas from the Silurian of New South Wales and the Devonian of Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 23.

HILL, D., & STUMM, E. C., 1956—*In* MOORE, R. C.—TREATISE ON INVERTEBRATE PALAEONTOLOGY. PART F: COELENTERATA. *Univeristy of Kansas, and Geological Society of America, Kansas.*

HILL, R. I., 1975—The geology of an area east of Michelago. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

HILLS, E. S., 1958—A brief review of Australian fossil vertebrates. *In* WESTOLL, T. S. (Editor)—STUDIES ON FOSSIL VERTEBRATES PRESENTED TO DAVID MEREDITH SEARES WATSON D.SC., LL.D., F.R.S. *Athlone Press, London*, 86-107.

HINE, R., WILLIAMS, I. S., CHAPPELL, B. W., & WHITE, A. J. R., 1978—Contrasts between I- and S-type granitoids of the Kosciusko Batholith. *Journal of the Geological Society of Australia*, 25, 219-34.

HOWELLS, M. F., LEVERIDGE, B. E., & EVANS, C. D. R., 1973—Ordovician ash-flow tuffs in eastern Snowdonia. *Institute of Geological Sciences, Report* 73/3.

IVANAC, J. F., & GLOVER, J. E., 1949—Geological reconnaissance of the proposed hydro-electric works in the Tumut-upper Murrumbidgee River area. *Bureau of Mineral Resources, Australia, Record* 1949/33 (unpublished).

JAKES, P., & GILL, J. B., 1970—Rare earth elements and the island arc tholeiitic series. *Earth and Planetary Science Letters*, 9, 17-28.

JAKES, P., & WHITE, A. J. R., 1969—Structure of the Melanesian arcs and correlation with distribution of magma types. *Tectonophysics* 8, 223-36.

JAKES, P., & WHITE, A. J. R., 1971—Composition of island arcs and continental growth. *Earth and Planetary Science Letters*, 12, 224-30.

JAKES, P., & WHITE, A. J. R., 1972a—Major and trace element abundances in volcanic rocks of orogenic areas. *Bulletin of the Geological Society of America*, 83, 29-40.

JAKES, P., & WHITE, A. J. R., 1972b—Hornblendes from calc-alkaline volcanic rocks of island arcs and continental margins. *American Mineralogist* 57, 887-902.

JAMES, D. E., BROOKS, C., & CUYUBAMBA, A., 1976—Andean Cenozoic volcanism: magma genesis in the light of strontium isotopic composition and trace-element geochemistry. *Bulletin of the Geological Society of America*, 87, 592-600.

JAQUES, A. L., 1976—High-K_2O island-arc volcanic rocks from the Finisterre and Adelbert Ranges, northern Papua New Guinea. *Bulletin of the Geological Society of America*, 87, 861-7.

JAQUET, J. B., 1897—Report on Mount Blundell, Uriarra, Queanbeyan district. *Department of Mines, New South Wales, Annual Report for 1896*, 139-40.

JAQUET, J. B., 1901—The iron ore deposits of New South Wales. *Geological Survey of New South Wales, Memoir Geology* 2.

JENKINS, C., 1878—Geology of Yass Plains. *Proceedings of the Linnean Society of New South Wales*, 3, 21-32.

JENNINGS, J. N., 1971—Some karst areas of Australia. *In* JENNINGS, J. N., & MABBUTT, J. A.—LANDFORM STUDIES FROM AUSTRALIA AND NEW GUINEA. *Australian National University Press, Canberra*, 256-92.

JENNINGS, J. N., 1972—The age of Canberra landforms. *Journal of the Geological Society of Australia*, 19, 371-378.

JENNINGS, J. N., 1974—Observations at the Blue Waterholes, March 1965-April 1969, and limestone solution on Cooleman Plain, NSW. *Helictite*, 10, 3-46.

JOHNSON, R. W., MACKENZIE, D. E., & SMITH, I. E. M., 1978a—Volcanic rock associations at convergent plate boundaries: reappraisal of the concept using case histories from Papua New Guinea. *Bulletin of the Geological Society of America*, 89, 96-106.

JOHNSON, R. W., MACKENZIE, D. E., & SMITH, I. E. M., 1978b—Delayed partial melting of subduction-modified mantle in Papua New Guinea. *Tectonophysics*, 46, 197-216.

JOLLY, W. T., 1970—Zeolite and prehnite-pumpellyite facies in south central Puerto Rico. *Contributions to Mineralogy and Petrology*, 27, 204-24.

JONES, J. G., 1967—Clastic rocks of Espirita Santo Island, New Hebrides. *Bulletin of the Geological Society of America*, 78, 1281-8.

JOPLIN, G. A., 1943—Petrological studies in the Ordovician of New South Wales. II: The northern extension of the Cooma complex. *Proceedings of the Linnean Society of New South Wales*, 68, 159-83.

JOPLIN, G. A., 1958—Basic and ultrabasic rocks near Happy Jacks and Tumut Pond in the Snowy Mountains of NSW. *Journal and Proceedings of the Royal Society of New South Wales*, 91, 120-41.

JOPLIN, G. A., 1962—An apparent magmatic cycle in the Tasman Geosyncline. *Journal of the Geological Society of Australia*, 9, 51-69.

JOPLIN, G. A., 1965—The problem of the potash-rich basaltic rocks. *Mineralogical Magazine*, 34, 266-75.

JOPLIN, G. A., 1971—A PETROGRAPHY OF AUSTRALIAN IGNEOUS ROCKS, 3rd edition. *Angus and Robertson, Sydney*.

JOPLIN, G. A., NOAKES, L. C., & PERRY, W. J., 1953—Canberra, New South Wales—4-Mile Geological Series Sheet I/55-16. *Bureau of Mineral Resources, Australia, Canberra*.

JOYCE, A. S., 1970—Geochemistry of the Murrumbidgee Batholith. *Ph.D. Thesis, Australian National University* (unpublished).

JOYCE, A. S., 1973—Petrogenesis of the Murrumbidgee Batholith, ACT. *Journal of the Geological Society of Australia*, 20, 179-198.

KELLER, J., 1974—Petrology of some volcanic rock series of the Aeolian Arc, southern Tyrrhenian Sea: calc-alkaline and shoshonitic associations. *Contributions to Mineralogy and Petrology*, 49, 29-47.

KESSON, S. E., & SMITH, I. E. M., 1972—TiO_2 content and the shoshonite and alkaline associations. *Nature Physical Science*, 236, 110-11.

KOLBE, P., & TAYLOR, S. R., 1966—Geochemical investigation of the granitic rocks of the Snowy Mountains area, New South Wales. *Journal of the Geological Society of Australia*, 13, 1-25.

KUBLER, B., 1967—Anchimetamorphisme et schistosite. *Centre de Recherches de Pau—SNPA, Bulletin* 1, 259-78.

KUNIYOSHI, S., & LIOU, J. G., 1976—Burial metamorphism of the Karmatsen volcanic rocks, northeastern Vancouver Island, British Columbia. *American Journal of Science*, 276, 1096-119.

LANG, P. A., & PURCELL, D. C., 1976—Geological investigations for the Ginninderra Sewer Tunnel, Belconnen, ACT, 1975. *Bureau of Mineral Resources, Australia, Record* 1976/44 (unpublished).

LANPHERE, M. A., CHURKIN, M., Jr., & EBERLEIN, G. D., 1977—Radiometric age of the *Monograptus cyphus* graptolite zone in southeastern Alaska—an estimate of the age of the Ordovician-Silurian boundary. *Geological Magazine*, 114, 15-24.

LEGG, D. P., 1968—The geology of the Cooleman Plains and surrounding areas, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

LEIGH, W. S., & ETHERIDGE, R., Jr, 1894—Report on the caves in Cooleman Creek, Cooleman Plains, on the headwaters of the Goodradigbee River, with notes on the surrounding district. *Department of Mines and Agriculture, New South Wales, Annual Report for 1893*, 134-40.

LIGHTNER, J. D., 1977—The stratigraphy, structure and depositional history of the Tumut region. *M.Sc. Thesis, Australian National University* (unpublished).

LINK, A. G., 1970—Age and correlations of the Siluro-Devonian strata in the Yass Basin, NSW. *Journal of the Geological Society of Australia*, 16, 711-22.

LINK, A. G., & DRUCE, E. C., 1972—Ludlovian and Gedinnian conodont stratigraphy of the Yass Basin, New South Wales. *Bureau of Mineral Resources, Australia, Bulletin* 134.

LOFGREN, G., 1971—Experimentally produced devitrification textures in natural rhyolitic glass. *Bulletin of the Geological Society of America*, 82, 111-24.

LUTH, W. C., 1976—Granitic rocks. *In* BAILEY, D. K., & MACDONALD, R. (Editors)—THE EVOLUTION OF THE CRYSTALLINE ROCKS. *Academic Press, London*, 335-417.

MCBIRNEY, A. R., 1963—Factors governing the nature of submarine volcanism. *Bulletin Volcanologique*, 26, 455-69.

MACKENZIE, D. E., 1968—The metamorphic and basaltic rocks of the Kiandra region, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

MACKENZIE, D. E., 1976—Nature and origin of late Cainozoic volcanoes in western Papua New Guinea. *In* JOHNSON, R. W. (Editor)—VOLCANISM IN AUSTRALASIA. *Elsevier, Amsterdam*, 227-38.

MACKENZIE, D. E., & CHAPPELL, B. W., 1972—Shoshonitic and calc-alkaline lavas from the highlands of Papua New Guinea. *Contributions to Mineralogy and Petrology*, 35, 50-62.

MACKENZIE, D. E., & WHITE, A. J. R., 1970—Phonolite globules in basanite from Kiandra, Australia. *Lithos*, 3, 309-17.

MAHONY, D. J., & TAYLOR, T. G., 1913—Report on a geological reconnaissance of the Federal Territory, with special reference to available building materials. *Government Printer, Melbourne*.

MALCOLM, D. K., 1954—The geology of the Cotter River and Uriarra areas, ACT. *Bureau of Mineral Resources, Australia, Record* 1954/71 (unpublished).

MANN, C. W., 1921—Preliminary note on the occurrence of porphyritic intrusions at Yass, NSW. *Journal of the Royal Society of New South Wales*, 55, 180-7.

MANSON, V., 1967—Geochemistry of basaltic rocks: major elements. *In* HESS, H. H., & POLDERVAART, A. (Editors)—BASALTS—THE POLDERVAART TREATISE ON ROCKS OF BASALTIC COMPOSITION. *Interscience, New York*.

MENARD, H. W., 1956—Archipelagic aprons. *Bulletin of the American Association of Petroleum Geologists*, 40, 2195-210.

MITCHELL, T. L., 1838—THREE EXPEDITIONS INTO THE INTERIOR OF AUSTRALIA; WITH DESCRIPTIONS OF RECENTLY EXPLORED REGION OF AUSTRALIA FELIX, AND OF THE PRESENT COLONY OF NEW SOUTH WALES. *T & W Boone, London*, 2.

MIYASHIRO, A., 1973—METAMORPHISM AND METAMORPHIC BELTS. *George Allen & Unwin Ltd, London.*

MIYASHIRO, A., 1974—Volcanic rock series in island arcs and active continental margins. *American Journal of Science*, 274, 321-55.

MOIGNARD, P. S., 1970—The geology of the Boambolo district, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

MOORE, R. M., 1958—Natural phenomena and microclimate. *In* Proceedings of the Canberra Symposium on Climatology and Microclimatology. *Unesco, Paris.*

MOYE, D. G., 1953—Report on geology of upper Tumut development. *Snowy Mountains Hydro-electric Authority, Cooma, New South Wales* (unpublished).

MOYE, D. G., 1957—Murrumbidgee-Eucumbene diversion, geological investigations. Progress report, January, 1957. *Snowy Mountains Hydro-electric Authority, Engineering Geology Report* SG 73 (unpublished).

MOYE, D. G., 1959—Historic Kiandra, a guide to the history of the district. *Cooma-Monaro Historical Society.*

MOYE, D. G., SHARP, K. R., & STAPLETON, D. H., 1963—Geology of the Snowy Mountains region. *Snowy Mountains Hydro-electric Authority, Cooma, New South Wales* (unpublished).

MUTTI, E., 1965—Submarine flood tuffs (ignimbrites) associated with turbidites in Oligocene deposits of Rhodes Island, Greece. *Sedimentology*, 5, 265-88.

NASH, W. P., & WILKINSON, J. F. G., 1970—Shonkin Sag Laccolith, Montana. I: Mafic minerals and estimates of temperature, pressure, oxygen fugacity and silica activity. *Contributions to Mineralogy and Petrology*, 25, 241-69.

NEWBERRY, J., 1956—Murrumbidgee-Eucumbene diversion geological investigations, progress report, February 1956. *Snowy Mountains Hydro-electric Authority, Engineering Geology Report* SG 69 (unpublished).

NICHOLLS, J., & CARMICHAEL, I. S. E., 1969—A commentary on the absarokite-shoshonite-banakite series of Wyoming, USA. *Schweizerische Mineralogische und Petrographische Mitteilungen*, 49, 47-64.

NICOLL, R. S., & REXROAD, C. B., 1974—Llandovery (Silurian) conodonts from southern New South Wales. *Geological Society of America, Abstracts with Programs for 1974*, 6(6), 534-535.

NINKOVICH, D., & HAYS, J. D., 1972—Mediterranean island arcs and origin of high potash volcanoes. *Earth and Planetary Science Letters*, 16, 331-45.

NOAKES, L. C., 1946—Dam sites in the upper Cotter valley between Bushrangers and Collins Creeks. *Bureau of Mineral Resources, Australia, Record* 1946/12 (unpublished).

OFFENBURG, A. C., 1974—Goulburn, New South Wales—1:250 000 Geological Series. *Geological Survey of New South Wales, Explanatory Notes* SI/55-12.

OLLIER, C. D., & BROWN, M. C., 1975—Geology and scenery of Canberra. Australian Geographer, 13, 97-103.

ÖPIK, A. A., 1952—Interpretation of the stratigraphy of the Palaeozoic sedimentary rocks of the Adaminaby tunnel-lines of the Snowy Mountains. *Bureau of Mineral Resources, Australia, Record* 1952/12 (unpublished).

ÖPIK, A. A., 1958—The geology of the Canberra city district. *Bureau of Mineral Resources, Australia, Bulletin* 32.

OWEN, H. B., 1944—The Black Andrew mine, near Burrinjuck, County Buccleuch, New South Wales. *Department of Supply and Shipping Report* 1944/22 (unpublished).

OWEN, J. A., 1975—Palynology of some Tertiary deposits in New South Wales. *Ph.D. Thesis, Australian National University* (unpublished).

OWEN, M., GARDNER, D. E., WYBORN, D., SALTET, J., WALTON, D. G., MIFSUD, J. M., & COOPER, R. D., 1974a—Tantangara, New South Wales and Australian Capital Territory—1:100 000 Geological Sheet. *Bureau of Mineral Resources, Australia, Canberra* (unpublished).

OWEN, M., GARDNER, D. E., WYBORN, D., SALTET, J., & SHACKLETON, M. S., 1974b—Geology of the Tantangara 1:100 000 Sheet area, Australian Capital Territory and New South Wales. *Bureau of Mineral Resources, Australia, Record* 1974/176 (unpublished).

OWEN, M., & WYBORN, D., 1976—Tantangara-Brindabella. *In* Geological Branch summary of activities 1975. *Bureau of Mineral Resources, Australia, Report* 194, 21-24.

PACKHAM, G. H., 1960—Sedimentary history of part of the Tasman Geosyncline in southeastern Australia. *21st International Geological Congress*, 12, 74-83.

PACKHAM, G. H. (Editor) 1969—The geology of New South Wales. *Journal of the Geological Society of Australia*, 16.

PACKHAM, G. H., & FALVEY, D. A., 1971—An hypothesis for the formation of marginal seas in the western Pacific. *Tectonophysics*, 11, 79-109.

PALMER, K., 1972—The geochemistry and tectonic evolution of the Cooleman volcanic centre, NSW. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

PEARCE, J. A., 1975—Basalt geochemistry used to investigate past tectonic environments on Cyprus. *Tectonophysics*, 25, 41-67.

PEARCE, J. A., & CANN, J. R., 1973—Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth and Planetary Science Letters*, 19, 290-300.

PEDDER, A. E. H., 1967—Devonian rocks of the Murrumbidgee area, New South Wales. *In* OSWALD, D. H. (Editor)—Proceedings of the International Symposium on the Devonian System. *Alberta Society of Petroleum Geologists*, 2, 143-6.

PEDDER, A. E. H., JACKSON, J. H., & PHILIP, G. M., 1970—Lower Devonian biostratigraphy in the Wee Jasper region of New South Wales. *Journal of Palaeontology*, 44, 206-51.

POGSON, D. J., & BAKER, C. J., 1974—Revised stratigraphic nomenclature for the Yass 1:100 000 Sheet. *Geological Survey of New South Wales, Quarterly Notes*, 16, 7-9.

POWELL, C. McA., EDGECOMBE, D. R., HENRY, N. M., & JONES, J. G., 1976—Timing of regional deformation of the Hill End Trough: a reassessment. *Journal of the Geological Society of Australia*, 23, 407-21.

PROFFETT, J. M., Jr, 1977—Cenozoic geology of the Yerington district, Nevada, and implications for the nature and origin of Basin and Range faulting. *Bulletin of the Geological Society of America*, 88, 247-66.

RAST, N., 1962—Textural evidence for the origin of ignimbrites. *Liverpool and Manchester Geological Journal* 3, 97-108

RICHARDSON, S., in press—Explanatory notes on the Michelago 1:100 000 Sheet. *Geological Survey of New South Wales, Sydney.*

RITTMAN, A., 1969—VOLCANOES AND THEIR ACTIVITY. (Translated by E. A. Vincent.) *Interscience, New York.*

RODDICK, J. C. M., 1974—Responses of strontium isotopes to some crustal processes. *Ph.D. Thesis, Australian National University* (unpublished).

RODDICK, J. C., & COMPSTON, W., 1976—Radiometric evidence for the age of emplacement and cooling of the Murrumbidgee Batholith. *Journal of the Geological Society of Australia*, 23, 223-33.

ROSS, C. S., & SMITH, R. L., 1961—Ash-flow tuffs: their origin, geologic relations and identification. *United States Geological Survey, Professional Paper* 366.

RYBURN, R. J., RAHEIM, A., & GREEN, D. H., 1976—Determination of the P, T paths of natural eclogites during metamorphism—record of subduction. *Lithos*, 9, 161-4.

SCHEIBNER, E., 1973—A plate tectonic model of the Palaeozoic tectonic history of New South Wales. *Journal of the Geological Society of Australia*, 20, 405-6.

SCHEIBNER, E. 1976—Explanatory notes on the tectonic map of New South Wales. *Geological Survey of New South Wales, Sydney*.

SCHLOEMER, M., 1964—Synthetic hydrothermal cocrystallisation of orthoclase and quartz—parts 1 and 2. *Geochemistry International*, 1, 578-612.

SEILACKER, A., 1967—Bathymetry of trace fossils. *Marine Geology*, 5, 413-28.

SEKI, Y., 1969—Facies series in low grade metamorphism. *Journal of the Geological Society of Japan*, 75, 255-66.

SHACKLETON, M. S., 1976—A stream-sediment geochemical survey of the western half of the Brindabella 1:100 000 Sheet area. *Bureau of Mineral Resources, Australia, Record* 1974/122, microfiche MF6 (unpublished).

SHEARSBY, A. J., 1905—On the occurrence of a bed of fossiliferous tuff and lavas between the Silurian and Middle Devonian at Cavan, Yass, NSW; similar in age and character to the Snowy River Porphyries of Victoria. *Proceedings of the Linnean Society of New South Wales*, 30, 275-88.

SHEARSBY, A. J., 1912—The geology of the Yass district. *Report of the 13th Meeting of the Australasian Association for the Advancement of Science, Sydney*, 1911, 106-19.

SHERRARD, K. M., 1936—The structural geology and petrology of an area near Yass, NSW. *Proceedings of the Linnean Society of New South Wales*, 61, 131-50.

SHERRARD, K. M., 1954—The assemblages of graptolites in New South Wales. *Journal and Proceedings of the Royal Society of New South Wales*, 87, 73-101.

SMITH, E. M., 1963—Notes on prospecting and mining in the Australian Capital Territory and environs. *Bureau of Mineral Resources, Australia*, Record 1963/110 (unpublished).

SMITH, I. E. M., 1972—High-potassium intrusives from southeastern Papua. *Contributions to Mineralogy and Petrology*, 34, 167-76.

SMITH, I. E. M., 1976—Volcanic rocks from southeastern Papua. The evolution of volcanism at a plate boundary. *Ph.D. Thesis, Australian National University* (unpublished).

SMITH, R. E., 1968—Redistribution of major elements in the alteration of some basic lavas during burial metamorphism. *Journal of Petrology*, 9, 191-219.

SMITH, R. E., & SMITH, S. E., 1976—Comments on the use of Ti, Zr, Y, Sr, K, P, and Nb in classification of basaltic magmas. *Earth and Planetary Science Letters*, 32, 114-20.

SMITH, R. L., 1960—Ash flows. *Bulletin of the Geological Society of America*, 71, 795-841.

SNELLING, N. J., 1960—The geology and petrology of the Murrumbidgee Batholith. *Quarterly Journal of the Geological Society of London*, 116, 187-215.

STAPLEDON, D. H., 1957—Report on the geology of T2 project. *Snowy Mountains Hydro-electric Authority, Cooma, New South Wales* (unpublished).

STEIGER, R. H., & JAGER, E., 1977—Subcommission on Geochronology: convention on the use of decay constants in geochronology and cosmochronology. *Earth and Planetary Science Letters*, 36, 359-62.

STEVENS, N. C., 1952—The petrology of the Cowra intrusion and associated xenoliths. *Proceedings of the Linnean Society of New South Wales*, 77, 132-41.

STEVENS, N. C., 1957—Murrumbidgee-Eucumbene diversion: geology of the Tantangara Reservoir and the country to the north. *Snowy Mountains Hydro-electric Authority, Engineering Geology Report* SG74 (unpublished).

STEVENS, N. C., 1958a—The geology of part of the Murrumbidgee-Eucumbene tunnel line. *Snowy Mountains Hydro-electric Authority, Engineering Geology Report* SG 78 (unpublished).

STEVENS, N. C., 1958b—Palaeozoic geology of the Cooleman Caves district, New South Wales. *Proceedings of the Linnean Society of New South Wales*, 83, 251-8.

STRECKEISEN, A., 1976—To each plutonic rock its proper name. *Earth Science Review*, 12, 1-33.

STRUSZ, D. L., 1971—Canberra, Australian Capital Territory and New South Wales—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SI/55-16.

STRUSZ, D. L., 1975—Silurian stratigraphic units of the southern part of the Molong High. *Bureau of Mineral Resources, Australia, Record* 1975/147 (unpublished).

STRUSZ, D. L., & HENDERSON, G. A. M., 1971—Canberra City, A.C.T.—1:50 000 geological map and explanatory notes. *Bureau of Mineral Resources Australia, Canberra*.

SUSSMILCH, C. A., 1909—Notes on the physiography of the Southern Tableland of New South Wales. *Journal and Proceedings of the Royal Society of New South Wales*, 43, 331-54.

SUSSMILCH, C. A., 1914—AN INTRODUCTION TO THE GEOLOGY OF NEW SOUTH WALES, 2nd edition. *Angus & Robertson, Sydney*.

TALENT, J. A., 1965—The stratigraphic and diastrophic evolution of central and eastern Victoria in middle Palaeozoic times. *Proceedings of the Royal Society of Victoria*, 79, 179-95.

TALENT, J. A., BERRY, W. B. N., & BOUCOT, A. J., 1975—Correlation of the Silurian rocks of Australia, New Zealand and New Guinea. *Geological Society of America, Special Paper* 150.

TAYLOR, G., & SMITH, I. E. M., 1975—The genesis of sub-basaltic silcretes from the Monaro, New South Wales. *Journal of the Geological Society of Australia*, 22, 377-85.

THOMAS, D. E., 1960—The zonal distribution of Australian graptolites. *Journal and Proceedings of the Royal Society of New South Wales*, 94, 1-58.

TOBI, A. C., & KROLL, H., 1975—Optical determination of the An content of plagioclases twinned by Carlsbad-Law: a revised chart. *American Journal of Science*, 275, 731-6.

TUTTLE, O. F., & BOWEN, N. L., 1958—Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O. *Geological Society of America, Memoir* 74.

VALLANCE, T. G., 1954—Studies in the metamorphic and plutonic geology of the Wantabadgery-Adelong-Tumbarumba district, NSW. Part III: The granitic rocks. *Proceedings of the Linnean Society of New South Wales*, 78, 197-220.

VALLANCE, T. G., 1969—Plutonic and metamorphic rocks. *In* PACKHAM, G. H. (Editor)—The geology of New South Wales. *Journal of the Geological Society of Australia*, 16, 180-200.

VANDENBERG, A. H. M., 1976—The Tasman Fold Belt in Victoria. *Geological Survey of Victoria, Report* 1976/3.

VANDYKE, A., & BYRNES, J. G., 1976—Palaeozoic succession beneath the Narragal Limestone, Oakdale Anticline near Mumbil. *Geological Survey of New South Wales, Record* 17, 123-34.

VEERABURUS, M., 1963—The geology of the Brungle-Adjungbilly district. *M.Sc. Thesis, University of New South Wales* (unpublished).

VISHER, G. S., 1965—Fluvial processes as interpreted from ancient and recent fluvial deposits. *In* MIDDLETON, G. V. (Editor)—Primary sedimentary structures and their hydrodynamic interpretation. *Society of Economic Palaeontologists and Mineralogists, Special Publication* 12, 116-32.

WAGER, L. R., 1960—The major element variation of the layered series of the Skaergaard intrusion. *Journal of Petrology* 1, 364-98.

WAGER, L. R., & BROWN, G. M., 1967—LAYERED IGNEOUS ROCKS. *Freeman, San Francisco.*

WALKER, R. G,. 1967—Turbidite sedimentary structures and their relationship to proximal and distal deposition. *Journal of Sedimentary Petrology,* 37, 25-43.

WALPOLE, B. P., 1952—The Wee Jasper-Cooleman Caves area. *Bureau of Mineral Resources, Australia, Record* 1952/63 (unpublished).

WALPOLE, B. P., 1964—Notes on the Brindabella-Cooleman Caves-Tantangara-Yaouk excursion. *In* Geological excursions, Canberra district. *Bureau of Mineral Resources, Australia, Canberra, for 37th Australian and New Zealand Association for the Advancement of Science Congress, Canberra, 1964,* 35-42.

WALTON, A. W., 1977—Petrology of volcanic sedimentary rocks, Vieja Group, southern Rim Rock County, Trans-Pecos, Texas. *Journal of Sedimentary Petrology,* 47, 137-57.

WASS, S. Y., & IRVING, A. J., 1976—Xenmeg—a catalogue of occurrences of xenoliths and megacrysts in volcanic rocks of eastern Australia. *Australian Museum Press, Sydney.*

WEBBY, B. P., 1976—The Ordovician System in south-eastern Australia. *In* BASSETT, M. G. (Editor)—THE ORDOVICIAN SYSTEM. Proceedings of a Palaeontological Symposium, Birmingham, September 1974. *University of Wales Press and the National Museum of Wales, Cardiff.*

WELLMAN, P., 1971—The age and palaeomagnetism of the Australian Cainozoic volcanic rocks. *Ph.D. Thesis, Australian National University* (unpublished).

WELLMAN, P., & MCDOUGALL, I., 1974—Potassium-argon ages on the Cainozoic volcanic rocks of N.S.W. *Journal of the Geological Society of Australia,* 21, 247-72.

WHITE, A. J. R., & CHAPPELL, B. W., 1976—Ultrametamorphism and granitoid genesis. *25th International Geological Congress, Abstracts* 3, 674-75.

WHITE, A. J. R., & CHAPPELL, B. W., 1977—Ultrametamorphism and granitoid genesis. *Tectonophysics,* 43, 7-22.

WHITE, A. J. R., CHAPPELL, B. W., & CLEARY, J. R., 1974—Geologic setting and emplacement of some Australian Palaeozoic batholiths and implications for intrusive mechanisms. *Pacific Geology,* 8, 159-71.

WHITE, A. J. R., CHAPPELL, B. W., & WILLIAMS, I. S., 1976a—Berridale, New South Wales—1:100 000 Geological Sheet. *Geological Survey of New South Wales, Sydney.*

WHITE, A. J. R., WILLIAMS, I. S., & CHAPPELL, B. W., 1976b—The Jindabyne Thrust and its tectonic, physiographic and petrogenetic significance. *Journal of the Geological Society of Australia,* 23, 105-12.

WILKINSON, J. F. G., 1956—Clinopyroxenes of alkali-basalt magma. *American Mineralogist,* 41, 724.

WILKINSON, J. F. G., 1957—The clinopyroxenes from a differentiated teschenite sill near Gunnedah, New South Wales. *Geological Magazine,* 94, 123-34.

WILLIAMS, C. R., 1974—Geology and geochemistry of the Happy Jacks-Jagungal area, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

WILLIAMS, I. S., 1977—The Berridale Batholith: a lead and strontium isotopic study of its age and origin. *Ph.D. Thesis, Australian National University* (unpublished).

WINKLER, H. G. F., 1974—PETROGENESIS OF METAMORPHIC ROCKS, 3rd edition. *Springer-Verlag, Berlin.*

WRIGHT, T. L., 1968—X-ray and optical study of alkali feldspars. II: An X-ray method for determining the composition and structural state from measurement of 2θ values for three reflections. *American Mineralogist,* 53, 88-104.

WYBORN, D., 1977—Discussion—the Jindabyne Thrust and its tectonic, physiographic and petrogenetic significance. *Journal of the Geological Society of Australia,* 24, 233-6.

WYBORN, L. A. I., 1977—Aspects of the geology of the Snowy Mountains region and their implications for the tectonic evolution of the Lachlan Fold Belt. *Ph.D. Thesis, Australian National University* (unpublished).

YODER, H. S., Jr, 1969—Calc-alkaline andesites: experimental data bearing on the origin of their assumed characteristics. *In* MCBIRNEY, A. R. (Editor)—Proceedings of the Andesite Conference. *Department of Geology and Mineralogy Industries, Oregon, Bulletin* 65, 77-89.

YOUNG, G. C., 1969—The geology of the Burrinjuck-Wee Jasper area, New South Wales. *B.Sc. (Honours) Thesis, Australian National University* (unpublished).

YOUNG, G. C., & GORTER, J. D., in prep.—A new fish fauna of probable Middle Devonian age from the Taemas/Wee Jasper region of New South Wales.

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APPENDIX 1

ANALYTICAL PRECISION AND ACCURACY OF GEOCHEMICAL ANALYSES

Precision

All the geochemical results presented in Appendix 2 were determined at AMDEL between 1972 and 1977. During this time, AMDEL analysed replicates of a mafic rock (sample 71840485) and a felsic rock (sample 71840257) with batches of other samples. Ten replicates of 71840485 and six replicates of 71830257 were analysed. The precision can be judged by the mean, standard deviation, and percentage error of these analyses tabulated below.

	Sample 71840485 %	% error	Sample 71840257 %	% error
SiO_2	49.48 ± 0.47	1.0	69.86 ± 0.40	0.6
TiO_2	0.74 ± 0.03	4.1	0.36 ± 0.01	2.8
Al_2O_3	14.73 ± 0.11	0.7	13.92 ± 0.10	0.7
Fe_2O_3	2.84 ± 0.44	15.5	1.00 ± 0.14	14.0
FeO	7.45 ± 0.36	4.8	2.23 ± 0.09	4.0
FeO total	10.07 ± 0.19	1.9	3.13 ± 0.07	2.2
MnO	0.16 ± 0.01	6.3	0.04 ± 0.01	25.0
MgO	6.23 ± 0.08	1.3	1.94 ± 0.04	2.1
CaO	8.41 ± 0.23	2.7	0.79 ± 0.03	3.8
Na_2O	3.29 ± 0.06	1.8	4.29 ± 0.06	1.4
K_2O	2.07 ± 0.04	1.9	3.18 ± 0.04	1.3
P_2O_5	0.33 ± 0.02	6.1	0.08 ± 0.01	12.5
H_2O+	3.16 ± 0.15	4.7	1.79 ± 0.18	10.1
H_2O-	0.18 ± 0.08	44.4	0.16 ± 0.05	31.3
CO_2	0.14 ± 0.03	21.4	0.11 ± 0.01	9.1

	Sample 71840485 ppm	% error	Sample 71840257 ppm	% error
Cu	171 ± 26	15.2	18 ± 11	61.1
Zn	109 ± 21	19.2	61 ± 12	19.7
Co	36 ± 8	22.2	9 ± 4	44.4
Ni	26 ± 6	23.1	20 ± 4	20.0
Cr	97 ± 29	29.9	193 ± 11	5.7
V	394 ± 117	29.7	80 ± 10	12.5
Ba	580 ± 47	8.1	570 ± 37	6.5
Ce	31 ± 14	45.2	56 ± 9	16.1
La	15 ± 5	33.3	25 ± 7	28.0
Pb	7 ± 4	57.1	220 ± 15	6.8
Rb	45 ± 3	6.7	98 ± 2	2.0
Sr	737 ± 22	3.0	138 ± 5	3.6
Th	ND	-	10 ± 4	40.0
U	ND	-	ND	-
Zr	46 ± 8	17.4	122 ± 7	5.7
Y	17 ± 3	17.6	16 ± 2	12.5
Nb	ND	-	ND	-

ND Below detection limit

This table shows that the precision of the major-element determination is good except for Fe_2O_3, FeO, MnO, P_2O_5, water, and CO_2. Feo total is good despite the lower accuracy of Fe_2O_3 and FeO. The precision of the trace-element determinations is not so good: all transition metals have a large relative error; only Ba, Rb, and Sr have reasonable relative errors for both samples, and Pb and Zr are reasonable for sample 71840257; and the errors for all other trace elements are too large for petrogenetic conclusions to be drawn from their abundances.

Accuracy

In order to determine accuracy, BMR standards were sent to AMDEL for analysis. A comparison of three standards SS1, SS3, and SS5 is tabulated below.

	SS1		SS3		SS5	
	BMR	AMDEL	BMR	AMDEL	BMR	AMDEL
SiO_2	66.84	66.54	49.28	48.59	75.87	76.16
TiO_2	0.56	0.55	1.21	1.19	0.09	0.10
Al_2O_3	15.24	15.15	16.43	16.16	12.40	12.40
FeO total	3.31	3.24	9.39	8.96	1.07	1.04
MnO	0.06	0.06	0.17	0.16	0.03	0.03
MgO	1.00	1.55	7.67	7.58	0.24	0.14
CaO	3.10	3.06	11.71	11.47	0.70	0.71
Na_2O	3.90	4.11	2.32	2.57	3.40	3.23
K_2O	3.11	3.18	0.12	0.15	5.28	5.43
P_2O_5	0.14	0.15	0.12	0.12	0.02	0.03
Loss on ignition	1.79	1.91	1.22	1.84	0.43	0.60
Cu	20	22	68	80	1	4
Zn	106	128	86	100	12	30
Ni	14	16	90	94	9	14
Cr	35	20	271	270	255	240
V	62	90	234	300	5	10
Ba	640	720	27	20	126	140
Pb	27	30	11	10	25	24
Rb	143	140	4	5	306	300
Sr	359	360	191	190	28	28
Th	23	20	ND	ND	41	40
U	4.7	4	0.3	ND	11	12
Zr	180	180	88	85	93	85
Y	18	12	25	24	48	40
Nb	9	4	2	ND	16	12

The conclusions drawn from this table are somewhat similar to those drawn from the previous table. The AMDEL and BMR results for most major elements, Ba, Rb, Sr, and Zr are close, but there are large discrepancies between the dual analyses for some of the trace transition metals.

APPENDIX 2. TABLES OF ANALYSES

In the following tables, we have abbreviated many names so that they fit conveniently into the narrow, uniform width of the columns. Though the full names of many of these abbreviations will be evident from the main text (e.g., 'McLaughlin Granodr' is the McLaughlins Flat Granodiorite, and 'B.P. Suite' is the Boggy Plain Suite), we have presented below a key to the abbreviations we have used for the names of minerals and rock types, and for descriptive terms.

Minerals

act - actinolite
alb - albite
biot - biotite
cpx - clinopyroxene
ep - epidote
hbl - hornblende
ol - olivine
opx - orthopyroxene
plag - plagioclase
pyx - pyroxene
qtz - quartz

Rock types

amphib - amphibolite
gbro - gabbro
granodr - granodiorite
hblite - hornblendite
leucoadam - leucoadamellite
leucogran - leucogranite
microdr - microdiorite
monzodr - monzodiorite

Descriptive terms

anorthos - anorthositic
contam - contaminated
cryst - crystal
granophyr - granophyric
int - intrusive
porph - porphyritic

Table A1: GOOANDRA VOLCANICS

Sample no.	71840385	71840510	72841008	76840010	76840011	76840029	76840071
Rock Type	albitised dolerite	albitised rhyolite	alb.ep.act basalt	albitised basalt	albitised andesite	albitised basalt	pillow lava
Grid reference	369435	379381	376361	378448	369417	383464	337327
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Yarrangob.
SiO_2	51.60	72.34	56.88	54.27	58.31	52.57	52.19
TiO_2	0.83	0.37	1.03	1.02	1.06	0.91	0.62
Al_2O_3	16.40	14.58	15.37	14.84	14.53	15.50	16.55
Fe_2O_3	1.80	2.14	1.94	1.54	5.00	0.96	3.44
FeO	5.90	1.20	6.50	7.25	4.15	8.05	4.05
MnO	0.14	0.03	0.15	0.31	0.27	0.42	0.13
MgO	6.95	0.11	4.21	6.38	2.66	6.72	5.41
CaO	9.25	0.28	5.86	5.51	3.86	4.82	11.05
Na_2O	4.05	7.88	4.25	4.82	7.24	5.50	3.20
K_2O	0.32	0.13	0.46	0.21	0.75	0.41	0.17
P_2O_5	0.10	0.08	0.16	0.11	0.11	0.10	0.09
H_2O+	1.98	0.19	2.54	2.95	0.95	2.99	2.51
H_2O-	0.22	0.07	0.18	0.24	0.15	0.19	0.13
CO_2	0.15	0.10	0.05	0.05	0.70	0.50	0.35
TOTAL	99.69	99.50	99.58	99.50	99.74	99.64	99.89
Ba	153		170	60	120	140	<5
Rb	12	3	8	7	20	11	5
Sr	218	60	300	140	120	140	180
Pb	651	<2	38	<2	8	<2	<2
Th	<4	<4	<4	<4	<4	4	<4
U	<4	6	4	<4	4	<4	<4
Zr	84	210	85	75	70	60	38
Nb	<4	<4	<4	<4	<4	<4	<4
Y	19	24	24	24	30	18	14
La	21	16	20	<10	<10	<10	<10
Ce	28	18	<10	<10	<10	<10	<10
V	200	55	220	250	300	240	240
Cr		10	30	25	20	10	140
Co	36	10	20	<2	<2	<2	<2
Ni	50	<5	12	14	6	22	50
Cu	79	16	56	4	22	26	82
Zn	82	84	140	148	85	430	79

Table A2: NINE MILE VOLCANICS

Sample no.	70840037	71840011	71840057	71840240	71840277	71840283	71840296	71840297	71840334	71840390
Rock Type	ol. cpx. monzonite	opx. hblite	cpx. monzonite	cpx. monzonite	fragmental tuff	cpx. monzonite	hbl.cpx. basalt	quartz monzodr.	fragmental tuff	porph.plag basalt
Grid reference	428547	378279	388288	421363	475413	412363	409386	407393	468449	456601
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	50.08	40.20	50.20	50.30	49.76	51.00	52.37	59.50	48.80	53.49
TiO_2	0.53	1.18	0.41	0.45	0.83	0.52	0.59	0.35	0.80	0.55
Al_2O_3	13.22	15.60	11.20	11.10	12.62	13.90	17.50	18.20	12.90	17.31
Fe_2O_3	3.24	7.50	3.25	2.35	2.01	1.35	1.24	1.90	3.40	3.49
FeO	6.85	7.20	6.70	7.15	7.05	7.50	6.75	3.10	7.45	4.45
MnO	0.19	0.28	0.21	0.22	0.23	0.20	0.18	0.14	0.20	0.16
MgO	7.63	6.90	9.40	9.90	8.49	7.20	4.56	2.40	8.05	4.15
CaO	8.85	15.70	12.90	11.90	9.10	9.00	6.20	5.55	9.05	4.09
Na_2O	1.81	0.76	1.29	1.29	3.66	2.30	3.84	3.95	2.65	4.01
K_2O	4.34	1.24	2.35	2.45	1.66	4.00	3.55	2.85	2.30	4.68
P_2O_5	0.38	0.76	0.30	0.34	0.27	0.45	0.27	0.24	0.31	0.44
H_2O+	2.27	1.93	1.45	2.05	2.17	1.88	1.90	1.26	2.80	2.39
H_2O-	0.05	0.13	0.09	0.06	0.34	0.11	0.18	0.05	0.36	0.19
CO_2	0.15	0.20	0.25	0.15	0.95	0.10	0.05	0.10	0.65	0.05
TOTAL	99.59	99.58	100.00	99.71	99.14	99.51	99.18	99.59	99.72	99.45
Ba	1200	550	1130	900	900	1630	1500	760	620	940
Rb	65	30	34	30	34	60	65	42	34	110
Sr	690	1160	575	560	410	720	640	1050	330	720
Pb	6	4	6	4	4	<2	<2	<2	190	6
Th	<4	<4	4	<4	<4	<4	<4	<4	<4	<4
U	4	<4	<4	4	<4	<4	<4	<4	<4	4
Zr	30	<5	12	24	55	26	38	48	26	46
Nb	6	<10	<10	<5	<4	<10	<10	4	<4	4
Y	12	20	10	12	18	25	18	12	14	16
La	<10	20	10	<10	<10	20	<10	<10	<10	<10
Ce	<10	<10	<10	50	30	10	<10	50	20	<10
V	580			285	280	400	280	140	355	370
Cr	470	15	45	20	390	42	45		30	15
Co	76	25	15	30		22		8	30	<5
Ni	80	18	22	45	152	22	18	8	42	10
Cu	210	290	100	170	66	170	114	10	75	122
Zn	215	45	28	45	162	45	112	30	65	104

Table A2: NINE MILE VOLCANICS (cont.)

Sample no.	71840485	71840490	71840492	71840498	71840501	71840506	71840529	72840264
Rock Type	cpx.plag. basalt	ol.plag. basalt	cpx.ol. basalt	ol.cpx. monzodr.	ol.cpx. monzodr.	ol.cpx. monzonite	fragmental tuff	hbl.qtz. monzodr.
Grid reference	457601	479610	471614	491624	491624	392408	456604	344232
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Yarrangob.
SiO_2	49.49	50.10	49.69	50.60	50.60	50.60	49.20	58.27
TiO_2	0.73	0.51	0.45	0.53	0.52	0.46	1.12	0.46
Al_2O_3	14.71	13.80	12.05	11.90	11.90	13.00	14.60	18.10
Fe_2O_3	2.48	1.90	3.18	1.85	1.85	2.80	5.40	1.80
FeO	7.70	8.85	6.50	7.15	7.20	6.60	7.30	3.93
MnO	0.16	0.18	0.17	0.15	0.16	0.20	0.17	0.12
MgO	6.30	6.85	8.88	9.35	9.35	8.20	6.20	2.28
CaO	8.61	8.30	9.10	10.70	10.70	10.20	6.65	6.63
Na_2O	3.19	1.89	1.52	2.35	2.35	2.00	2.60	3.80
K_2O	2.08	3.90	4.17	1.57	1.59	3.10	3.05	2.61
P_2O_5	0.32	0.41	0.35	0.24	0.25	0.37	0.36	0.30
H_2O+	3.10	2.80	2.50	2.70	2.70	2.30	2.80	1.11
H_2O-	0.10	0.30	0.35	0.29	0.22	0.03	0.30	0.20
CO_2	0.15	0.35	0.50	0.20	0.25	0.15	0.20	0.10
TOTAL	99.12	100.14	99.41	99.58	99.64	100.01	99.95	99.71
Ba	623	1120	1200	540	632	950	720	880
Rb	43	60	75	24	21	48	48	46
Sr	768	720	340	590	677	875	900	1150
Pb	4	6	<2	4	4	6	8	4
Th	<4	<4	<4	<4	<4	<4	<4	4
U	<4	<4	<4	<4	<4	<4	4	4
Zr	43	10	24	22	34	19	22	60
Nb	<4	<4	<4	<4	<4	<4	<4	<4
Y	16	15	10	15	12	10	20	12
La	<10	<10	<10	<10	22	<10	10	<10
Ce	24	10	<10	20	10	20	10	20
V	335		280		230			200
Cr		40	350			55		10
Co	43	28	<5	25	43	20	50	<5
Ni	22	18	58	38	64	30	25	6
Cu	175	130	110	110	118	115	90	28
Zn	115	65	106	55	106	45	90	62

Table A3: GINGERA BATHOLITH

Sample no.	71840319	71840538	72840024	72840026	72840048	72840050	72840087	72840088	72840089	72840090
Formation	Half Moon Pk.Adam.	minor int. S-Type	McLaughlin Granodr.	McLaughlin Granodr.	Half Moon Pk.Adam.	Half Moon Pk.Adam.	McKeahnie Adamellite	Unnamed intrusion	Unnamed intrusion	Unnamed intrusion
Rock Type	biotite adamellite	qtz.plag. porphyry	biotite granodr.	biotite granodr.	biotite adamellite	biotite adamellite	biotite adamellite	leuco-granite	leuco-granite	qtz.plag. porphyry
Grid reference	591388	580518	597219	519257	612437	619447	611614	630651	645542	641559
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	69.70	69.40	68.70	68.50	72.30	72.90	71.80	76.70	76.60	70.70
TiO_2	0.68	0.55	0.66	0.70	0.40	0.42	0.42	0.06	0.06	0.53
Al_2O_3	14.40	14.10	13.90	14.00	13.60	13.10	14.00	13.10	13.50	13.90
Fe_2O_3	0.67	0.65	0.48	0.64	0.62	0.71	0.41	0.17	0.21	0.67
FeO	3.55	3.60	3.85	3.90	2.15	2.50	2.60	0.50	0.36	2.60
MnO	0.07	0.05	0.05	0.07	0.05	0.05	0.06	0.02	0.01	0.04
MgO	1.79	1.46	2.55	2.35	1.08	1.16	1.38	0.17	0.13	1.27
CaO	1.89	1.51	3.35	3.25	2.25	2.05	1.75	0.68	0.82	2.30
Na_2O	2.25	2.25	3.05	2.70	2.55	2.50	2.45	2.95	2.90	2.50
K_2O	3.40	4.15	1.48	2.00	4.05	3.65	4.10	4.65	4.65	3.95
P_2O_5	0.14	0.19	0.13	0.14	0.11	0.12	0.12	0.12	0.12	0.11
H_2O+	0.69	1.57	1.71	1.68	0.72	0.61	0.83	0.71	0.23	0.91
H_2O-	0.33	0.11	0.17	0.14	0.16	0.17	0.03	0.05	0.05	0.05
CO_2	0.15	0.40	0.05	<0.05	0.05	0.05	0.05	0.10	0.05	0.05
TOTAL	99.71	99.99	100.13	100.07	100.09	99.99	100.00	99.98	99.69	99.58
Ba	700	840	340	420	560	510	520	60	45	700
Rb	175	160	75	80	195	185	215	340	320	195
Sr	145	160	220	180	120	115	110	26	22	130
Pb	34	10	150	40	36	40	135	42	50	155
Th	16	18	14	14	16	12	14	4	4	12
U	4	6	4	4	4	4	4	8	10	6
Zr	160	190	160	190	115	130	120	38	36	170
Nb	10	6	<4	4	<4	<4	<4	10	<4	<4
Y	35	36	30	30	40	30	32	10	30	45
La	60	30	60	30	40	40	40	<10	<10	50
Ce	70	90	70	70	60	70	40	<10	<10	90
V		75		95					10	
Cr		70	60	12	45	45	48	48	28	35
Co	12	15	15	12	5	8	5	<5	<5	10
Ni	25	[illegible]	28	25	8	8	12	<5	<5	12
Cu	15	18	2	18	5	5	8	5	8	5
Zn	60	45	40	50	38	40	45	5	8	35

Table A3: GINGERA BATHOLITH (cont.)

Sample no.	72840092	72840093	72840094	72840095	72840096	72840286	73840024	73840474	74840078
Formation	Ginini Leucoadam.	Ginini Leucoadam.	Bimberi Leucogran.	McKeahine Adamellite	McKeahnie Adamellite	McLaughlin Granodr.	Bendora Granodr.	McLauglin Granodr.	Bendora Granodr.
Rock Type	leuco-granite	leuco-adamellite	leuco-granite	biotite adamellite	biotite adamellite	biotite granodr.	biotite granodr.	biotite granodr.	granodr. porphyry
Grid reference	619653	624617	620522	612579	605553	576145	649791	552167	620788
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Berridale	Brind.	Tantangara	Brind.
SiO_2	75.40	72.90	75.60	71.30	71.00	67.80	70.44	67.98	70.07
TiO_2	0.16	0.29	0.13	0.53	0.53	0.67	0.50	0.58	0.53
Al_2O_3	13.30	13.70	13.60	14.00	13.90	14.70	14.29	14.42	14.53
Fe_2O_3	0.23	0.54	0.32	0.56	0.56	0.45	0.46	0.47	0.23
FeO	1.15	1.75	0.79	2.55	3.05	4.20	3.33	3.95	3.18
MnO	0.05	0.05	0.06	0.06	0.06	0.07	0.06	0.07	0.04
MgO	0.47	0.85	0.19	1.28	1.50	2.10	1.44	2.13	1.53
CaO	0.95	1.68	0.50	2.00	2.30	2.75	1.84	2.54	2.62
Na_2O	2.60	2.70	2.75	2.05	2.30	2.15	3.14	2.15	2.32
K_2O	4.65	4.05	4.75	4.30	3.45	3.60	2.71	3.35	3.60
P_2O_5	0.11	0.12	0.13	0.12	0.12	0.14	0.12	0.14	0.06
H_2O+	0.85	0.96	0.65	0.90	0.96	1.03	1.05	1.14	0.82
H_2O-	0.09	0.02	0.09	0.08	0.06	0.17	0.11	0.10	0.08
CO_2	<0.05	0.05	0.05	0.05	<0.05	0.05	0.10	0.05	<0.05
TOTAL	100.01	99.66	99.61	99.78	99.79	99.88	99.59	99.07	99.61
Ba	200	362	100	493	518	620	400	460	900
Rb	290	299	355	216	180	180	140	150	160
Sr	50	91	30	109	130	135	110	120	190
Pb	38	25	50	28	36	65	24	16	12
Th	8	12	<4	13	13	20	20	16	22
U	<4	5	4	<4	4	<4	18	4	4
Zr	55	113	32	148	171	145	190	200	200
Nb	<4	<4	<4	<4	4	10	5	<4	4
Y	20	25	10	26	32	30	35	30	30
La	20	45	<10	54	36	60	30	40	70
Ce	20	38	10	50	65	70	70	70	80
V		45		60	75		123	108	120
Cr	45		55		10	25	40	65	50
Co	<5	11	<5	8	12	15	8	8	8
Ni	<5	2	<2	10	11	25	20	28	4
Cu	2	7	2	23	15	20	20	24	10
Zn	20	40	30	61	68	70	63	55	37

Table A4: KOSCIUSKO AND YOUNG BATHOLITHS

Sample no.	71840175	71840202	71840203	71840235	71840380	71840429	73840147	73840150	73840286	73840368
Formation	Gang Gang Adamellite	Lucas Ck. Granite	Gang Gang Adamellite	Lucas Ck. Granite	SpicersCk. Adamellite	minor int. S-Type	Gang Gang Adamellite	Gang Gang Adamellite	Brok.Cart Granodr.	Brok.Cart Granodr.
Rock Type	sodic leucogran.	leuco-granite	leuco-granite	biotite adamellite	biotite adamellite	qtz. plag. porphyry	biotite adamellite	biotite adamellite	biotite granodr.	biotite granodr.
Grid reference	438227	468217	461247	458176	382527	436431	410188	381168	419860	413917
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Brind.	Brind.
SiO_2	78.20	74.00	76.31	71.40	69.00	67.00	75.23	75.42	69.61	68.81
TiO_2	0.04	0.19	0.02	0.48	0.72	0.68	0.10	0.07	0.56	0.52
Al_2O_3	13.20	13.90	12.96	14.00	13.80	14.50	13.06	13.31	14.15	14.37
Fe_2O_3	0.35	0.55	0.54	0.36	0.77	0.50	0.19	0.31	0.72	0.15
FeO	0.37	1.39	0.55	2.80	3.60	4.05	0.95	0.93	3.42	3.75
MnO	0.01	0.05	0.05	0.05	0.13	0.08	0.02	0.04	0.06	0.06
MgO	0.14	0.64	0.07	1.17	1.47	2.10	0.33	0.24	1.37	1.66
CaO	0.18	0.98	0.18	1.76	2.60	2.10	1.29	0.88	2.67	2.34
Na_2O	5.80	2.90	3.30	2.45	2.75	2.60	3.53	3.50	2.80	2.42
K_2O	0.83	4.70	4.56	3.95	3.10	3.85	4.04	3.98	3.27	3.37
P_2O_5	0.05	0.11	0.07	0.12	0.07	0.13	0.03	0.05	0.11	0.11
H_2O+	0.39	0.46	0.75	0.82	1.52	1.94	0.33	0.52	0.81	1.07
H_2O-	0.29	0.22	0.03	0.28	0.28	0.09	0.07	0.08	0.03	0.03
CO_2	0.15	0.10	0.20	0.05	0.12	0.05	<0.05	0.05	0.05	0.05
TOTAL	100.00	100.19	99.59	99.69	99.93	99.67	99.17	99.38	99.63	98.71
Ba	140	350	180	530	620	560	520	500	560	520
Rb	34	250	275	205	155	160	170	180	140	160
Sr	160	65	38	105	155	160	100	95	140	135
Pb	6	160	24	140	20	22	24	30	18	18
Th	8	12	8	14	12	20	12	14	16	16
U	4	4	6	<4	<4	6	8	6	<4	<4
Zr	55	90	40	150	170	210	70	60	180	220
Nb	<10	<4	<4	<4	<4	12		4	<4	5
Y	30	50	30	30	30	32	30	30	30	40
La	20	20	<10	40	50	30	40	40	30	20
Ce	30	40	10	60	70	100	50	30	60	70
V			5			110			100	93
Cr	<5		<5			15			35	50
Co	<5	<5	<5	8	10	15	<5	<5	14	10
Ni	<5	5	10	12	15	20	6	4	8	20
Cu	2	2	8	15	18	15	4	8	14	36
Zn	5	25	58	55	55	70	32	30	47	47

Table A5: KELLYS PLAIN VOLCANICS

Sample no.	71840245	71840247	71840250	71840257	71840258	71840440	71840449	71840450	72840086	75840283
Rock Type	albitised dacite	albitised dacite	K-metasom dacite	albitised dacite	albitised dacite	dacite porphyry	dacite tuff	albitised dacite	albitised dacite	cordierite dacite
Grid reference	470363	470354	474359	478410	481402	567545	508515	571550	489366	500431
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	75.08	74.90	79.20	69.60	73.70	70.60	69.30	72.20	67.70	68.76
TiO_2	0.39	0.45	0.25	0.35	0.30	0.64	0.66	0.46	0.63	0.65
Al_2O_3	12.27	12.50	10.30	14.08	14.20	14.40	13.90	12.90	14.10	14.34
Fe_2O_3	1.09	1.03	0.81	1.09	0.31	0.80	0.75	0.65	0.57	0.69
FeO	1.40	1.43	0.59	2.20	1.61	2.35	4.30	2.60	3.70	3.75
MnO	0.05	0.05	0.01	0.04	0.02	0.06	0.08	0.05	0.07	0.05
MgO	1.11	1.13	0.30	1.92	1.09	1.27	2.30	1.05	2.55	1.82
CaO	0.16	0.14	0.12	0.80	0.14	1.40	2.60	1.55	0.51	2.38
Na_2O	3.50	3.60	0.77	4.20	6.55	1.56	2.85	2.80	2.65	2.10
K_2O	3.13	3.15	6.10	3.17	0.36	5.30	1.60	3.55	4.85	3.44
P_2O_5	0.09	0.09	0.06	0.07	0.07	0.14	0.12	0.12	0.13	0.13
H_2O+	1.46	1.12	0.78	1.57	0.90	1.20	1.18	1.17	2.35	1.07
H_2O-	0.10	0.44	0.48	0.15	0.84	0.20	0.16	0.49	0.14	0.17
CO_2	<0.05	0.18	0.13	0.13	0.12	0.25	0.10	0.10	0.15	0.10
TOTAL	99.83	100.21	99.90	99.37	100.21	100.17	99.90	99.69	100.10	99.45
Ba	600	480	1400	620	520	730	390	640	750	640
Rb	95	90	205	98	26	280	90	140	200	160
Sr	55	60	34	144	54	130	210	140	85	130
Pb	26	30	10	200	90	24	20	28	70	30
Th	20	16	10	12	12	12	16	12	12	18
U	4	4	4	<4	<4	4	<4	<4	4	4
Zr	200	200	105	120	110	170	190	145	170	200
Nb	<4	<5	<4	<4	10	<4	<4	<4	10	<4
Y	34	34	25	17	20	30	30	30	30	30
La	30	<10	30	36	40	50	40	40	50	20
Ce	50	50	30	52	50	60	70	70	80	80
V	65	40		80						80
Cr	90		42						45	50
Co	8	10	<5	11	<5	12	15	5	10	<2
Ni	14	10	<5	21	5	20	18	15	20	10
Cu	8	5	5	16	2	25	18	25	20	18
Zn	55	35	15	55	30	45	75	48	100	79

Table A6: GOOBARRAGANDRA VOLCANICS

Sample no.	71840378	71840382	71840527	71840528	71840532	71840549	71840557	71840560	71840563	72840120
Rock Type	dacite porphyry	albitised dacite	albitized dacite	dacite porphyry	dacite porphyry	albitised rhyolite	albitised dacite	albitised dacite	albitised dacite	dacite
Grid reference	374528	405535	349506	412547	469640	371459	372467	363477	355489	375895
1:100 000 sheet	Tantangara	Tantangara	Yarrangob.	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Yarrangob.	Brind.
SiO_2	70.10	69.00	69.70	67.60	70.80	74.72	69.61	69.67	70.74	69.30
TiO_2	0.68	0.66	0.57	0.72	0.42	0.25	0.58	0.50	0.46	0.60
Al_2O_3	13.60	14.00	12.80	14.10	13.80	12.23	13.35	13.61	12.29	14.00
Fe_2O_3	0.79	0.75	1.50	1.00	0.65	0.69	0.69	0.37	0.60	0.95
FeO	3.15	3.70	2.65	4.05	2.85	1.45	3.30	3.20	3.45	3.20
MnO	0.12	0.07	0.09	0.07	0.10	0.03	0.06	0.06	0.04	0.07
MgO	1.45	2.20	1.08	2.25	1.26	1.09	1.55	1.36	0.99	1.75
CaO	2.25	1.62	1.57	2.15	1.86	1.37	1.89	0.78	0.75	2.95
Na_2O	2.80	3.25	4.25	2.90	2.55	2.90	2.83	3.55	2.98	2.60
K_2O	3.05	2.45	2.65	2.30	3.00	2.66	3.48	4.41	5.39	2.85
P_2O_5	0.07	0.13	0.11	0.14	0.10	0.02	0.11	0.11	0.10	0.12
H_2O+	1.18	1.96	1.52	2.00	1.52	1.57	1.79	1.47	1.56	1.29
H_2O-	0.34	0.14	0.22	0.30	0.24	0.01	0.01	0.01	0.10	0.11
CO_2	0.20	0.10	1.10	0.05	0.55	0.65	0.15	0.10	0.45	0.10
TOTAL	99.78	100.03	99.81	99.63	99.70	99.64	99.40	99.20	99.90	99.89
Ba	700	555	800	580	690	520	740	860	840	580
Rb	100	102	125	85	90	135	155	140	195	150
Sr	175	152	130	200	215	240	220	90	60	155
Pb	10	31	8	18	18	12	16	18	20	75
Th	12	15	10	14	8	18	18	14	16	16
U	<4	<4	4	<4	<4	6	4	4	4	<4
Zr	170	206	180	170	160	220	290	180	180	155
Nb	<4	<4	<4	<4	<4	<4	<4	<4	10	<4
Y	30	29	28	30	30	165	34	44	28	30
La	40	51	50	50	40	90	70	40	30	50
Ce	60	73	60	70	70	60	90	70	60	60
V		90	103			35	140	108	135	
Cr										42
Co	5	16	12	12	5	<5	10	8	4	12
Ni	8	24	30	25	8	14	26	28	32	15
Cu	2	20	8	22	15	14	16	14	12	8
Zn	20	91	84	65	48	48	60	71	100	55

Table A6: GOOBARRAGANDRA VOLCANICS (cont.)

Sample no.	73840369	73840370	73840371	73840372	73840375
Rock Type	porph. dacite	cordierite dacite	opx. dacite	albitised dacite	porph. dacite
Grid reference	496970	517966	512994	529032	397217
1:100 000 sheet	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	68.28	69.62	66.18	70.53	71.72
TiO_2	0.58	0.53	0.78	0.54	0.43
Al_2O_3	14.03	14.14	13.99	13.46	13.88
Fe_2O_3	0.83	0.47	0.59	0.61	0.48
FeO	3.44	3.44	5.05	3.42	2.77
MnO	0.07	0.06	0.10	0.06	0.02
MgO	1.43	1.03	1.97	2.00	1.13
CaO	3.05	2.52	3.62	0.48	2.57
Na_2O	3.00	2.50	2.86	2.10	2.56
K_2O	2.74	3.35	1.91	5.05	3.53
P_2O_5	0.12	0.12	0.15	0.12	0.09
H_2O+	1.53	1.38	1.63	1.44	0.49
H_2O-	0.05	0.08	0.11	0.10	0.07
CO_2	0.05	<0.05	0.05	0.15	0.01
TOTAL	99.20	99.24	98.99	100.06	99.75
Ba	480	520	600	740	520
Rb	115	125	50	210	130
Sr	150	150	180	65	125
Pb	14	20	10	14	20
Th	14	14	8	12	14
U	4	4	<4	4	6
Zr	200	200	210	170	180
Nb	<4	<4	5	<4	<4
Y	30	30	30	30	30
La	20	30	30	40	30
Ce	50	70	60	70	70
V	113	100	155	98	93
Cr	35	35	40	30	35
Co	12	10	12	8	10
Ni	13	15	20	13	10
Cu	24	20	24	20	18
Zn	84	67	73	56	69

Table A7: WALKER VOLCANICS

Sample no.	73840491	73840487	73840488	73840489	73840490	74840031	74840042	74840043	74840044	74840068
Rock Type	altered dacite	albitised dacite	altered dacite	altered dacite	altered dacite	albitised dacite	albitised dacite	albitised andesite	albitised dacite	dacite
Grid reference	805973	810970	804973	809971	805973	762897	774932	772939	766950	767993
1:100 000 sheet	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	66.80	67.78	68.42	67.84	65.86	69.53	68.74	67.30	68.83	67.10
TiO_2	0.55	0.54	0.51	0.55	0.62	0.54	0.55	0.61	0.54	0.57
Al_2O_3	13.68	13.95	12.86	14.10	14.37	13.79	13.80	14.43	13.61	14.53
Fe_2O_3	3.32	2.12	2.58	0.87	3.62	0.59	1.81	1.23	2.36	1.36
FeO	1.63	2.08	3.73	4.06	1.63	3.35	2.18	3.78	1.36	2.68
MnO	0.09	<0.01	0.09	<0.01	0.08	0.06	0.08	0.08	0.08	0.07
MgO	1.46	1.70	1.63	1.92	1.70	2.08	1.92	2.40	1.75	2.21
CaO	1.83	1.73	0.41	0.32	1.44	0.29	1.24	0.40	1.67	2.24
Na_2O	1.38	2.33	0.72	1.27	1.22	2.66	2.34	5.45	2.58	2.17
K_2O	5.88	3.55	5.46	6.43	6.46	4.50	4.57	1.31	3.93	3.73
P_2O_5	0.12	0.11	0.11	0.14	0.13	0.12	0.14	0.18	0.13	0.07
H_2O+	2.07	2.53	2.22	2.17	2.02	1.58	1.68	2.51	2.18	2.14
H_2O-	0.15	0.33	0.26	0.19	0.22	0.06	0.18	0.17	0.12	0.20
CO_2	1.05	0.90	0.05	0.05	0.55	<0.05	0.25	<0.05	0.40	0.35
TOTAL	100.01	99.65	99.05	99.91	99.92	99.15	99.48	99.85	99.57	99.42
Ba	1310	450	1180	1020	1330	1000	620	230	620	780
Rb	280	250	240	230	310	150	220	44	200	180
Sr	50	95	40	45	60	110	100	60	120	130
Pb	1150	105	6	10	14	20	34	3	22	20
Th	18	16	16	16	12	18	20	14	16	16
U	4	4	6	6	4	6	4	4	4	4
Zr	190	180	160	180	170	190	185	270	210	175
Nb	10	<4	<4	5	10	<4	4	4	4	4
Y	25	30	30	30	30	30	30	40	35	25
La	30	40	40	40	40	70	50	40	60	50
Ce	70	70	60	60	70	70	80	90	80	80
V	150	130	110	140	150	130	85		85	135
Cr	85	65	60	50	55	45	65	55	45	60
Co	6	6	8	8	6	<5	10	10	6	4
Ni	18	20	15	20	18	16	16	12	20	22
Cu	12	14	8	6	6	10	42	8	20	24
Zn	58	56	55	53	50	56	82	140	78	67

Table A8: WALKER VOLCANICS AND PADDYS RIVER VOLCANICS

Sample no.	74840071	75360003	74840029	74840030	74840034	74840037	74840051	74840074
Formation	Walker Volcanics	Walker Volcanics	Paddys R. Volcanics	Paddys R. Volcanics	Paddys R. Volcanics	Paddys R. Volcanics	Paddys R. Volcanics	Paddys R. Volcanics
Rock Type	dacite	albitized dacite	albitised dacite	albitised dacite	albitised dacite	albitised dacite	altered dacite	albitised dacite
Grid reference	760967	840942	764884	764884	778851	777858	714973	694878
1:100 000 sheet	Brind.	Canberra	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	66.77	68.16	67.83	68.03	68.33	65.03	68.52	69.68
TiO_2	0.55	0.54	0.58	0.60	0.65	0.57	0.52	0.50
Al_2O_3	14.80	14.11	14.26	14.33	14.52	14.90	14.06	13.48
Fe_2O_3	0.56	2.59	0.87	0.81	2.09	1.26	0.62	1.85
FeO	3.29	1.65	3.53	3.27	2.12	3.79	2.86	2.38
MnO	0.06	0.05	0.06	0.06	0.05	0.10	0.08	0.06
MgO	1.83	1.49	2.36	2.28	1.72	4.01	1.78	1.42
CaO	1.94	1.37	1.62	1.59	1.32	2.59	0.99	1.82
Na_2O	2.30	2.65	3.38	3.61	2.90	4.17	2.00	3.17
K_2O	4.66	4.38	2.48	2.72	4.63	1.11	5.22	3.64
P_2O_5	0.06	0.13	0.12	0.16	0.12	0.10	0.11	0.17
H_2O+	2.07	1.85	2.03	1.97	0.80	2.00	1.97	0.83
H_2O-	0.13	0.23	0.05	0.05	0.04	0.08	0.11	0.01
CO_2	0.35	0.65	0.05	<0.05	<0.05	<0.05	0.50	<0.05
TOTAL	99.37	99.85	99.22	99.48	99.29	99.71	99.34	99.01
Ba	740	620	460	500	980	500	820	900
Rb	180	240	100	100	170	38	230	130
Sr	180	80	150	140	140	260	50	190
Pb	44	18	16	20	16	14	10	16
Th	16	18	16	16	16	10	18	18
U	<4	4	4	6	6	4	6	4
Zr	180	190	185	180	185	150	195	175
Nb	4	<4	4	4	4	4	4	<4
Y	25	30	30	30	25	20	30	30
La	50	60	50	50	60	40	10	60
Ce	80	100	90	90	90	70	70	70
V	115	110	120	120	100	160	120	120
Cr	60	50	90	55	60	100	60	60
Co	10	6	10	<5	<5	20	8	<5
Ni	30	10	32	38	28	46	18	28
Cu	24	6	125	26	46	14	6	24
Zn	94	72	66	62	205	80	77	71

Table A9: JINDABYNE AND COODRAVALE I-TYPE GRANITOID SUITES

Sample no.	71840318	72840044	72840045	72840046	73840053	73840347	77840068
Formation	Starv.Pt. Adamellite	Bugtown Tonalite	Bugtown Tonalite	Bugtown Tonalite	Condor Granodr.	Coodravale Granodr.	Ashvale 'tonalite'
Rock Type	hornblende adamellite	hornblende tonalite	hornblende granodr.	hornblende tonalite	augite tonalite	hornblende granodr.	tonalite
Grid reference	391532	553236	539201	533180	669903	499115	689168
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Brind.	Brind.	Tantangara
SiO_2	71.70	65.10	67.00	62.00	63.27	73.61	60.88
TiO_2	0.45	0.48	0.46	0.61	0.50	0.28	0.48
Al_2O_3	13.40	16.40	15.20	16.60	16.40	13.18	17.26
Fe_2O_3	0.89	1.22	1.43	1.86	1.97	0.86	1.70
FeO	2.65	3.05	2.70	3.65	3.05	1.85	3.98
MnO	0.08	0.09	0.09	0.11	0.09	0.05	0.12
MgO	0.45	1.96	1.76	2.65	2.47	0.55	2.50
CaO	1.62	5.05	4.65	6.00	5.48	2.28	6.36
Na_2O	4.20	2.95	2.95	2.85	3.18	3.76	2.60
K_2O	2.85	2.15	2.25	1.51	1.47	2.44	1.44
P_2O_5	0.07	0.10	0.08	0.10	0.11	0.04	0.15
H_2O+	0.73	0.97	1.01	1.52	1.53	0.75	1.48
H_2O-	0.41	0.15	0.15	0.16	0.01	0.05	0.04
CO_2	0.08	<0.05	<0.05	<0.05	0.10	0.10	0.05
TOTAL	99.58	99.67	99.73	99.62	99.63	99.80	99.04
Ba	530	400	380	340	320	460	330
Rb	125	85	100	70	50	80	60
Sr	90	240	195	240	230	140	290
Pb	20	135	95	50	8	8	80
Th	16	10	16	6	10	8	4
U	<4	<4	<4	<4	<4	4	<4
Zr	200	90	100	95	130	190	85
Nb	<4	<4	<4	<4	5	<4	<4
Y	65	20	25	20	20	30	18
La	60	30	40	20	40	30	<10
Ce	60	50	60	40	60	60	40
V					150	35	
Cr		35	35	28	40	15	
Co	<5	10	8	12	6	4	10
Ni	12	8	8	8	18	5	8
Cu	20	5	5	5	32	20	8
Zn	42	48	42	48	53	25	42

Table A10: LAIDLAW VOLCANICS

Sample no.	73840436	73840438	73840446	73840449	73840455	73840457	73840458	73840460	73840463	73840464
Rock Type	rhyodacite	rhyodacite	rhyodacite	rhyodacite	rhyodacite	rhyodacite	albitised rhyolite	rhyodacite	rhyodacite	rhyodacite
Grid reference	759104	773123	739214	803221	783105	780130	822120	814153	802187	785160
1:100 000 sheet	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	67.98	69.63	69.88	67.80	70.42	69.33	74.92	66.80	67.98	67.91
TiO_2	0.51	0.46	0.41	0.50	0.41	0.46	0.16	0.53	0.47	0.49
Al_2O_3	14.94	14.67	14.04	15.18	14.32	14.43	12.92	15.40	14.99	14.81
Fe_2O_3	1.39	1.53	1.05	1.25	1.06	1.32	0.89	1.44	1.11	1.19
FeO	2.35	1.98	2.14	2.44	2.14	2.11	0.81	2.40	2.44	2.46
MnO	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
MgO	1.43	1.30	1.27	1.37	1.19	1.23	0.55	1.49	1.51	1.73
CaO	3.81	3.05	3.10	3.70	3.49	3.66	0.83	4.13	3.65	2.77
Na_2O	2.48	2.52	2.66	2.86	2.48	2.54	2.82	2.64	2.56	2.92
K_2O	2.85	3.29	3.16	2.97	3.01	3.03	5.09	2.94	3.03	3.20
P_2O_5	0.11	0.10	0.08	0.10	0.09	0.10	0.04	0.11	0.11	0.10
H_2O+	1.26	1.41	1.22	1.54	1.09	1.35	0.78	1.13	1.27	1.45
H_2O-	0.16	0.09	0.10	0.10	0.11	0.11	0.18	0.11	0.11	0.17
CO_2	<0.05	0.10	0.05	0.05	<0.05	<0.05	0.05	0.05	0.05	0.05
TOTAL	99.31	100.17	99.21	99.91	99.86	99.72	100.09	99.23	99.34	99.31
Ba	600	660	640	620	560	600	400	620	620	620
Rb	110	125	120	120	120	130	230	120	120	120
Sr	195	185	180	220	190	190	85	210	200	200
Pb	14	14	22	18	20	18	24	14	18	26
Th	14	14	14	16	14	16	18	10	14	14
U	<4	<4	4	6	4	<4	4	4	4	4
Zr	200	200	180	210	170	180	95	200	200	200
Nb	<4	5	5	5	5	5	<4	5	5	5
Y	25	30	25	25	25	25	80	25	25	30
La	40	60	50	50	40	40	60	50	40	50
Ce	70	80	80	80	90	90	90	80	80	70
V	83	80	85	100	85	98	40	113	98	100
Cr	30	30	30	30	20	20	10	25	25	20
Co	10	18	4	<5	10	14	4	4	<5	10
Ni	10	13	13	18	13	18	15	15	15	18
Cu	18	20	24	22	20	22	14	22	22	20
Zn	59	45	50	74	46	56	30	63	46	53

Table A10: LAIDLAW VOLCANICS (cont.)

Sample no.	73840465	73840470	74950009	74950027	74840076	75840001	75840002	75840004	75840005	75840006
Rock Type	rhyodacite	albitised rhyodacite	rhyodacite	rhyodacite	rhyodacite	rhyodacite	dacite	dacite	albitised dacite	dacite
Grid reference	738111	724107	Tugg.Tun.	Tugg.Tun.	784883	867805	867805	866827	865832	865837
1:100 000 sheet	Brind.	Brind.	Canberra	Canberra	Brind.	Canberra	Canberra	Canberra	Canberra	Canberra
SiO_2	68.09	68.61	72.44	73.96	69.75	68.60	69.62	70.10	70.70	71.17
TiO_2	0.52	0.48	0.27	0.27	0.42	0.51	0.48	0.46	0.46	0.42
Al_2O_3	15.05	14.61	13.32	12.88	14.99	14.42	13.44	14.01	12.80	14.20
Fe_2O_3	1.41	1.21	1.09	0.73	0.98	0.77	0.56	0.64	0.19	0.49
FeO	2.46	2.29	1.10	1.10	1.93	2.70	2.75	2.50	2.70	2.30
MnO	0.06	0.06	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
MgO	1.57	1.72	1.22	1.16	1.31	1.53	1.52	1.28	1.37	1.08
CaO	2.96	1.15	1.75	1.55	3.83	3.11	3.43	3.88	2.06	3.44
Na_2O	3.02	4.18	2.92	2.23	2.38	2.79	2.40	2.24	3.50	2.56
K_2O	3.27	3.48	3.32	4.01	3.06	2.86	2.78	2.81	2.44	3.07
P_2O_5	0.11	0.09	0.05	0.05	0.04	0.14	0.10	0.10	0.09	0.09
H_2O+	1.53	1.42	1.33	1.32	0.94	1.68	1.11	0.57	1.70	1.02
H_2O-	0.19	0.22	0.11	0.10	0.04	0.12	0.09	0.05	0.32	0.02
CO_2	0.05	0.10	0.05	0.25	0.05	0.35	0.30	0.30	0.90	0.05
TOTAL	100.29	99.62	98.99	99.63	99.77	99.63	98.63	98.99	99.28	99.96
Ba	620	580	520	640	700	700	680	680	540	740
Rb	130	110	125	150	120	130	125	115	110	140
Sr	190	155	175	130	210	190	200	210	110	200
Pb	16	10	24	14	30	40	500	50	26	32
Th	12	16	22	20	14	12	12	16	14	16
U	4	4	6	6	4	<4	4	6	<4	4
Zr	200	190	125	120	185	200	200	195	195	170
Nb	5	5	<4	<4	4	<4	<4	<4	10	<4
Y	25	25	36	28	20	25	20	30	20	25
La	50	30	190	70	40	50	50	70	50	60
Ce	80	80	280	100	90	100	90	120	110	120
V	100	100	65	70	85	140	120	140	100	100
Cr	25	25	10	15	30	30	25	30	25	25
Co	10	8	78	<5	2	2	<2	6	2	<2
Ni	15	18	4	12	12	10	16	10	6	6
Cu	20	14	4	3	14	24	24	18	20	18
Zn	66	43	40	33	132	50	59	57	64	58

Table A10: LAIDLAW VOLCANICS (cont.)

Sample no.	75840007	75840012	75840020	75360005	75360008
Rock Type	rhyodacite	rhyodacite	rhyodacite	rhyodacite	rhyodacite
Grid reference	864851	Tugg.Tun.	822027	851847	786086
1:100 000 sheet	Canberra	Canberra	Canberra	Canberra	Brind.
SiO_2	71.30	72.78	72.01	70.55	68.59
TiO_2	0.40	0.24	0.31	0.45	0.49
Al_2O_3	13.47	13.76	13.34	14.16	14.79
Fe_2O_3	0.73	0.33	0.85	2.00	1.35
FeO	2.15	1.50	1.48	1.55	2.15
MnO	0.05	0.05	0.03	0.05	0.06
MgO	1.03	0.74	0.95	1.16	1.33
CaO	3.20	1.67	2.17	3.68	3.88
Na_2O	2.52	2.98	2.79	2.50	2.42
K_2O	2.96	4.54	3.93	2.81	2.96
P_2O_5	0.12	0.06	0.12	0.10	0.12
H_2O+	0.83	0.94	1.04	0.92	1.40
H_2O-	0.05	0.04	0.04	0.06	0.04
CO_2	0.05	0.25	0.05	<0.05	0.05
TOTAL	98.86	99.88	99.11	99.99	99.63
Ba	660	620	680	720	740
Rb	130	185	155	135	140
Sr	190	170	170	200	210
Pb	42	40	46	22	65
Th	16	26	22	10	14
U	4	6	<4	4	<4
Zr	170	125	140	180	200
Nb	<4	<4	<4	10	<4
Y	25	30	25	20	20
La	90	60	70	60	60
Ce	130	110	130	100	110
V	85	35	35	80	100
Cr	25	15	20	30	25
Co	<2	<2	<2	8	10
Ni	6	10	12	12	10
Cu	20	14	24	10	12
Zn	61	45	35	59	51

Table All: GINNINDERRA PORPHYRY AND URIARRA VOLCANICS

Sample no.	73840434	73840435	74840041	74840069	74840070	74840072	74840075	74840077
Formation	Ginninder. Porphyry	Ginninder. Porphyry	Uriarra Volcanics	Uriarra Volcanics	Uriarra Volcanics	Uriarra Volcanics	Uriarra Volcanics	Uriarra Volcanics
Rock Type	albitised dacite	albitised dacite	albitised cryst. tuff	albitised cryst. tuff	albitised cryst. tuff	ashstone	albitised cryst. tuff	albitised cryst. tuff
Grid reference	752056	748040	751918	763993	763993	754950	754921	763993
1:100 000 sheet	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	67.97	67.92	69.27	68.17	71.10	74.63	68.66	72.91
TiO_2	0.49	0.47	0.45	0.40	0.31	0.26	0.41	0.29
Al_2O_3	15.00	14.85	14.31	15.52	14.33	13.24	14.73	13.54
Fe_2O_3	1.13	1.15	0.43	0.47	0.41	0.36	0.56	0.28
FeO	2.38	2.13	2.49	2.21	1.77	1.26	2.32	1.77
MnO	0.06	0.07	0.07	0.08	0.07	0.06	0.06	0.06
MgO	1.59	1.56	1.46	1.36	1.07	0.81	1.69	1.08
CaO	1.29	0.82	1.11	0.99	0.77	0.99	1.25	0.70
Na_2O	4.30	4.10	3.80	4.85	4.17	4.67	3.66	3.94
K_2O	3.77	4.24	4.37	3.77	4.08	2.67	4.13	3.76
P_2O_5	0.11	0.10	0.10	0.02	0.01	0.03	0.03	0.01
H_2O+	1.33	1.44	1.31	1.34	1.25	0.79	1.50	1.10
H_2O-	0.29	0.30	0.09	0.04	0.03	0.03	0.06	0.10
CO_2	0.10	0.15	0.25	0.15	0.10	0.05	0.60	0.10
TOTAL	99.81	99.30	99.51	99.37	99.47	99.85	99.66	99.64
Ba	620	720	1000	880	800	520	1100	800
Rb	140	155	160	150	180	110	150	160
Sr	125	135	170	140	150	190	140	140
Pb	16	<2	4	32	26	8	6	40
Th	14	12	18	18	16	26	18	16
U	4	6	4	6	4	6	4	4
Zr	210	210	190	185	180	150	195	175
Nb	5	5	4	4	4	<4	6	4
Y	30	30	25	25	30	35	25	25
La	40	50	50	60	60	60	40	50
Ce	80	80	90	70	80	100	90	80
V	65	75	85	70	50	50	85	70
Cr	30	30		50	30	45	15	20
Co	10	10	<5	<5	<5	<5	2	2
Ni	10	10	<4	2	10	4	8	<2
Cu	14	14	10	12	12	10	16	10
Zn	80	104	66	57	51	36	67	58

Table A12: BOGGY PLAIN ADAMELLITE

Sample no.	71840181	71840183	71840185	71840191	71840201	71840573	72840085	73840158	73840170	73840172
Rock Type	hornblende adamellite	pyx. granodr.	two pyx. gabbro	pyx. granodr.	hornblende adamellite	pyx. granodr.	hornblende adamellite	hornblende adamellite	hornblende adamellite	hornblende adamellite
Grid reference	438318	445324	426329	439291	384263	435292	387264	400255	386263	429315
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	66.60	61.00	52.40	60.80	65.70	62.90	66.80	70.35	65.55	69.59
TiO_2	0.49	0.61	0.80	0.61	0.52	0.69	0.54	0.34	0.54	0.38
Al_2O_3	14.60	14.60	16.90	14.70	14.90	14.80	14.30	13.74	14.57	13.73
Fe_2O_3	2.00	2.05	2.10	2.05	2.25	2.30	1.50	1.25	1.63	1.18
FeO	2.30	4.20	7.50	4.30	2.45	3.30	2.75	1.98	3.05	2.13
MnO	0.07	0.12	0.18	0.12	0.08	0.11	0.07	0.05	0.08	0.06
MgO	2.50	4.75	6.75	4.75	2.65	3.35	2.55	1.55	2.56	1.69
CaO	4.00	6.45	9.30	6.45	3.90	5.50	4.15	2.96	4.25	3.03
Na_2O	3.00	2.65	2.70	2.65	2.95	3.05	2.80	3.00	2.90	2.80
K_2O	3.30	2.50	0.72	2.55	3.45	2.50	3.25	3.85	3.53	4.06
P_2O_5	0.15	0.24	0.27	0.22	0.17	0.20	0.14	0.10	0.16	0.09
H_2O+	0.38	0.37	0.05	0.28	0.40	0.75	0.74	0.69	0.75	0.59
H_2O-	0.20	0.29	0.21	0.26	0.28	0.12	0.04	0.05	0.03	0.03
CO_2	0.10	0.12	0.15	0.10	0.10	0.10	0.10	0.05	0.10	0.05
TOTAL	99.69	99.95	100.03	99.84	99.80	99.67	99.73	99.96	99.70	99.41
Ba	820	800	380	720	960		1180	700	1030	760
Rb	130	85	18	90	120		133	145	125	145
Sr	450	760	745	680	450		463	310	440	320
Pb	20	25	30	35	30		28	10	10	12
Th	22	10	<4	10	22		11	22	14	24
U	6	6	<4	4	6		6	<4	4	4
Zr	190	150	24	140	190		178	130	180	150
Nb	4	4	<4	<4	4		<4	5	5	5
Y	28	18	15	18	28		24	25	20	20
La	40	20	10	20	60		45	40	40	70
Ce	90	100	20	80	80		74	60	70	60
V	115	195		185	130		115	98	145	100
Cr	18	25	48	35	38			60	90	55
Co	10	20	5	20	15		16	6	14	10
Ni	15	18	12	15	25		19	15	30	15
Cu	30	65	35	100	30		30	10	28	18
Zn	28	35	18	35	30		66	21	38	25

Table A12: BOGGY PLAIN ADAMELLITE (cont.)

Sample no.	73840174	73840480	73840481	73840482	73840483	73840484	73840485	73840486
Rock Type	pyx. granodr.	pyx. granodr.	pyx. granodr.	two pyx. qtz.gbro.	pyx. granodr.	hornblende adamellite	pyx. granodr.	hornblende adamellite
Grid reference	433320	438290	437293	426330	426324	429390	437323	430313
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	62.28	61.52	60.54	53.43	61.40	66.80	60.46	70.43
TiO_2	0.50	0.52	0.57	0.62	0.54	0.52	0.57	0.32
Al_2O_3	15.29	14.35	15.41	15.26	15.15	14.30	14.56	13.53
Fe_2O_3	2.17	1.75	2.52	2.40	2.16	1.78	1.98	1.30
FeO	3.62	4.06	3.65	6.98	3.80	2.64	4.06	1.60
MnO	0.10	0.11	0.12	0.17	0.12	0.08	0.12	0.06
MgO	3.31	4.24	3.75	7.20	3.55	2.55	3.98	1.50
CaO	5.95	6.49	6.06	9.87	6.05	4.12	6.07	2.63
Na_2O	3.00	2.80	3.12	2.35	3.16	2.92	3.00	2.90
K_2O	2.09	2.26	2.11	0.94	2.09	3.32	2.22	4.21
P_2O_5	0.17	0.20	0.02	0.16	0.21	0.14	0.20	0.08
H_2O+	0.79	0.75	0.82	0.44	0.72	0.66	0.85	0.79
H_2O-	0.03	0.09	0.12	0.08	<0.02	0.14	0.11	0.13
CO_2	0.05	<0.05	0.05	0.05	0.05	<0.05	0.05	0.05
TOTAL	99.35	99.14	98.86	99.95	99.00	99.97	98.23	99.53
Ba	540	830	740	410	820	1080	840	760
Rb	70	80	80	32	70	125	85	180
Sr	540	700	680	670	680	450	730	310
Pb	10	14	8	6	14	12	12	30
Th	4	6	8	<4	4	16	4	32
U	<4	<4	4	<4	<4	<4	<4	10
Zr	110	110	130	40	110	170	110	130
Nb	<4	5	10	<4	<4	5	<4	10
Y	15	20	20	15	20	25	20	20
La	20	30	30	<10	40	40	50	70
Ce	50	60	70	20	70	80	70	80
V	210	220	280	380	250	190	300	130
Cr	70				75	90		55
Co	18	16	14	30	10	6	18	6
Ni	25	23	15	50	15	20	20	13
Cu	46	52	120	76	38	18	48	12
Zn	48	45	51	65	56	31	61	29

Table A13: COOLAMINE IGNEOUS COMPLEX

Sample no.	71840304	71840329	71840358	71840360	71840363	71840433	71840446	71840447	71840448	71840455
Rock Type	two pyx. granodr.	two pyx. granodr.	uralite granodr.	two pyx. granodr.	quartz monzogbro	plag. pyx. porphyry	two pyx. granodr.	two pyx. granodr.	plag. pyx. porph.	two pyx. granodr.
Grid reference	547485	517518	532551	508518	540534	506582	504505	527530	527536	487577
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	60.40	59.50	62.50	56.40	57.70	63.60	55.80	60.00	59.20	61.60
TiO_2	0.65	0.79	1.06	0.70	0.83	1.07	0.70	0.74	0.74	0.80
Al_2O_3	14.00	13.90	15.70	13.30	14.40	15.40	13.60	14.50	14.40	15.00
Fe_2O_3	0.70	1.55	2.75	3.35	2.05	0.85	1.85	1.85	2.20	1.35
FeO	4.45	5.20	3.50	5.50	5.40	4.65	5.55	4.90	4.55	4.85
MnO	0.09	0.12	0.13	0.15	0.13	0.07	0.17	0.23	0.13	0.12
MgO	5.65	5.15	2.45	6.15	5.55	1.99	7.55	4.45	4.85	2.55
CaO	4.70	6.65	4.75	7.30	7.50	4.65	7.55	6.55	7.15	5.55
Na_2O	2.05	1.90	3.00	2.20	1.77	2.85	1.75	1.97	2.20	3.00
K_2O	3.30	2.30	2.95	2.10	1.89	3.15	2.05	2.45	2.15	2.95
P_2O_5	0.15	0.24	0.29	0.20	0.27	0.25	0.13	0.12	0.17	0.31
H_2O+	2.10	1.71	0.64	2.05	1.53	1.25	2.65	1.95	1.77	1.44
H_2O-	0.57	0.31	0.14	0.17	0.25	0.21	0.31	0.27	0.17	0.16
CO_2	0.85	0.85	0.25	0.20	0.82	0.10	0.10	0.10	0.10	<0.05
TOTAL	99.66	100.17	100.11	99.77	100.09	100.09	99.76	100.08	99.78	99.68
Ba	814	1028	780	580	900	800	620	920	620	998
Rb	131	72	110	70	82	141	85	120	85	113
Sr	359	540	600	360	550	600	425	420	436	603
Pb	14	24	25	140	14	16	12	18	9	15
Th	14	9	10	6	6	10	6	8	8	12
U	<4	<4	6	6	4	4	<4	<4	4	<4
Zr	160	141	160	120	100	191	100	120	137	151
Nb	<4	<4	6	<4	<4	<4	<4	<4	<4	<4
Y	21	20	28	24	30	32	20	25	23	26
La	49	39	20	<10	40	30	30	40	<10	38
Ce	69	63	90	60	60	82	40	60	40	72
V	80	200	105	290	340	100			195	150
Cr			28	28		65			50	48
Co	29	26	8	20	20	15	22	18	30	19
Ni	128	22	5	10	25	14	70	20	28	12
Cu	50	67	18	32	48	5	60	55	41	35
Zn	89	98	45	45	42	38	48	50	38	80

Table A13: COOLAMINE IGNEOUS COMPLEX (cont.)

Sample no.	71840456	71840457	71840458	71840459	71840460	71840461	71840463	71840464	71840471	71840472
Rock Type	contam. porphyry	two pyx. granodr.	quartz monzodr.	two pyx. adamellite	pyx. granodr.	uralite microdr.	quartz monzogbro.	pyx.qtz. diorite	quartz monzodr.	pyx.hbl. adamellite
Grid reference	488568	476562	477555	491571	491572	487576	482616	513618	490596	498605
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	70.30	54.50	56.30	64.40	60.60	55.20	57.30	61.20	54.50	62.40
TiO_2	0.56	0.94	0.99	0.98	0.84	0.74	0.70	0.56	0.93	0.79
Al_2O_3	13.90	15.20	15.30	14.70	15.70	15.50	17.70	15.30	15.70	15.30
Fe_2O_3	0.50	3.80	3.30	1.15	1.55	0.85	1.45	1.75	3.60	2.20
FeO	3.20	5.40	4.65	4.00	5.00	8.10	5.20	4.40	5.45	3.75
MnO	0.05	0.17	0.15	0.11	0.12	0.16	0.10	0.11	0.16	0.12
MgO	1.60	4.65	4.05	1.61	2.80	4.85	3.10	3.75	5.15	2.40
CaO	1.93	8.20	7.05	3.55	5.60	7.55	7.15	6.30	8.05	5.00
Na_2O	2.85	2.30	2.90	3.90	3.55	2.90	2.80	2.50	2.50	3.45
K_2O	3.55	1.80	2.30	3.55	2.70	0.90	2.00	2.05	1.77	3.05
P_2O_5	0.12	0.48	0.38	0.22	0.33	0.18	0.22	0.11	0.40	0.29
H_2O+	1.38	1.98	2.40	1.60	1.14	2.45	1.93	1.81	1.30	0.71
H_2O-	0.18	0.22	0.10	0.02	0.04	0.14	0.21	0.13	0.12	0.31
CO_2	0.07	0.12	0.10	0.20	0.15	0.55	0.20	<0.05	<0.05	<0.05
TOTAL	100.19	99.76	99.97	99.99	100.12	100.07	100.06	99.97	99.63	99.77
Ba	660	690	770	1020	951	400	772	525	650	970
Rb	120	75	90	125	99	34	50	104	70	125
Sr	175	600	595	555	613	575	614	297	650	525
Pb	28	16	14	16	7	4	5	12	8	20
Th	12	6	12	14	12	<4	4	9	6	10
U	<4	<4	4	<4	4	<4	<4	<4	4	<4
Zr	160	95	110	160	134	70	129	113	85	130
Nb	<4	<4	<4	10	<4	<4	<4	<4	<4	
Y	30	25	25	30	24	20	19	18	20	25
La	60	40	40	50	41	30	37	<10	30	40
Ce	70	50	50	90	69	30	50	49	50	40
V					150		140	175		240
Cr					30		50	42		
Co	8	22	20	8	14	22	26	20	18	8
Ni	15	30	32	10	23	8	20	20	32	8
Cu	12	65	85	15	41	30	78	53	70	32
Zn	45	50	75	60	81	50	94	99	45	45

Table A13: COOLAMINE IGNEOUS COMPLEX (cont.)

Sample no.	71840478	71840481	71840482	71840499	72840217	72840218	73840285
Rock Type	plag.pyx. porphyry	plag.pyx. porphyry	plag.pyx. porphyry	pyroxenite	quartz monzogbro.	hornblende adamellite	hbl.biot. gabbro
Grid reference	508582	520599	519604	503611	545674	545673	534668
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	63.70	62.60	61.50	50.80	49.80	65.30	48.22
TiO_2	1.23	0.52	0.63	0.37	1.76	0.95	1.09
Al_2O_3	15.30	16.10	16.20	10.40	15.30	15.60	17.81
Fe_2O_3	1.35	1.40	2.35	1.85	2.55	1.95	1.97
FeO	4.60	4.35	3.50	3.75	6.95	3.45	6.76
MnO	0.15	0.09	0.06	0.10	0.18	0.12	0.15
MgO	1.75	3.15	3.10	11.00	5.80	0.85	7.13
CaO	4.15	5.25	6.25	17.20	11.20	3.25	11.37
Na_2O	3.15	1.98	1.78	0.99	2.65	3.85	2.42
K_2O	3.05	2.35	1.59	1.34	1.00	3.39	0.49
P_2O_5	0.28	0.12	0.11	0.07	0.30	0.13	0.30
H_2O+	1.21	1.45	2.25	1.63	1.48	0.69	2.03
H_2O-	0.19	0.27	0.20	0.31	0.10	0.13	0.01
CO_2	<0.05	0.05	0.15	0.20	0.85	0.10	0.05
TOTAL	100.11	99.68	99.67	100.01	99.92	99.76	99.80
Ba	1026	588	352	420	430	1350	140
Rb	114	107	66	75	40	120	14
Sr	626	281	291	290	390	470	430
Pb	18	7	9	6	8	26	14
Th	11	6	10	<4	4	14	<4
U	4	5	5	4	<4	6	<4
Zr	190	120	124	24	95	660	100
Nb	<4	<4	<4	<4	<4	12	<4
Y	30	19	19	10	25	40	20
La	52	36	43	10	30	40	<10
Ce	94	49	53	10	60	70	30
V	60	140	185			10	260
Cr	50		50		15		
Co	11	20	18	5	15	5	38
Ni	2	13	12	48	28	5	90
Cu	6	30	13	30	55	12	74
Zn	90	88	69	12	25	80	80

Table A14: MINOR INTRUSIONS OF THE BOGGY PLAIN SUITE

Sample no.	71840411	71840412	71840414	71840416	71840418	71840517	73840146	73840169	76840065
Formation	minor int. B.P.Suite	minor int. B.P.Suite	Hell Hole Adamellite	minor int. B.P.Suite	minor int. B.P.Suite	minor int. B.P.Suite	minor int. B.P.Suite	minor int. B.P.Suite	minor int. B.P.Suite
Rock Type	two pyx. granodr.	hornblende adamellite	hornblende adamellite	two pyx. granodr.	two pyx. granodr.	pyx. granodr.	quartz monzodr.	two pyx. gabbro	quartz monzogbro.
Grid reference	436419	437422	450418	465497	456473	420524	410182	388288	347282
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Yarrangob.
SiO_2	60.70	65.20	63.80	56.80	58.60	60.40	54.88	48.06	56.11
TiO_2	0.72	0.60	0.63	0.83	0.78	0.54	0.73	0.53	0.75
Al_2O_3	15.10	14.90	14.90	15.00	15.70	14.20	16.15	13.71	13.79
Fe_2O_3	1.70	1.71	1.74	2.50	1.85	2.05	2.40	2.03	1.10
FeO	5.05	2.95	3.45	5.80	5.05	4.45	5.97	7.78	6.35
MnO	0.11	0.07	0.10	0.19	0.15	0.13	0.14	0.15	0.14
MgO	4.30	2.50	2.90	5.00	4.70	4.60	5.55	12.34	8.08
CaO	6.05	4.00	4.35	7.80	6.95	6.15	8.48	11.33	7.48
Na_2O	2.65	2.45	2.40	1.77	2.20	2.60	2.46	1.54	2.40
K_2O	2.50	3.50	3.25	1.71	2.40	2.55	1.67	1.02	2.16
P_2O_5	0.21	0.15	0.16	0.19	0.23	0.17	0.18	0.11	0.22
H_2O+	0.80	1.45	1.70	1.94	1.03	1.89	1.03	1.44	0.78
H_2O-	0.14	0.19	0.24	0.20	0.21	0.12	0.05	0.04	0.11
CO_2	<0.05	0.07	0.05	0.12	0.05	0.10	0.15	0.15	0.05
TOTAL	100.03	99.74	99.67	99.85	99.90	99.95	99.84	100.24	99.52
Ba	650	640	740	440	700	500	500	300	700
Rb	100	160	145	60	95	80	48	28	75
Sr	465	280	320	400	525	420	560	500	520
Pb	12	110	150	55	30	17	6	<2	85
Th	4	16	14	6	6	10	8	6	8
U	<4	4	<4	4	<4	4	4	<4	<4
Zr	105	190	150	130	105	120	80	30	120
Nb	<4	4	<4	<4	<4	<4	<4	<4	<4
Y	20	26	25	20	20	18	25	15	18
La	40	20	40	<10	30	20	20	<10	20
Ce	50	80	50	50	50	40	50	20	70
V		65		60		195	300	370	200
Cr		35		15		12	105		480
Co	15	12	12	20	12	28	30	48	<2
Ni	18	18	18	15	15	15	30	105	130
Cu	65	40	38	60	45	45	78	124	84
Zn	38	60	70	38	35	38	68	60	112

Table A15: HIGH-SILICA I-TYPE INTRUSIONS OF THE BOGGY PLAIN SUITE

Sample no.	71840327	71840328	71840356	71840357	71840359	71840365	71840465	71840544	72840145
Formation	Gurrangor. Granophyre	Gurrangor. Granophyre	Jackson Granite	Jackson Granite	Gurrangor. Granophyre	Jackson Granite	Jackson Granite	Jackson Granite	Jackson Granite
Rock Type	granophyre	granophyre	biotite adamellite	biotite adamellite	granophyre	biotite adamellite	pink granite	pink granite	biotite adamellite
Grid reference	484535	502524	539548	537550	549513	537553	539613	537609	552675
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	73.70	74.00	76.70	73.30	73.00	72.60	76.80	76.30	67.00
TiO_2	0.40	0.40	0.15	0.26	0.31	0.41	0.18	0.17	0.63
Al_2O_3	12.90	12.60	12.10	13.70	13.20	13.70	12.10	12.50	16.80
Fe_2O_3	0.66	0.83	0.85	0.95	1.85	1.16	0.80	0.65	0.38
FeO	1.10	0.96	0.44	0.81	0.84	0.93	0.45	0.60	2.35
MnO	0.05	0.06	0.06	0.05	0.26	0.08	0.03	0.04	0.08
MgO	0.26	0.26	0.16	0.45	0.25	0.42	0.15	0.19	0.80
CaO	0.86	0.81	0.29	1.29	0.23	1.29	0.47	0.57	2.95
Na_2O	3.10	3.35	3.35	3.50	3.25	3.45	3.45	3.55	3.55
K_2O	4.90	4.80	4.80	4.70	5.50	4.35	4.50	4.70	3.95
P_2O_5	0.03	0.03	0.02	0.05	0.04	0.06	0.01	0.02	0.11
H_2O+	0.59	0.58	0.01	0.43	0.69	0.35	0.34	0.38	0.82
H_2O-	0.31	0.32	0.37	0.29	0.27	0.37	0.36	0.24	0.06
CO_2	0.80	0.70	0.30	0.15	0.35	0.79	<0.05	0.05	0.05
TOTAL	99.66	99.70	99.60	99.93	100.04	99.96	99.64	99.96	99.53
Ba	1130	1110	300	1300	1000	1490	490	250	2670
Rb	195	205	280	185	180	180	195	260	132
Sr	150	160	65	260	160	280	120	70	641
Pb	24	32	38	40	290	32	22	18	44
Th	20	16	32	18	18	16	24	30	8
U	4	<4	8	4	6	4	4	4	4
Zr	230	230	130	155	280	170	100	120	330
Nb	<4	<4	8	<4	4	<4	10	10	6
Y	40	40	38	25	44	40	30	32	55
La	50	50	30	50	40	80	50	60	97
Ce	100	90	90	70	100	90	70	150	160
V			20		10			60	60
Cr			60		48				
Co	<5	<5	<5	5	<5	5	<5	<5	11
Ni	<5	<5	<5	5	<5	5	<5	<5	6
Cu	2	2	8	8	5	2	2	5	28
Zn	28	35	30	28	48	42	15	15	71

Table A15: HIGH-SILICA I-TYPE INTRUSIONS OF THE BOGGY PLAIN SUITE (cont.)

Sample no.	73840385	73840471	75840027
Formation	Burrinjuck Adamellite	Burrinjuck Adamellite	Eugowra Granite
Rock Type	biotite adamellite	biotite adamellite	biotite adamellite
Grid reference	418245	445254	
1:100 000 sheet	Brind.	Brind.	Parkes
SiO_2	71.28	74.09	73.22
TiO_2	0.43	0.27	0.30
Al_2O_3	14.38	13.08	13.47
Fe_2O_3	1.35	0.70	0.59
FeO	1.42	1.20	1.15
MnO	0.07	0.07	0.06
MgO	0.57	0.39	0.43
CaO	1.90	1.20	1.38
Na_2O	3.66	3.42	3.80
K_2O	4.31	4.66	4.00
P_2O_5	0.08	0.04	0.07
H_2O+	0.39	0.46	0.55
H_2O-	0.15	0.18	0.15
CO_2	<0.05	<0.05	0.05
TOTAL	99.99	99.76	99.22
Ba	1630	800	900
Rb	135	190	150
Sr	370	200	140
Pb	14	14	18
Th	12	16	16
U	6	6	4
Zr	280	160	200
Nb	5	5	4
Y	40	30	22
La	50	40	<10
Ce	100	60	60
V	50	28	
Cr	15	5	
Co	4	2	<2
Ni	10	10	<2
Cu	12	14	6
Zn	39	37	64

Table A16: MOUNTAIN CREEK VOLCANICS

Sample no.	71840361	71840468	71840469	71840479	71840531	72840084	72840144	72840146	72840214	72840215
Rock Type	plag. pyx. latite	granophyr. rhyolite	rhyolite ignimbrite	plag.pyx. latite	plag.pyx. latite	banded rhyolite	pyritic andesite	rhyolite lava	rhyolite porphyry	amphib. xenolith
Grid reference	512549	531622	529624	511579	573560	602919	545654	640903	675937	536622
1:100 000 sheet	Tantangara	Tantangara	Tantangara	Tantangara	Tantangara	Brind.	Tantangara	Brind.	Brind.	Tantangara
SiO_2	62.00	67.30	69.40	61.70	61.70	73.10	57.20	73.00	67.70	53.80
TiO_2	0.56	0.57	0.56	0.59	0.59	0.46	0.80	0.50	0.59	0.41
Al_2O_3	13.70	14.40	14.20	13.10	13.20	13.40	16.10	13.70	14.70	7.00
Fe_2O_3	1.25	1.80	1.35	1.90	1.45	0.79	1.18	1.32	0.85	1.50
FeO	4.55	2.15	2.05	4.15	4.50	1.25	6.00	0.84	2.40	4.70
MnO	0.11	0.08	0.08	0.09	0.09	0.07	0.12	0.07	0.03	0.38
MgO	5.50	1.86	0.82	5.65	5.35	0.24	4.80	0.30	1.70	12.70
CaO	5.35	3.60	2.30	4.85	5.40	1.50	6.50	0.52	0.65	15.30
Na_2O	2.00	3.25	2.65	1.99	1.40	3.30	2.10	3.05	0.16	1.47
K_2O	2.65	3.30	5.00	3.05	3.60	4.85	1.49	5.00	8.65	1.36
P_2O_5	0.13	0.12	0.10	0.12	0.13	0.05	0.12	0.05	0.12	0.09
H_2O+	1.99	1.32	0.90	2.20	1.85	0.66	1.73	0.99	1.80	0.57
H_2O-	0.15	0.14	0.16	0.22	0.31	<0.01	0.07	0.21	0.11	0.05
CO_2	0.20	<0.05	0.35	0.05	0.10	0.05	0.10	0.05	0.50	0.05
TOTAL	100.14	99.89	99.92	99.66	99.67	99.72	98.31	99.60	99.96	99.38
Ba	540	939	870	731	610	1290	380	1320	1960	220
Rb	120	144	225	118	140	180	65	190	265	55
Sr	270	378	215	232	240	295	305	235	45	120
Pb	100	8	22	13	16	44	60	55	<2	4
Th	16	13	20	14	12	16	8	16	18	8
U	6	<4	6	7	<4	4	<4	<4	6	<4
Zr	160	210	175	162	125	240	100	240	175	34
Nb	4	10	<4	<4	<4	10	<4	10	10	<4
Y	24	24	30	21	20	35	20	30	40	20
La	20	45	40	26	30	70	30	50	50	10
Ce	50	74	90	60	50	80	40	60	90	10
V	165	80		150						
Cr	65			85		42	45	25	18	48
Co	15	14	8	28	15	<5	22			<5
Ni	55	9	15	72	45	<5	18	<5	8	10
Cu	45	10	55	48	45	5	60	2	18	8
Zn	38	68	38	75	40	45	50	45	12	10

Table A16: MOUNTAIN CREEK VOLCANICS (cont.)

Sample no.	73840256	74840053	74840054	74840055	74840056	74840057	74840058	74840059	74840060	74840061
Rock Type	rhyolite ignimbrite	porph. dacite	rhyolite lava	albitised tuff	albitised tuff	albitised tuff	rhyolite ignimbrite	rhyolite ignimbrite	fine tuff	rhyolite lava
Grid reference	575108	682958	677956	656951	656951	656951	639937	630931	622932	612931
1:100 000 sheet	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	70.53	69.39	71.89	54.40	63.33	64.08	73.03	72.69	48.42	72.07
TiO_2	0.57	0.47	0.53	1.37	0.92	0.94	0.40	0.41	1.66	0.44
Al_2O_3	13.61	14.83	13.93	19.16	17.46	16.20	13.57	13.57	14.71	13.20
Fe_2O_3	1.40	1.00	0.83	0.97	0.60	0.74	1.13	0.74	1.24	0.74
FeO	1.42	1.86	1.39	5.24	2.62	2.99	0.78	1.08	9.19	1.11
MnO	0.04	0.04	0.12	0.22	0.10	0.14	0.11	0.09	0.19	0.09
MgO	0.29	1.14	0.60	2.67	1.22	1.38	0.42	0.39	4.48	0.38
CaO	1.36	3.50	1.86	2.52	1.74	1.96	2.12	1.35	6.95	1.28
Na_2O	3.38	2.87	3.62	4.56	6.64	5.66	4.05	3.85	3.52	3.55
K_2O	4.76	3.51	4.29	4.65	3.14	3.24	3.36	4.18	1.17	4.83
P_2O_5	0.08	0.11	0.07	0.36	0.23	0.29	0.07	0.06	0.33	0.05
H_2O+	0.82	0.70	0.23	2.53	1.02	1.34	0.43	0.55	3.98	0.56
H_2O-	0.02	0.06	0.05	0.07	0.06	0.04	0.07	0.05	0.04	0.02
CO_2	0.90	0.05	<0.05	0.20	0.05	0.25	0.05	0.30	3.05	0.75
TOTAL	99.18	99.53	99.41	98.92	99.13	99.25	99.59	99.31	98.93	99.07
Ba	1030	720	940	1550	920	940	820	1000	380	1250
Rb	175	150	170	170	100	110	120	160	34	190
Sr	310	240	390	390	350	310	490	340	350	260
Pb	16	18	22	8	4	12	28	10	<2	24
Th	16	20	18	10	18	10	16	16	<4	20
U	<4	4	6	<4	4	<4	4	4	<4	6
Zr	240	200	220	160	210	180	270	250	110	280
Nb	5	4	4	<4	<4	<4	4	4	<4	8
Y	30	25	30	30	35	30	35	35	30	30
La	40	70	50	40	40	50	60	70	20	70
Ce	80	100	80	80	90	70	100	90	50	90
V	35	110	35	140	55	40	5	70	470	35
Cr	15	45	25	35	5	15		5	10	
Co	<5	2	<5	6	<5	<5	<2	<5	20	<4
Ni	5	16	8	8	4	2	4	2	10	4
Cu	12	10	12	154	182	176	8	8	10	8
Zn	50	36	68	194	85	120	63	58	116	69

Table A17: MOUNTAIN CREEK VOLCANICS AND ROLLING GROUNDS LATITE

Sample no.	74840066	74840067	71840361	71840479	71840531	72840144
Formation	Mtn. Ck. Volcanics	Mtn. Ck. Volcanics	Rolling Gr. Latite	Rolling Gn.Latite	Rolling Gn.Latite	Rolling Gn.Latite
Rock Type	porph. rhyodacite	rhyolite lava	plag. pyx. latite	plag.pyx. latite	plag.pyx. latite	pyritic andesite
Grid reference	661910	665911	512549	511579	573560	545654
1:100 000 sheet	Brind.	Brind.	Tantangara	Tantangara	Tantangara	Tantangara
SiO_2	69.68	71.28	62.00	61.70	61.70	57.20
TiO_2	0.49	0.52	0.56	0.59	0.59	0.80
Al_2O_3	14.41	14.15	13.70	13.10	13.20	16.10
Fe_2O_3	0.58	0.90	1.25	1.90	1.45	1.18
FeO	1.90	1.34	4.55	4.15	4.50	6.00
MnO	0.07	0.10	0.11	0.09	0.09	0.12
MgO	0.76	0.56	5.50	5.65	5.35	4.80
CaO	2.05	1.94	5.35	4.85	5.40	6.50
Na_2O	1.75	3.64	2.00	1.99	1.40	2.10
K_2O	6.66	4.32	2.65	3.05	3.60	1.49
P_2O_5	0.06	0.02	0.13	0.12	0.13	0.12
H_2O+	1.08	0.37	1.99	2.20	1.85	1.73
H_2O-	<0.02	0.03	0.15	0.22	0.31	0.07
CO_2	0.20	0.05	0.20	0.05	0.10	0.10
TOTAL	99.69	99.22	100.14	99.66	99.67	98.31
Ba	1000	960	540	731	610	380
Rb	260	160	120	118	140	65
Sr	180	420	270	232	240	305
Pb	22	24	100	13	16	60
Th	18	16	16	14	12	8
U	4	<4	6	7	<4	<4
Zr	200	220	160	162	125	100
Nb	4	<4	4	<4	<4	<4
Y	30	30	24	21	20	20
La	60	50	20	26	30	30
Ce	80	80	50	60	50	40
V	120	35	165	150		
Cr	55	5	65	85		45
Co		<5	15	28	15	22
Ni	10	2	55	72	45	18
Cu	12	10	45	48	45	60
Zn	56	71	38	75	40	50

Table A18: MICALONG SWAMP BASIC IGNEOUS COMPLEX

Sample no.	71840397	71840398	72840124	72840132	72840219	73840276	73840314	73840350	73840357	73840363
Rock Type	olivine gabbro	leuco-gabbro	quartz dolerite	porph. dolerite	cpx. gabbro	porph.hbl. dolerite	graphic tonalite	ferro gabbro	ferrohast. tonalite	uralite leucogbro.
Grid reference	393629	402626	366903	379935	364722	443966	402975	463112	371179	398049
1:100 000 sheet	Tantangara	Tantangara	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	49.40	46.40	54.50	49.90	49.50	51.62	69.09	50.75	61.92	49.14
TiO_2	0.43	0.31	1.82	1.07	0.27	0.98	0.54	1.67	1.09	0.23
Al_2O_3	17.50	20.00	14.60	16.10	17.20	16.06	14.63	16.02	14.84	23.54
Fe_2O_3	1.55	1.45	4.55	2.15	1.05	2.38	1.61	4.89	4.40	0.82
FeO	4.65	3.25	7.35	7.45	4.00	7.10	3.37	7.21	4.98	2.40
MnO	0.11	0.08	0.16	0.22	0.11	0.16	0.06	0.13	0.17	0.03
MgO	10.10	9.95	3.55	7.65	9.40	6.63	0.72	4.97	1.38	5.97
CaO	12.20	14.50	6.40	11.10	15.00	10.81	3.66	10.17	5.10	15.59
Na_2O	2.10	1.16	4.30	2.10	1.70	2.14	4.90	2.36	4.10	1.64
K_2O	0.12	0.18	0.08	0.12	0.06	0.43	0.26	0.56	0.15	0.06
P_2O_5	0.03	0.02	0.21	0.12	0.02	0.05	0.10	0.06	0.33	0.03
H_2O+	1.51	2.20	1.98	1.50	1.60	1.36	1.04	1.33	1.32	0.76
H_2O-	0.19	0.22	0.10	0.06	0.07	0.04	0.04	0.01	0.10	0.02
CO_2	<0.05	0.05	0.05	<0.05	0.05	0.05	0.05	0.05	0.05	0.05
TOTAL	99.89	99.77	99.65	99.54	100.03	99.81	100.07	100.18	99.93	100.28
Ba	70	28	90	85	15	100	220	150	110	20
Rb	12	9	11	10	3	10	10	16	1	<1
Sr	150	133	207	145	150	170	200	210	240	230
Pb	<2	<2	263	152	<2	<2	<2	<2	3	<2
Th	4	<4	<4	<4	<4	<4	10	<4	6	<4
U	<4	<4	4	<4	<4	<4	6	4	4	<4
Zr	20	12	145	53	14	50	260	80	390	<5
Nb	<4	<4	<4	<4	<4	<4	<4	<4	4	<4
Y	10	<10	42	21	8	20	40	20	40	<10
La	30	<10	36	10	<10	<10	20	<10	<20	<10
Ce		11	28	13	<10	<10	50	20	50	<10
V		110	320	220	150	385	38	830		145
Cr				15	10	35	15	30	70	
Co	35	53	42	44	10	40	22	48	5	18
Ni	90	170	5	94	48	20	<2	40	10	65
Cu	170	93	7	24	42	40	52	46	8	10
Zn	25	36	46	83	10	69	16	48	48	4

Table A18: MICALONG SWAMP BASIC IGNEOUS COMPLEX (cont.)

Sample no.	73840366	73840367	73840397	73840399	73840401	73840402	73840403	73840406	73840407	73840408
Rock Type	epidotised granophyre	uralite dolerite	leuco- granodr.	ferro.qtz dolerite	uralite dolerite	ferro.qtz dolerite	uralite dolerite	ferro gabbro	ol. pyx. gabbro	ferro gabbro
Grid reference	368998	362997	451104	376956	379960	380959	380957	386961	391970	396970
1:100 000 sheet	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.	Brind.
SiO_2	66.90	52.64	76.15	53.00	50.90	51.77	50.70	45.09	50.05	45.30
TiO_2	0.60	1.00	0.13	1.78	0.76	1.94	0.94	2.63	0.55	3.30
Al_2O_3	14.61	15.70	12.52	15.04	16.44	15.01	15.74	14.87	14.85	14.31
Fe_2O_3	2.12	1.65	0.78	3.57	1.76	4.21	2.36	6.27	1.66	5.20
FeO	2.66	6.93	1.46	8.56	6.34	8.21	6.43	9.92	5.86	10.60
MnO	0.04	0.15	0.03	0.21	0.13	0.09	0.16	0.19	0.15	0.22
MgO	0.93	5.88	0.17	3.91	7.30	3.85	6.73	5.57	9.75	5.64
CaO	4.15	10.28	1.39	8.12	11.66	8.19	10.82	10.44	13.58	10.61
Na_2O	4.80	2.94	4.28	3.38	2.64	3.80	3.10	2.48	1.82	2.25
K_2O	0.03	0.19	2.26	0.27	0.13	0.11	0.23	0.10	0.14	0.10
P_2O_5	0.13	0.11	0.01	0.23	0.09	0.24	0.10	0.05	0.04	0.06
H_2O+	1.78	1.58	0.54	1.52	1.47	1.64	1.53	1.35	1.43	1.22
H_2O-	0.14	0.02	0.16	0.16	0.15	0.10	0.19	0.17	0.15	0.10
CO_2	<0.05	0.05	0.05	0.05	0.05	0.05	0.05	<0.05	<0.05	0.05
TOTAL	98.89	99.12	99.93	99.80	99.82	99.21	99.08	99.13	100.03	98.96
Ba	30	70	500	<10	30	100	80	120	20	30
Rb	2	5	75	12	5	4	8	<2	5	2
Sr	170	165	80	130	180	230	155	140	145	220
Pb	<2	<2	4	32	<2	<2	<2	<2	<2	6
Th	8	<4	12	<4	<4	<4	<4	<4	<4	<4
U	<4	<4	4	<4	<4	<4	<4	<4	<4	<4
Zr	250	75	210	110	50	75	60	35	20	30
Nb	<4	<4	<4	<4	<4		<4	<4	<4	<4
Y	40	20	50	40	20	30	20	15	15	15
La	<10	<10	40	<10	<10	<10	<10	<10	<10	<10
Ce	50	<10	70	20	<10	20	<10	<10	<10	<10
V	125	325		400	275	510	295	1050	305	1250
Cr		55	10	20		20		15		20
Co	14	36	<5	30	42	40	44	62	48	50
Ni	5	25	15	10	55	8	45	18	70	5
Cu	10	18	14	40	18	14	30	56	40	46
Zn	2	33	36	100	52	54	58	104	52	85

Table A18: MICALONG SWAMP BASIC IGNEOUS COMPLEX (cont.)

Sample no.	73840409	73840411	73840412	74840045
Rock Type	graphic tonalite	graphic granodr.	graphic granodr.	anorthos. gabbro
Grid reference	400971	402976	402976	399055
1:100 000 sheet	Brind.	Brind.	Brind.	Brind.
SiO_2	63.39	71.72	70.99	45.85
TiO_2	0.82	0.25	0.27	0.07
Al_2O_3	15.15	13.73	13.78	28.22
Fe_2O_3	2.72	2.07	1.38	1.09
FeO	4.34	2.55	2.96	1.35
MnO	0.11	0.04	0.07	0.04
MgO	1.20	0.26	0.28	4.31
CaO	4.46	2.21	2.48	16.47
Na_2O	4.90	5.00	4.72	1.28
K_2O	0.58	1.19	1.35	0.07
P_2O_5	0.27	0.03	0.04	0.02
H_2O+	0.98	0.62	0.89	1.22
H_2O-	0.16	0.16	0.15	0.02
CO_2	<0.05	0.05	<0.05	0.05
TOTAL	99.08	99.88	99.36	100.06
Ba	300	600	600	40
Rb	22	32	36	12
Sr	175	120	115	240
Pb	<2	<2	<2	<2
Th	8	10	12	<4
U	<4	4	<4	<4
Zr	210	310	330	44
Nb	<4	<4	<4	<4
Y	50	50	60	20
La	30	30	30	<10
Ce	60	70	60	50
V	18		10	65
Cr	15	15	15	
Co	16	4	4	50
Ni	5	5	<3	118
Cu	14	18	12	32
Zn	30	11	30	24

Table A19: TERTIARY BASALTS

Sample no.	72840052	72840216
Rock Type	alkali basalt	alkali basalt
Grid reference	362388	453463
1:100 000 sheet	Tantangara	Tantangara
SiO_2	45.30	45.20
TiO_2	2.45	1.91
Al_2O_3	15.00	15.40
Fe_2O_3	2.05	2.50
FeO	8.20	9.85
MnO	0.15	0.22
MgO	8.15	9.20
CaO	10.20	10.40
Na_2O	3.05	3.20
K_2O	1.36	0.86
P_2O_5	1.16	0.08
H_2O+	2.02	0.55
H_2O-	0.90	0.21
CO_2	0.10	0.05
TOTAL	100.09	99.63
Ba	720	580
Rb	19	13
Sr	1200	980
Pb	10	5
Th	6	6
U	6	4
Zr	220	150
Nb	85	55
Y	25	22
La	60	40
Ce	140	100
V	215	235
Cr	12	35
Co	40	80
Ni	170	130
Cu	90	75
Zn	80	75

ORDOVICIAN STRATIGRAPHIC UNITS

The Ordovician rocks of TANTANGARA and BRINDABELLA have been divided into six units. The two oldest - the Boltons and Nungar beds, whose bases are not exposed - consist of distal quartz-rich flysch, and are at least as old as the Darriwilian. In the west, the Boltons beds are succeeded by upper Darriwilian to upper Gisbornian volcanics which have been divided into three formations: the Gooandra Volcanics, Nine Mile Volcanics, and Temperance Formation. In the east, distal quartz-rich flysch sedimentation continued with the Nungar beds, and persisted after volcanism had ceased.

During the middle Eastonian a thick sheet of proximal quartz-rich flysch (Adaminaby beds) covered the area; its deposition continued into the early Bolindian. The Ordovician was brought to a close by a widespread tectonic episode - the first phase of the Benambran fold episode - the style of which is largely obscured by later events.

Boltons beds

Nomenclature

As a result of reconnaissance mapping around the Happy Jacks River (KOSCIUSKO) for SMHA, Fairbridge & others (1951) gave the name 'Boltons Greywacke' to a sequence of fine-grained clastic rocks with minor bands of thin-bedded chert, impure quartzite, dark slate, and shale. The unit was said to crop out over a wide area on Boltons Hill, in the Wagga Wagga and Tallangatta 1:250 000 Sheet areas. Moye (1953), as a result of more detailed mapping, found the sequence to be essentially quartzite, tuffaceous quartzite, greywacke, and slate, and called it the 'Boltons Beds'.

Gardner (in Owen & others, 1964b), from mapping which covered TANTANGARA as well as the area around Boltons Hill, distinguished five lithological units: three are fine-grained to very fine-grained quartz arenite and interbedded argillite, and two are argillaceous beds with interbedded arenite; Gardner considered the arenite unit at the top of the sequence to be slightly tuffaceous. The quartz arenite has an argillaceous matrix, commonly recrystallised to sericite, with chlorite and minor epidote; it is apparently the same as Fairbridge's 'Boltons Greywacke'. As lithic fragments are scarce or absent the term 'arenite' is preferred to 'greywacke'. For the sequence as a whole we have adopted the name Boltons beds.

The Boltons beds were regarded by the earlier workers as the basal unit of the Ordovician succession in the area. However, traverses to Farm Ridge (grid ref. 260055, KOSCIUSKO) and west of Jagungal (grid ref. 240000, KOSCIUSKO) indicate that the Boltons beds, though markedly thinner, continue south of the reference area of Fairbridge & others (1951); at Jagungal they are underlain by metabasalts which do not crop out farther north, and are overlain by a chert-volcanogenic sequence continuous with the Kiandra Group.

Since the area between Happy Jacks River and Jagungal will have to be mapped in detail before the relation between the Boltons beds and the underlying metabasalts is fully understood, the name is used informally. In TANTANGARA and BRINDABELLA the unit forms the basal part of the exposed Ordovician succession.

Derivation of name

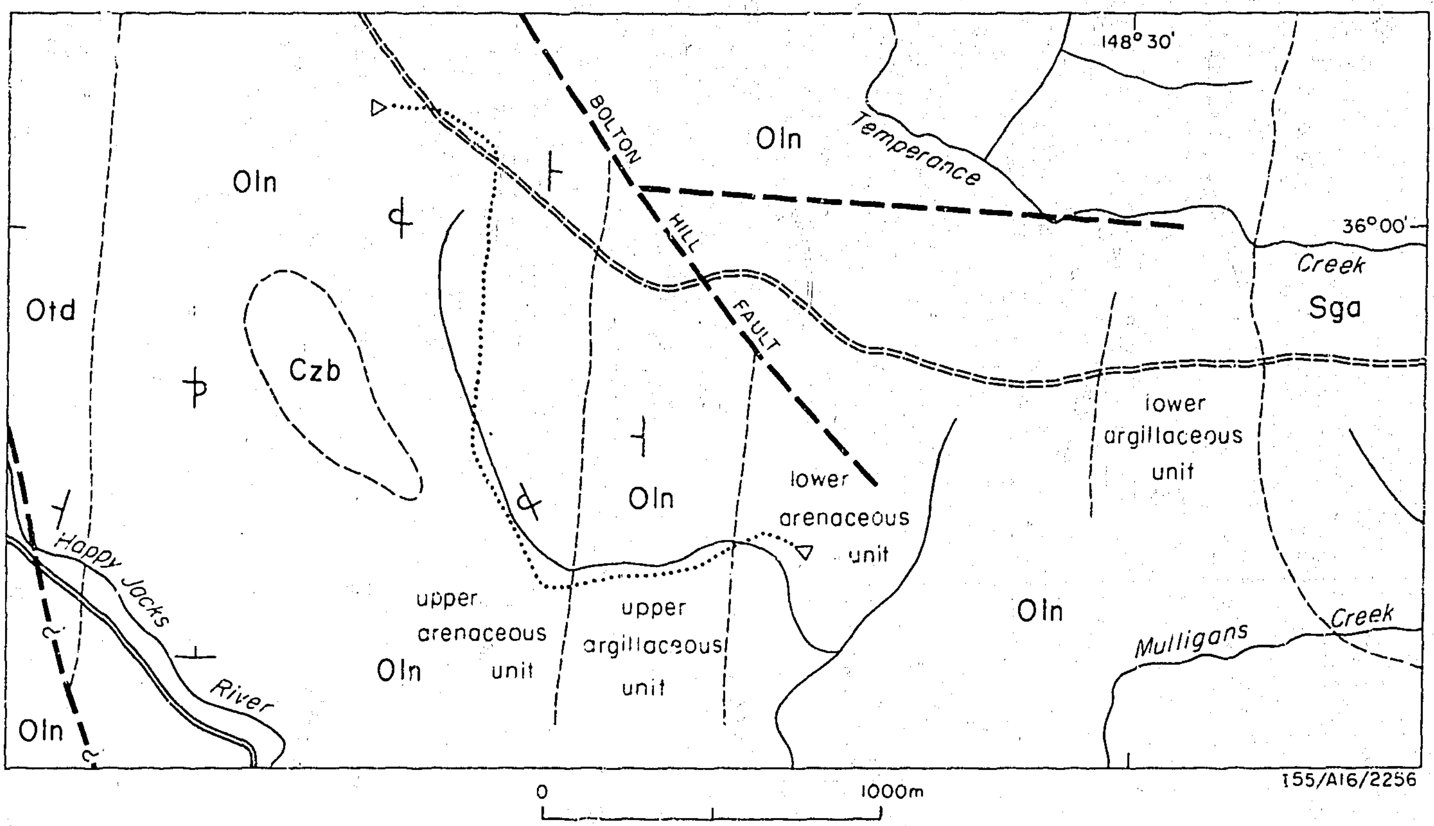
The name is derived from Boltons Hill - latitude 36°S, longitude 148°28'E (grid ref. 325125, KOSCIUSKO) - where the beds are well exposed.

Reference section

Fairbridge & others (1951) described the distribution of the Boltons beds between Temperance Creek and Happy Jacks River, but did not name a type section. A continuous section through the complete succession has not been found because the sequence is faulted at several localities along Temperance Creek, Temperance Spur, and Happy Jacks Road. We have described a reference section in the reference area of Fairbridge & others (1951) between Boltons Creek and Boltons Hill (Table M1, Fig. M1), and recommend that this section be considered as the type section if the unit is formally defined at a later date. Owen & others (1974b) have described additional reference sections of the Boltons beds in the Bega, Tallangatta, and Wagga Wagga 1:250 000 Sheet areas near the reference area of Fairbridge & others (1951).

TABLE M1. REFERENCE SECTION OF THE BOLTONS BEDS

Approx distance (m)	Geographic description	Geological description
0	Start of section: Boltons Creek, 350 m NNW of mouth of tributary creek that flows from NNE (grid ref. 339138, KOSCIUSKO). Section line runs 280o	Lower arenaceous unit; thick-bedded fine-grained quartz arenite
80	Section line turns to 240o	Fine-grained quartz arenite or sandstone and interbeds of silty mudstone
150		Top of lower arenaceous unit; section passes into upper argillaceous unit. Outcrop is scarce; fragments in soil are of thin-bedded siltstone and laminated shale.
300		Siltstone, shale, fine-grained quartz sandstone
380	Section line turns to 267o	Thin-bedded siltstone and shale
520		Siltstone, shale, fine-grained quartz sandstone
670		Top of upper argillaceous unit; section passes into upper arenaceous unit
720	Section line turns to 330o	Fine-grained quartz sandstone (probably tuffaceous), siltstone, and shale
1170	Section line turns to 005o	Fine-grained argillaceous arenite, siltstone, and interbeds of slate
2010	Section line crosses track on crest of Boltons Hill	
2060	Section line turns to 306o	Fine-grained argillaceous arenite, siltstone, and argillite interbeds
2260	Section line turns to 270o	Very fine-grained argillaceous and quartzose siltstone, thin beds of argillite
2380	End of section (grid ref. 326154, YARRANGOBILLY)	Fine-grained slightly argillaceous quartz arenite or impure quartzite



- - - - -	*Geological boundary*	Czb	*Tertiary basalt*
— — - —	*Fault*	Sga	*Gang Gang Adamellite*
⊥	*Strike and dip of strata*	Otd	*Temperance Formation*
	Stike and dip of overturned strata	Oln	*Boltons beds*
▷·····◁	*Type section line*		
═══	*Road*		
=====	*Vehicle track*		

Fig MI Location of reference section of the Boltons beds

Distribution

From Happy Jacks Road (Tallangatta and Wagga Wagga 1:250 000 Sheet areas) the outcrop of the Boltons beds extends north and northeast past Sawyers Hill and Tantangara Mountain to the edge of Boggy Plain in TANTANGARA, where it is bounded by the Gang Gang Adamellite and Boggy Plain Adamellite. From Happy Jacks Road northwards past Four Mile Hill, the outcrop width is more than 3000 m; about 800 m south of the Eucumbene River, the Boggy Plain Adamellite has intruded the lower units, and the outcrop width of the Boltons beds is reduced to less than 1000 m. A small outcrop of the Boltons beds 8 km north of Tantangara Mountain is surrounded by the Temperance Formation; it is here called the 'Gooandra Inlier', after Gooandra homestead 2 km to the west. The Boltons beds also occupy a small area at the edge of Blanket Plain, 1 km southeast of the 'Gooandra Inlier'. Most of Blanket Hill, 5 km north of Tantangara Mountain, consists of the Boltons beds; this is part of the outcrop near Tantangara Mountain displaced along a sinistral wrench fault, the Boggy Plain Fault. The outcrops on Blanket Hill continue south on the eastern side of the Boggy Plain Adamellite before being cut out by faulting south of Blackfellows Hill.

At Far Bald Mountain (grid ref. 314099, KOSCIUSKO), within 4 km south of the type area, Williams (1974) showed that the Boltons beds are cut out by faulting and the intrusion of the Happy Jacks Granite. However, as mentioned above, traverses that we have made south of Far Bald Mountain indicate that the Boltons beds crop out as a distinct unit of fine sandstone and cherty siltstone. South of Jagungal the extent of the Boltons beds is uncertain.

Lithology

Gardner (in Owen & others 1974b) identified five lithological units within the Boltons beds in the reference area, on Boltons Hill:

tuffaceous unit
upper arenaceous unit
upper argillaceous unit
lower arenaceous unit
lower argillaceous unit

Gardner postulated the presence of tuffaceous beds in the uppermost unit primarily from the occurrence of actinolite and epidote which he considered to represent altered fine-grained Ca-rich volcanic debris. We have re-examined all thin sections from the tuffaceous unit but failed to identify actinolite; the reported occurrence apparently results from misidentification of chloritic minerals. In addition, epidote is restricted to veins. Also, detrital plagioclase which Gardner identified in thin section exhibits reverse zonation in some samples, and hence is more likely of metamorphic rather than volcanic origin. Only one sample from the tuffaceous unit shows any evidence of volcanic activity; it contains albitised plagioclase grains.

We therefore consider that the presence of tuffaceous beds within the Boltons beds is restricted, and that Gardner's tuffaceous unit is best regarded as part of the upper arenaceous unit, thus reducing the number of units recognised to four. Of these only the upper arenaceous unit crops out north of the Eucumbene River; the lower units abut against the Boggy Plain Adamellite south of the river.

The Boltons beds are dominated by fine quartz arenite, quartz siltstone, and shale. Coarser quartz arenite with grains up to 1 mm is present mainly in the arenaceous units. Sedimentary structures are common and facilitate the recognition of Bouma's (1962) and Walker's (1967) divisions of the ideal turbidite unit; divisions A and B of Bouma's sequence are commonly missing, particularly in the argillaceous units, indicating that much of the Boltons beds was deposited in the distal parts of turbidite flows.

A typical fine quartz arenite has a bimodal size distribution of quartz grains. The larger grains, well rounded and about 0.25 mm, are scattered through a matrix of angular grains less than 0.10 mm. The smaller size fraction commonly forms about 60% of the rock; the larger fraction around 10%. The quartz grains are typically unstrained, and have few inclusions. Fine phyllosilicate minerals form the remainder, except for minor muscovite, zircon, tourmaline, potash feldspar, and plagioclase. Rock fragments are very rare.

The bimodal size distribution is typical of many sandstones in the Ordovician and Lower Silurian flysch units of the Lachlan Fold Belt. The cause is uncertain. It may represent two different sources for the quartz grains, the angular quartz being derived from an igneous or metamorphic source, and hence 'first-cycle' grains, while the rounded grains must have been through at least one previous sedimentary cycle before they were incorporated in the Boltons beds. The muscovite occurs as elongate, often deformed, flakes up to 0.3 mm long; it appears to be of primary origin. Biotite may also occur, but unlike muscovite is clearly of contact-metamorphic origin. Zircon may be a fairly abundant accessory mineral, and occurs as rounded grains up to 0.1 mm across. Tourmaline is also a common accessory mineral; three verieties, with pleochroism from light brown, olive green or blue to colourless,are present, the first two being more common. Rare plagioclase grains have an oligoclase-andesine composition; some of them show reverse zonation, indicating that they are probably derived from a metamorphic source. Microcline, orthoclase, and grains of fine quartzite are also rare. No volcanic rock fragments have been identified.

One sample from near the top of the Boltons beds in Temperance Creek (YARRANGOBILLY) is unusual in containing about 25% of rounded albitised plagioclase grains about 0.15 mm wide. The remainder of the rock is composed of quartz (60%), and minor zircon, tourmaline, and a phyllosilicate matrix. The presence of the albite suggests that an early phase of volcanic activity associated with the Kiandra Group or Gooandra Volcanics had commenced during the final stage of deposition of the Boltons beds.

Coarser-grained arenites are similar mineralogically to the fine arenites described above, differing only in the size of the quartz grains. The larger grains may be up to 1 mm in diameter, and the framework grains may be up to 0.2 mm across. Concomitant with the increase in the quartz grainsize, the plagioclase and muscovite grainsizes are unchanged, but the zircon and tourmaline grainsizes increase, and the degree of sorting decreases.

On the other hand, as grainsize decreases, the proportion of phyllosilicate matrix increases; in most siltstones it may form over 50% of the rock, while the well-rounded larger quartz grains and plagioclase disappear. A continuation of this trend results in mudstones, most of which still contain scattered small quartz grains.

Chert is unknown from the lower part of the Boltons beds, but towards the upper boundary with the Temperance Formation impure chert containing scattered small quartz grains and rare recrystallised radiolaria tests becomes increasingly common.

Sedimentary structures

The Boltons beds contain many of the sedimentary structures typical of flysch deposits: graded bedding, plane-parallel lamination, ripple cross-lamination, and contorted bedding are all present. Graded bedding, forming the basal division of a turbidite unit, is almost totally restricted to the arenaceous units, indicating a relatively more proximal flysch facies for these two units than for the argillaceous units. However, it should be emphasised that the arenaceous units may still represent a distal facies. Sole marks are rare; no doubt they were destroyed by interbed shearing that accompanied the intense folding of the Boltons beds.

Environment of deposition

The sedimentary structures indicate that the Boltons beds are a sequence of mainly distal flysch sediments deposited by turbidity currents, probably in deep water. The source of the sediments and the direction of flow of the currents are not directly known. The abundance of quartz, and the presence of muscovite, plagioclase (metamorphic in origin), orthoclase, microcline, zircon, and tourmaline, indicate that the source area must have included regionally metamorphosed rocks, and possibly granitic bodies. Possible source areas are the Carpentarian rocks of the Willyama Complex and the Kanmantoo Fold Belt, to the west; the ?Cambrian Girilambone beds and their probable southern continuation, the Jindalee beds, north of Tumut, to the northwest; and Cambrian rocks in Victoria, Tasmania, and Antarctica, to the south. We consider a southerly source to be most likely, and postulate, from regional considerations, that the Boltons beds were deposited on the outer fronts of a large submarine fan.

Thickness

Gardner, in Owen & others (1974b), suggested that the Boltons beds are about 4000 m thick, a maximum estimate since no allowance for folding was made. As the Boltons beds are isoclinally folded in places (Moye, Sharp, & Stapledon, 1963), a more likely estimate of the thickness would be between 1000 and 2000 m.

Relations

The Boltons beds are apparently conformably underlain by a metabasalt unit near Jagungal (KOSCIUSKO), and are overlian by the Kiandra Group in the Happy Jacks area and in TANTANGARA. Eastwards they are thought to pass laterally into the lower part of the Nungar beds.

Age

The Boltons beds are unfossiliferous, so their age can be deduced only from their relation with other units in the area. The Kiandra Group contains Gisbornian graptolites (Sherrard 1954; Öpik, 1952). East of the Happy Jacks area, the Nungar beds and their equivalents contain graptolites ranging in age from Gisbornian to Eastonian. Since the Boltons beds underlie the Kiandra Group and are considered laterally equivalent to the lower Nungar beds, they may be of Darriwilian age - that is, contemporaneous with the lower part of the Pittman Formation in Canberra, a distal flysch unit from which Öpik (1958) reported Darriwilian graptolites.

Gooandra Volcanics

(new name)

The name Gooandra Volcanics has been introduced as a result of additional petrographic and geochemical studies since our previous account of the area (Owen & others, 1974b), in which we included these rocks in the Nine Mile Volcanics. Lavas of the Gooandra Volcanics are now known to be distinct from those of the Nine Mile Volcanics and from lava clasts in the Temperance Formation. Moreover, the Gooandra Volcanics are separated from the Temperance Formation by the Kiandra Fault, whereas the Nine Mile Volcanics conformably overlie that unit.

Nomenclature

Best & others(1964) included in the 'Peppercorn Beds'much of what we recognise as the Gooandra Volcanics, since they mapped as the Long Plain Fault what we recognise as the Kiandra Fault. Mackenzie (1968) identified the correct location of the Long Plain Fault near Kiandra, and included the volcanics in question in the Nine Mile Volcanics. This nomenclature was followed by Owen & others (1974b), but we now separate the volcanics and sediments between the Long Plain Fault to the west and the Kiandra Fault to the east, and here call these rocks the Gooandra Volcanics. Almost all the volcanics mapped by Mackenzie (1968) as Nine Mile Volcanics are within our Gooandra Volcanics.

Derivation of name

The volcanics are named after Gooandra Creek, a tributary of Tantangara Creek.

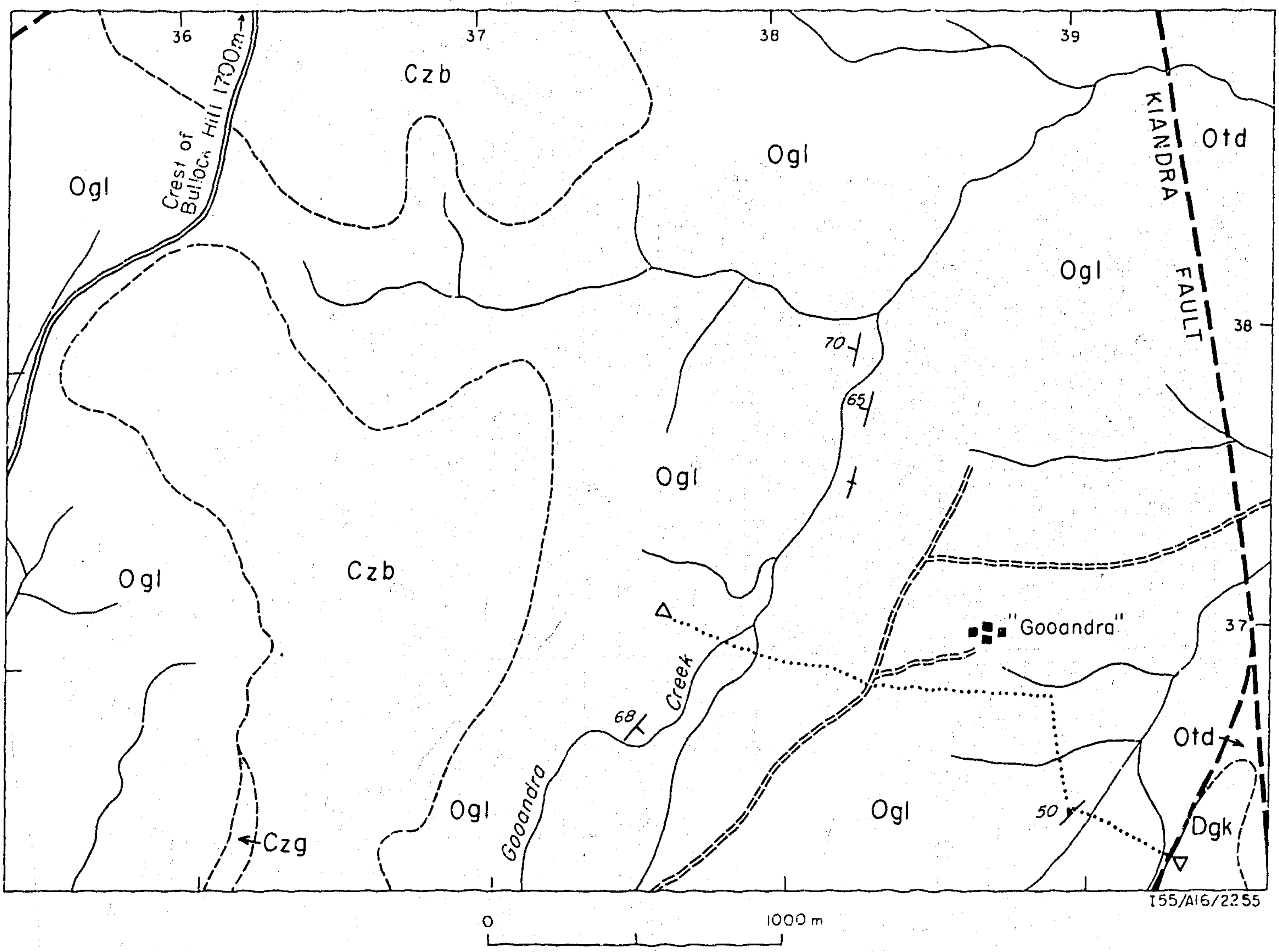
Type section

The type section is designated as lying just south of Gooandra homestead, and extending west-northwest from the Kiandra Fault to a point 160 m west of Gooandra Creek. Owen & others (1974b) named this section as a reference section for the lower half of the lava unit of the Nine Mile Volcanics. The location of the type section is shown in Figure M2 and a description is given in Table M2.

Distribution

The Gooandra Volcanics occupy a fault-bounded block that extends from Long Plain (at grid ref. 417528) south to Kiandra Plain (grid ref. 355345) and the Gooandra Creek valley, and from there south-southwest into YARRANGOBILLY, where it is cut out in the headwaters of Clear Creek near Selwyn Quarry. This block is about 32 km long and reaches a maximum width of about 5.5 km near the type section, but part of the area is obscured by Tertiary basalt. On Kiandra Plain, much of the area formerly occupied by the Gooandra Volcanics now exposes the 'Shaw Hill Gabbro' (after Mackenzie, 1968), which is possibly the intrusive equivalent of the Gooandra Volcanics.

Since the Gooandra Volcanics are entirely fault-bounded their relation with other rock units such as the Tumut Ponds beds (YARRANGOBILLY) and Kiandra Group are unknown. In the Geehi and Tumut River valleys (KOSCIUSKO) L.A.I. Wyborn (1977) has mapped lavas and tuffs that may be similar to the Gooandra Volcanics; these rocks generally occur in fault blocks west of rocks correlatable with the Kiandra Group. The 'O'Hares Beds' (Stapledon, 1957) and the Coppermine Creek Volcanics (Moye, 1953) may also be equivalent to the Gooandra Volcanics.



- - - -	*Geological boundary*	Czg	*Tertiary gravel*
— —	*Fault*	Czb	*Tertiary basalt*
▷·······◁	*Type section line*	Ogl	*Lava and breccia Gooandra Volcanics*
⊥	*Strike and dip of strata*	Otd	*Temperance Formation*
+	*Vertical strata*	Dgk	*Devonian diorite*
	Strike and dip of foliation		
═	*Road*		
====	*Vehicle track*		

Fig M2 Location of type section of the Gooandra Volcanics

Lithology

Field occurrence. The Gooandra Volcanics consist almost entirely of basaltic to andesitic lava and breccia, with minor interbedded rhyolite (Ogl) and tuffaceous sandstone, siltstone, and shale (Ogs). The lavas and breccias commonly form large oval outcrops up to several metres high and aligned parallel to the prominent north-northeast-trending foliation in the region. this style of outcrop is well developed on both sides of the Snowy Mountains Highway between Kiandra and Gooandra Hill. the tuffaceous sediments are poorly exposed, highly weathered, and strongly cleaved, and may be more abundant than indicated.

TABLE M2

TYPE SECTION OF THE GOOANDRA VOLCANICS

Reference point	Geological description
Start of section: in creek bed (grid ref. 393361). 1 km SE of Gooandra homestead. Section bears 300°	Kiandra Fault; no outcrop, but fault presumed to run along creek on bearing of 020°. Devonian dioritic intrusion on eastern side of creek
At 100 m	Weathered tuff
At 350 m, section bears 348°	Grey-green lava with small plagioclase phenocrysts; flow banding appears to dip 50° towards 315°, cleavage dips 70° towards 295°
At 750 m, section bears W	Lava porphyritic in plagioclase
Track to Gooandra homestead	Sheared lava
200 m W of track	Sheared porphyritic lava
Down the steep slope to Gooandra Creek	Grey-green lava in small weathered exposures
Bottom of slope beside Gooandra Creek	Sheared banded argillite and plagioclase-rich tuff
End of section: 160 m W of Gooandra Creek (grid ref.377370)	Pillow-like agglomerate with oval 15-cm cobbles elongated parallel to cleavage

Owen & others (1974b) divided the sequence in the Gooandra Creek and upper Eucumbene River areas into two belts: an eastern lava belt and a western breccia belt; the boundary between the two roughly follows Gooandra Creek. To the north this subdivision is not possible, and to the southwest, outside TANTANGARA, our reconnaissance mapping failed to detect the two belts. Their relative age is unknown, as dips are steep and facing is unknown. Folding is probably intense, for the 'Shaw Hill Gabbro' (after Mackenzie, 1968), which intrudes the Gooandra Volcanics north of New Chum Hill (YARRANGOBILLY), is folded into a number of anticlines and synclines with a wavelength of less than 1 km (Mackenzie, 1968).

The lava belt is about 1.5 km wide and extends north-northeasterly from Chance Creek to the western edge of Tantangara Plain. Much of the lava north of Bullock Hill is probably a continuation of this belt. South of the northwesterly flowing upper part of Gooandra Creek, the lava belt consists of fine to medium-grained porphyritic and aphyric andesitic lavas. North of the creek a narrow belt of breccia occupies the middle of the belt. Porphyritic andesite at grid reference 383368 consists of feldspar phenocrysts up to 1.0 mm long in a matrix of flow-oriented feldspar laths 0.1 to 0.2 mm long. This is typical of flows that are obviously porphyritic in outcrop; similar porphyritic lava crops out in the south at grid reference 365327. Fine-grained porphyritic andesite crops out at grid references 391363 and 361333. In the north, east of the boundary with the main breccia belt, medium-grained holocrystalline non-porphyritic lava forms a belt about 400 m wide.

Flow banding is present in the lava at many localities (e.g., in porphyritic basaltic andesite at grid refs. 364316 and 391363). Measurements at four localities give dips of greater than 50° towards 290-315°; more often the banding is masked by shearing or foliation (e.g., at grid ref. 376353) and the attitude cannot be determined. The lava may be finely banded (e.g., the fine-grained andesite at grid ref. 366312) or forms massive outcrops 5 to 6 m wide (e.g., the porphyritic andesite at grid ref. 363318).

East of the Snowy Mountains Highway and north of Gooandra Hill the andesite is nearly all aphyric, though porphyritic lava crops out at grid references 385459 and 389463. Amygdales filled with one or both of calcite and epidote are common in this area.

Sedimentary rocks are not common in the lava belt. Well-bedded fine to medium-grained tuffaceous arenite crops out in the south at grid reference 373346. In the north a thin layer of fine-grained argillaceous tuff and slate trends north-northeast through grid references 380367, 382367, and 382364; it rests on a thick flow of medium-grained prophyritic andesite, and is overlain by a similar though finer-grained flow. A band of tuffaceous shale over 30 m wide emerges from beneath the Tertiary basalt at grid reference 364415 and can be traced on a bearing of 025° for about 300 m before giving way to lava, which in this area is mostly porphyritic - containing phenocrysts of euhedral feldspar aths up to 4 mm long - and highly cleaved along 020°. At grid reference [illegible] a finely banded siliceous tuff displays intricate slump folding suggestive of a turbidite, and at grid reference 384379 finely banded tuffaceous arenite and siltstone are interbedded. Dips in the sedimentary rocks are generally towards 270° to 280° and are greater than 60°. Dips to the east are rare.

The breccia belt consists of both brecciated lava and aphyric flows. The flows are commonly paler than those to the east, and have been termed 'rhyolites'. They are best exposed in YARRANGOBILLY in a belt about 300 m wide immediately west of the Snowy Mountains Highway south of Six Mile Creek. In TANTANGARA, 'rhyolites' crop out at grid references 379381, 378372, and 358343. They appear aphyric in hand specimen, but contain about 5% feldspar phenocrysts, mostly less than 2 mm long. Visibly porphyritic lavas crop out at grid reference 369351, and vesicular lava is exposed at grid references 363344 and 371360.

Throughout the breccia belt the lava is interbedded with or grades into lava-breccia (hyaloclastite) which contains fragments, usually rounded, that range up to 25 cm (e.g., at grid ref. 380372). At some outcrops the rock is a pseudoconglomerate composed almost entirely of fragments. At grid reference 379358 the fragments appear to have been plastically deformed (Fig. M3) and are paler than the matrix. Some breccia fragments are mainly rounded but have one angular edge, suggesting they were broken during transport; these fragmental rocks are interpreted as pillow breccias composed of partly reworked pillows in a tuffaceous matrix. Pillow lavas are well exposed at grid reference 991730 (Cabramurra SMA 1-Mile Series Sheet area), where the pillows are up to 1 m long and 60 cm wide with little matrix (Fig. M4). At grid reference 358340 smaller pillows (20 cm) are exposed and the matrix is more abundant. With an increase in the proportion of matrix the pillow lavas probably grade into the pillow breccias and flow breccias.

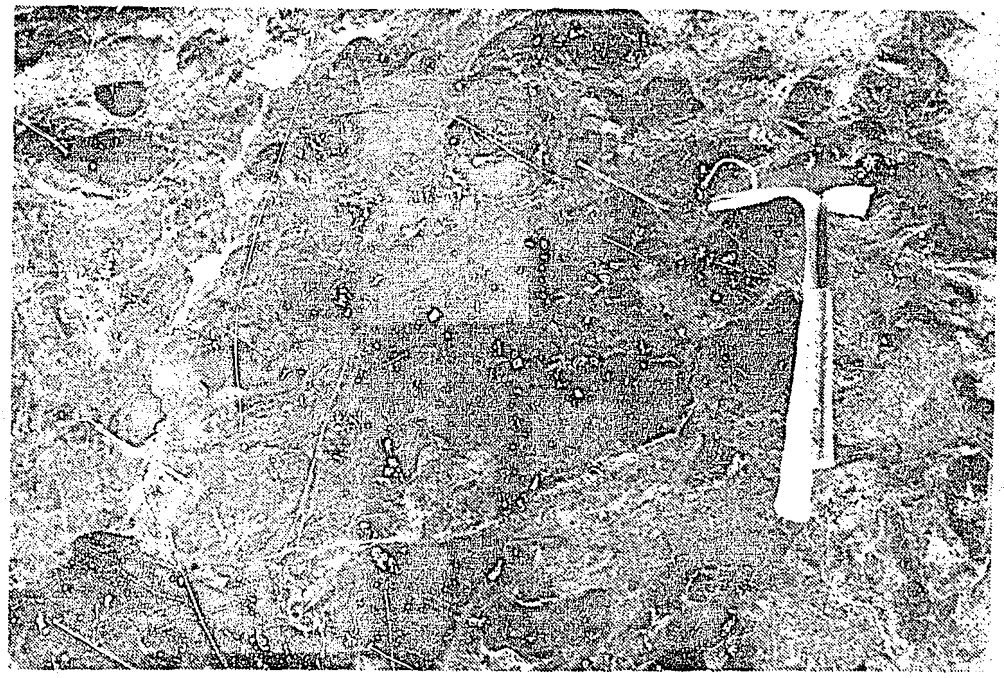


Fig. M3. Plastically deformed lava fragments in a tuffaceous matrix in the Gooandra Volcanics at grid reference 379358, TANTANGARA.
(GB/1833)

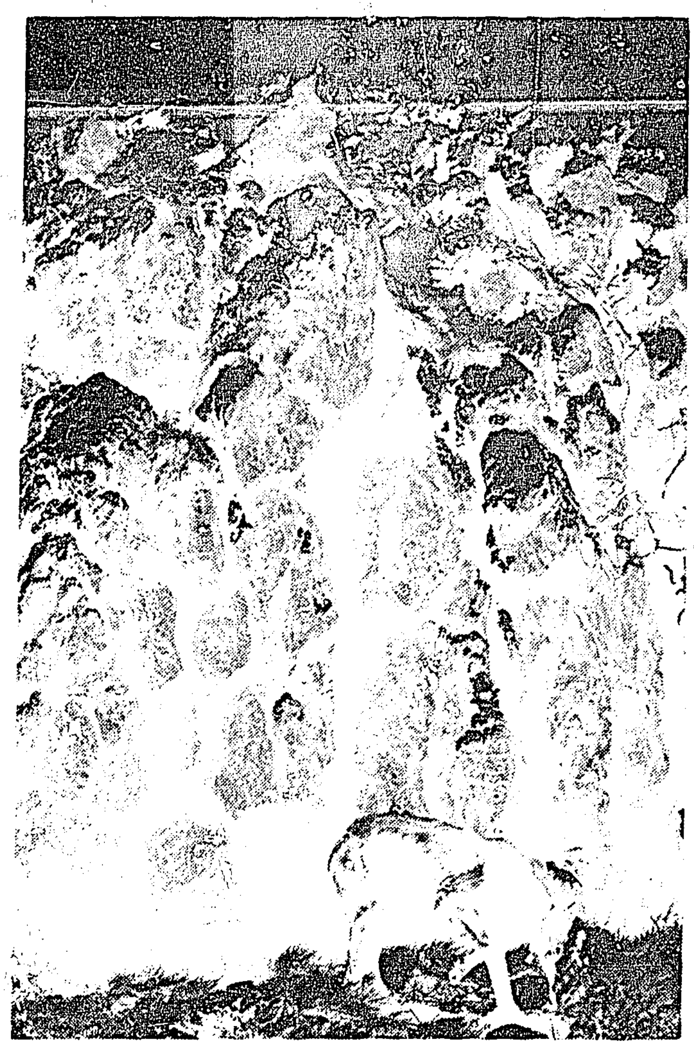


Fig. M4. Pillow lavas in the Gooandra Volcanics at grid reference 991730, Cabramurra SMA 1-Mile Series Sheet area.
(GB/1824)

Petrography. The lavas of the Gooandra Volcanics have been much more extensively altered by regional metamorphism than those of the Nine Mile Volcanics at the northern end of Long Plain. Most samples are aphyric and composed of the metamorphic assemblage albite-epidote-actinolite-chlorite, indicating greenschist grade metamorphism. Unlike the Nine Mile Volcanics, there is no evidence that potash feldspar was a major constituent of the original lavas. They are highly feldspathic, however, with albite constituting as much as 75% of the rock, and occurring as laths up to 1 x 0.2 mm in the aphyric rocks. The laths are all aligned to some degree, giving the rock a trachytic texture. Epidote, actinolite, opaques, quartz (rare), and chlorite are interstitial to the albite laths. Widely scattered patches of epidote and quartz up to 10 mm are present in some lavas. Some samples (e.g., from grid refs. 383462 and 372360) contain interstitial actinolite pseudomorphing clinopyroxene, but in only one basaltic lava sample (from grid ref. 400488) has relict clinopyroxene been identified. The clinopyroxene grains are less than 0.2 mm, and are rimmed by actinolite needles.

Euhedral albitised plagioclase phenocrysts are present in some lavas; they are up to 9 x 3 mm and occupy 25% of a lava from grid reference 382367. The phenocrysts are mostly oriented parallel to the flow alignment of microlites in the groundmass. No mafic phenocrysts or pseudomorphs after mafic phenocrysts have been found in the Gooandra Volcanics, and in this respect they differ markedly from the Nine Mile Volcanics, in which olivine and clinopyroxene phenocrysts developed before plagioclase.

In one aphyric lava (from grid ref. 376370) about 20% magnetite, in addition to epidote, actinolite, and chlorite, is interstitial to the albite microlites; however, the total mafic content is no higher, and maybe lower, than in most of the lavas. If this high magnetite content is an original feature of the lava, it indicates that the lava has undergone magmatic iron enrichment, suggesting a tholeiitic magma source. The lack of potassic minerals and the early crystallisation of the plagioclase also suggest such a source, and so does geochemical evidence (see GEOCHEMISTRY AND PETROGENESIS).

Minor 'rhyolites' are interbedded with the more abundant andesitic to basaltic lavas. They contain about 5% phenocrysts of feldspar in a groundmass of feldspar microlites, quartz, chlorite, muscovite, and biotite. Two types of 'rhyolite' have been distinguished: the most abundant contains albite phenocrysts; the less common variety contains phenocrysts that are patchy antiperthite - interpreted as unmixed anorthoclase of about Or_{30} composition - in a groundmass that contains some potash feldspar. Biotite in the 'rhyolites' is of metamorphic origin and indicates upper greenschist metamorphism. It forms irregular flakes, less than 0.1 mm, pleochroic from X = Y = very pale olive-green to Z = dark yellowish green. Biotite is much more abundant in the anorthoclase-bearing 'rhyolites' than in the albite 'rhyolites'. Although quartz is abundant in the groundmass of the 'rhyolites', it is not apparent as phenocrysts.

A thin section from the core of a pillow lava from grid reference 991730 (Cabramurra SMA 1-Mile Series Sheet area) revealed a mosaic of albite and actinolite laths and needles with interstices filled with epidote and chlorite. In places epidote is the most abundant mineral.

Tuffaceous sediments interbedded with the Gooandra Volcanics are mostly fine-grained with detrital albite and less common lava fragments less than 1 mm. Granular epidote, chlorite, opaques, and secondary quartz make up the matrix material.

<u>Intrusions related to the Gooandra Volcanics</u> (Ogi)

Two large and several smaller intrusions are interpreted to be intrusive equivalents of the Gooandra Volcanics. All but one, which is about 2 km south-southwest of Four Mile Hill, intrude the western part of the volcanic sequence. The body near Four Mile Hill is about 2 x 1 km, and partly covered by Tertiary basalt; it intrudes the upper part of the Boltons beds. The other large body, named the 'Shaw Hill Diorite' by Mackenize (1968) though 'Shaw Hill Gabbro' is preferred, occupies much of Kiandra Plain and does not extend east into TANTANGARA, though dykes (?sills) at grid references 356387 and 369435 are probably connected to it at depth. Mackenzie (1968) has mapped several dykes immediately west of the first of these, but according to his map they are not connected to the main 'Shaw Hill Gabbro' mass.

All samples are similar, being composed of roughly equal proportions of plagioclase and clinopyroxene between 0.5 and 1.5 mm across. The plagioclase has been albitised, and the clinopyroxene mostly altered to pale or colourless actinolite, but a well-developed ophitic texture is still preserved. Unaltered clinopyroxene is colourless, with $2V_z = 40^o$ and $Z \wedge c = 41^o$. Epidote derived from the albitisation of plagioclase, granular very dark brown ?iron oxide, chlorite, and quartz are common in irregular veins and patches.

A sample from the dyke at grid reference 356387 has not been albitised. Much of the plagioclase is sericitised but fresh grains are strongly zoned from An_{60} to An_{20}. The strong zoning may be a result of partial albitisation.

The intrusion south-southwest of Four Mile Hill is similar to those in the Gooandra Volcanics, as it is composed mostly of subophitic plagioclase and clinopyroxene. Average grainsize is about 0.3 mm. The subophitic texture and absence of potash feldspar (proved by staining) are in marked contrast to the intrusions related to the Nine Mile Volcanics. If this body is related to the Gooandra Volcanics it provides one of the few clues to their age.

Thickness of the Gooandra Volcanics

The greatest width across strike of the Gooandra Volcanics is 5 km, near the type section. Dips are generally to the west-northwest at 60^o or more. Whether the sequence is repeated by folding is not known, but the gross difference in the lithologies between the eastern (lavas) and western (breccia and pillow lavas intruded by gabbro) outcrops suggests that any repetition is probably only local. Consequently, and as the volcanics are fault-bounded, they are probably at least 3 km thick.

Environment of deposition

The breccias of the western Gooandra Volcanics were obviously deposited in a subaqueous environment; this is shown by the presence of pillow lavas and pillow breccias. In contrast, the lava belt in the east of the outcrop is more difficult to interpret. Most lavas are massive and some are flow-banded, though breccias are present, and interbedded sediments are uncommon, probably more so than in the west. However, this does not preclude them from a subaqueous environment of deposition, as lavas can flow quietly on the sea floor at pressures greater than the critical pressure of water

(McBirney,1963) corresponding to a depth of 2000 m or more. McBirney (1963) and Rittmann (1969) showed that quiet eruptions could also occur at shallower depths (as shallow as 500 m) - the depth depending on the water content of the magma. Thus the lavas in the Gooandra Volcanics could conceivably have erupted as quiet flows on the sea floor if the water was greater than 500 m deep. Alternatively these lavas could be subaerial, but there is little evidence of a shallow-water environment - such as interbedded limestone, shallow-water ash beds, and reworked tuffs - between the western breccia belt and the eastern lava belt. There is no evidence to suggest that the eastern belt is the younger, though intrusive equivalents are concentrated in the western belt.

The most likely interpretation is that the whole of the Gooandra Volcanics is submarine. That the lavas behaved differently in the two belts may be due to their eruption in contrasting depths of water (shallower in the west); their composition (more evolved in the west); or their water content (higher in the west).

Age and relations

The Gooandra Volcanics are entirely fault-bounded, so their relations with other rock units are difficult to assess. None of the arenites in the Temperance Formation contains lava fragments that could have come from only the Gooandra Volcanics, although some from low in the formation are low in K_2O, a feature in common with the Gooandra Volcanics. Some of the lava fragments in the Temperance Formation contain clinopyroxene and hornblende phenocrysts, which have not been observed in the Gooandra lavas. Perhaps some of the fragments are from the Gooandra Volcanics and others are from unexposed volcanics.

The Gooandra lavas have been metamorphosed along with the Kiandra Group. The greenschist-grade Nine Mile Volcanics are unconformably overlain by the unmetamorphosed late Llandoverian to ?early Ludlovian Peppercorn Formation north of Long Plain. The Gooandra Volcanics must have been metamorphosed before the Peppercorn Formation was deposited - i.e. before the late Llandoverian.

The Gooandra Volcanics are more highly metamorphosed than the adjacent Nine Mile Volcanics and Temperance Formation. This could be an indication that the Gooandra Volcanics are lower in the sequence, and hence older.

Two kilometres southwest of Four Mile Hill a dolerite stock intrudes the Darriwilian Boltons beds. This stock is petrographically similar to intrusions within the Gooandra Volcanic pile; if these are indeed related, then the volcanics cannot be older than the Darriwilian.

A Late Ordovician age is most likely for the Gooandra volcanism, part of the Molong Volcanic Arc. Chemical affinities to an island-arc tholeiite (see GEOCHEMISTRY AND PETROGENESIS) suggest that the Gooandra Volcanics erupted early in the history of the arc. We suggest that they correspond to the age of the earliest volcanic detritus in the Temperance Formation and so are probably late Darriwilian or early Gisbornian.

KIANDRA GROUP:

Temperance Formation and Nine Mile Volcanics

Fairbridge & others (1951) introduced the name 'Kiandra Beds' for the Ordovician rocks exposed around Happy Jacks Pondage, and subdivided them into the 'Boltons Greywacke', 'Temperance Chert', and 'Nine Mile Shale'. Moye (1953) restricted the 'Kiandra Beds' to those units in which volcanic rocks were an important component - that is, the 'Temperance Chert' and Nine Mile Volcanics ('Nine Mile Shale' of Fairbridge & others) - and regarded the Boltons beds (='Boltons Greywacke' of Fairbridge & others) as a separate unit underlying the 'Kiandra Beds'. This nomenclature has been followed by later authors (Best & others, 1964; Moye, Sharp, & Stapleton in Packham, 1969; and Crook, Bein, Hughes, & Scott, 1973).

In this work we rename the 'Kiandra Beds' the Kiandra Group, and consider it to comprise the Temperance Formation (renamed herein from 'Temperance Chert') and Nine Mile Volcanics. In our previous account (Owen & others, 1974b) we included in the Nine Mile Volcanics a large belt of 'andesitic' lava which crops out from Kiandra, north to Rules Point on the western edge of TANTANGARA. Further work on the petrography and geochemistry of these lavas, and an examination of the type section of the Nine Mile Volcanics, on the Tumut River, has demonstrated that the lavas have a different composition from those in the Nine Mile Volcanics. We therefore recognise this belt of lava as a separate formation, the Gooandra Volcanics, which we exclude from the Kiandra Group because of the uncertain relations between the Gooandra Volcanics and other units.

The Kiandra Group contains lavas having high-potassium calcalkaline affinities, as distinct from the Gooandra Volcanics, which appear to have tholeiitic affinities.

Temperance Formation

Nomenclature

Fairbridge & others (1951) gave the name 'Temperance Chert' to a formation of interbedded chert and volcanic rocks near the junction of the Happy Jacks and Tumut Rivers (KOSCIUSKO and YARRANGOBILLY). Moye (1953) recognised the unit as the basal part of the 'Kiandra Beds' and referred to it as the 'Temperance Cherts'. Our work in the Happy Jacks Pondage area and in TANTANGARA has shown that agglomerate, tuff, and volcanic litharenite, with quartz-bearing siltstone near the base, are important components of the formation, and that chert is not the main lithology. The name Temperance Formation and not 'Temperance Chert' therefore appears more appropriate.

Derivation of name

The formation was named after Temperance Creek, a tributary of the Tumut River (YARRANGOBILLY).

Type section

Fairbridge & others (1951) referred to the outcrop of the formation in Temperance Creek as the type area. We have described a type section on Temperance Creek (Fig. M5, Table M3), from 1100 m southwest of Skeleton Creek to 400 m east of Frenchmans Creek (YARRANGOBILLY). Owen & others (1974b) have described several supplementary sections.

TABLE M3. TYPE SECTION OF THE TEMPERANCE FORMATION

Location: YARRANGOBILLY (Fig. M5)

Approximate distance (m)	Geographic description	Geological description
0	Start of section; on S side of Temperance Creek, 1100 m SE of Skeleton Creek. Longitude 148°28'00", latitude 35°59'19" on Cabramurra SMA 1-Mile Series Sheet; section runs parallel to creek, in downstream direction	Chert and impure chert; interbeds of siltstone and fine quartzite, gradational contact with underlying Boltons beds
30		Large exposure of very fine bedded chert, cherty tuff and quartz siltstone
170	Opposite crest of spur	Interbedded tuff, chert, and tuffaceous chert
290	SW from crest of spur	Massive banded chert; cherty volcanic arenite and fine-grained cherty tuff. Interbeds of very fine-grained albite-arenite, in part tuffaceous
410	Across gully that joins Temperance Creek	Tuff
430		Soil fragments of black slaty argillite and very fine-grained tuff
650	A minor spur, where creek curves W	Coarse tuff and agglomerate with clasts of basalt and chert up to 20 cm
770	Across minor tributary gully	Fragments of chert and tuff
800		Chert and very fine-grained tuffaceous chert
820	End of section, opposite mouth of unnamed creek that flows into Temperance Creek from northeast. Longitude 148°27'27", latitude 35°59'18" on Cabramurra SMA 1-Mile Series Sheet	Inferred 'M-Bend' Fault. Tuff, tuffaceous chert, and chert to E, no exposure to W

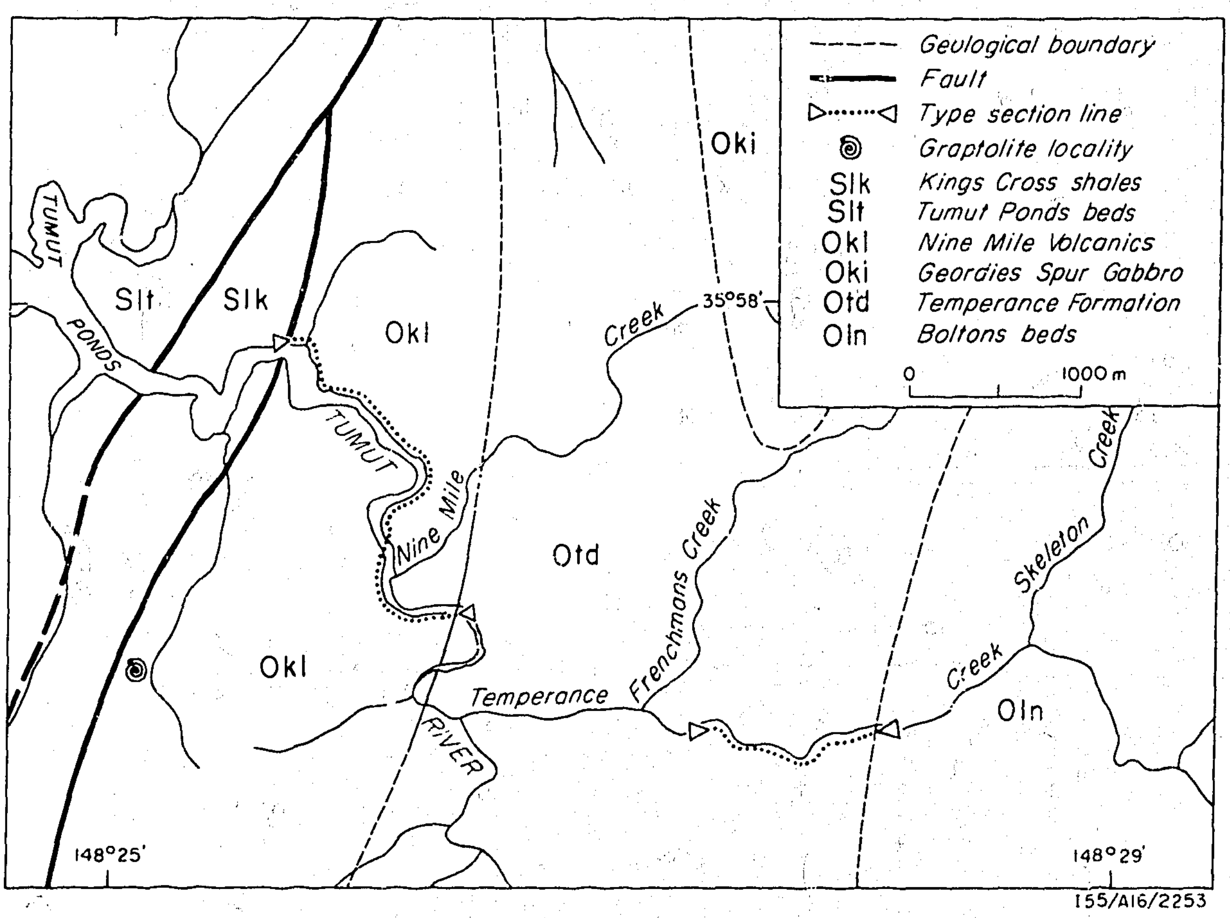


Fig M5 Location of type sections of Nine Mile Volcanics and Temperance Formation

Distribution

The Temperance Formation extends north-northeast from the type area into TANTANGARA. From the northern side of Sawyers Hill, it continues northeast to Boggy Plain and north in a narrowing belt to about the latitude of Rules Point, where much of it dips unconformably beneath the Tantangara Formation. A short distance farther north on the eastern side of Long Plain the outcrop widens, and extends past McPhersons Creek to where the chert dips beneath the Kellys Plain and Nine Mile Volcanics; to the east, a narrow southward extension becomes broader near Tantangara Reservoir, and a small inlier within Silurian sediments crops out on the Murrumbidgee River upstream of Tantangara Dam. Farther north, the Temperance Formation crops out east of Peppercorn Hill.

Lithology

General description. The Temperance Formation is formed essentially of chert, clinopyroxene tuff, and albite siltstone. In addition, agglomerate, tuffaceous chert, quartz-bearing siltstone, and shale locally dominate the lithology. Mapping of TANTANGARA, together with parts of YARRANGOBILLY and KOSCIUSKO, has enabled us to subdivide the Temperance Formation into four mappable units: interbedded chert and tuff (Otd in TANTANGARA); mainly pure chert (Otc); and a subordinate thick agglomerate bed (Otb), and tuff beds (Ott) of mappable extent in Otc.

In the following pages a general account of the rock types in each unit is given first, followed by a detailed description of the petrography of individual rock types.

The unit of interbedded chert and tuff (Otd) is the most widespread unit in the Temperance Formation. Reinvestigation of the type area around Happy Jacks Pondage has indicated that it is the only unit present there (contrary to the opinion of Owen & others, 1974b), and it extends northwards to the northern limit of outcrop of the Temperance Formation in Peppercorn Creek. It is particularly well developed in the area north of Sawyers Hill and Tantangara Mountain, where it has a gradational boundary with the underlying Boltons beds.

The basal part of the unit consists of poorly sorted quartz arenite, quartz siltstone, chert, and pyroxene tuff in beds from 20 mm to 3 m thick; evidence from rarely preserved sedimentary structures indicates that at least some of the quartz-rich rocks have been deposited in a distal turbidite environment. One hundred metres above the base of the unit, clastic quartz material is rare, and chert and tuff predominate. Chert is the more common, and forms beds - commonly slumped - 5 cm to 1 m thick with bands 1 mm to 5 cm thick (Fig. M6). Pure chert is relatively rare; usually fine albite grains are scattered through the rock. Tuff beds from 1 cm to 1 m thick are common, and at some localities they are much thicker - for example, a layer of tuff exposed on the Eucembene River east of Kiandra is about 200 m thick. Albite-rich arenite and siltstone form thin beds up to 5 cm thick throughout the unit but are never a major component. Otd exposed on Little Peppercorn Plain differs from that farther south: it lacks thick tuff beds, and instead comprises alternating lamellae, 2 mm to 2 cm and rarely to 5 cm thick, of chert and tuff which show graded bedding.

The chert unit (Otc) forms a northward thickening wedge that divides the interbedded chert and tuff unit into a lower and upper member from Kiandra northwards. The chert reaches a maximum exposed thickness in the Boundary Creek/McPhersons Creek area, but is covered by younger formations farther north. It is mainly pure chert, in which detrital grains are virtually absent, and tuffaceous interbeds rare. In two areas, tuffaceous beds within the chert unit are distinctive enough to be mapped: on Wild Horse Plain is a sequence of tuff and chert with a distinctive agglomerate bed (Otb); and on Dairymans Plain one thick and several thinner mappable beds of pyroxene-rich basaltic tuff (Ott) are exposed within the chert unit.

The agglomerate bed on Wild Horse Plain is perhaps 10 m thick, and comprises rounded to angular clasts of basalt, tuff, and chert, generally up to 30 cm, in a cherty tuffaceous matrix. In places, boulders of basalt and tuff are up to 2 m (e.g., at grid ref. 385325). Sorting is generally extremely poor and bedding absent, though in some places thinly bedded coarse, moderately sorted volcaniclastic sediments and graded bedding are evident. The tuff associated with the agglomerate is usually massive, in beds up to 1.5 m thick, and shows rare graded bedding. The chert interbeds are rarely more than 4 cm thick. The total thickness of the sequence is about 100 to 150 m. From the evidence of rare graded bedding and the presence of both volcanic and sedimentary clasts in a cherty tuffaceous matrix, the sequence is likely to have been deposited by a series of submarine rubble flows (Jones, 1967).

The tuff unit within the chert on Dairymans Plains (Ott) is a coarse to fine-grained reworked tuff possibly 250 m thick. The coarser beds are massive, whereas the finer-grained beds show parallel lamination, graded bedding, and contorted bedding. Angular chert fragments, and volcanic rock fragments up to 20 cm, are common. The contact with the underlying chert is commonly marked by a zone of contorted bedding up to 2 m thick. The whole sequence appears to have been deposited by a series of turbidity flows.

Petrography: Quartz arenite and siltstone are present only within the lowest part of the Temperance Formation, and reflect the gradational contact with the underlying quartz-rich flysch of the Boltons beds. the arenites are similar in composition to those described earlier from the Boltons beds: poorly sorted subangular to angular quartz grains, rarely greater than 0.2 mm in diameter, in a partly recrystallised clayey matrix. Zircon and tourmaline are present in the coarser beds. The arenites differ from those in the Boltons beds, however, in that they may contain up to 5% of volcanically derived grains of plagioclase and rare altered clinopyroxene. Sedimentary structures within the quartz arenite and siltstone indicate deposition in the distal part of turbidite flows.

One arenite sample (from grid ref. 422479) is remote from any Boltons beds outcrops, but contains about 6% subangular detrital quartz grains less than 0.2 mm, and a few grains of pale brownish green tourmaline. The rest of the rock is detrital plagioclase, clinopyroxene, hornblende, and basic volcanic rock fragments. The presence of quartz and tourmaline at this locality is difficult to explain, unless the Boltons beds/Temperance Formation gradational contact is just below the surface.

Albite arenite and siltstone are widespread throughout the Temperance Formation. They occur as interbeds up to 5 cm thick, often show graded bedding, and are poorly sorted and composed of rounded to subangular grains of albite in a fine groundmass of phyllosilicates, calcium silicates, authigenic albite, calcite, and chert. Some albitised detrital plagioclase grains retain a subhedral or even a euhedral outline. Instead of albite, fresh plagioclase of labradorite composition occurs in places (see below). A complete gradation exists between albite, pyroxene-hornblende, and volcanic arenites. As the proportions of clinopyroxene and hornblende grains and rock fragments increase, the grainsize tends to increase and the beds thicken. In the thicker beds, in which the average grainsize exceeds 1 to 2 mm, basaltic and tuffaceous rock fragments become the main detritus. These fragments are commonly up to 10 mm but larger ones have been recorded, as in units Otb and Ott. The texture and mineralogy of these basaltic rock fragments is mostly identical to the lavas in the Nine Mile Volcanics, but, because of the variety of rock fragments concentrated in the coarse arenites, a number of primary igneous features have been observed in them that have not been seen in the Nine Mile Volcanics; indeed one arenite thin section may contain more lava types and mineral species than a dozen thin sections from lavas of the Nine Mile Volcanics.

Unalbitised plagioclase phenocrysts have not been found in the Nine Mile Volcanics lavas because they have been regionally metamorphosed, but fresh igneous plagioclase is present in Temperance Formation arenites and agglomerates in unmetamorphosed zones on the ridge northwest of Black Walters Creek, on the ridge southeast of Kiandra Creek, and near the unconformity with the overlying Tantangara Formation about 2 km south of Black Hill. The plagioclase is invariably labradorite, mostly of composition An_{55} to An_{60} but up to An_{70}. The crystals exhibit normal and oscillatory zoning and commonly have narrow margins of about An_{40}. Albite twinning is ubiquitous and Carlsbad twinning common. Rarely, unalbitised plagioclase occurs in agglomerate fragments in metamorphosed rock, in which the plagioclase is normally albitised: for example, in agglomerate (Otb, at grid ref. 369304) metamorphosed to the lower greenschist facies (see METAMORPHISM OF THE KIANDRA GROUP AND GOOANDRA VOLCANICS), porphyritic basaltic rock fragments contain euhedral plagioclase phenocrysts up to 6 x 2 mm; these phenocrysts are mostly highly sericitised, but in some unsericitised parts original albite twinning and Carlsbad twinning indicate compositions around An_{65}. Apparently fluids necessary for albitisation were not available in some of these agglomerates.

Most clinopyroxene crystals in the Nine Mile Volcanics and Temperance Formation are about 2 mm but they may reach 10 mm; such large crystals have been observed in basaltic rock fragments in unit Ott at grid reference 451451. They occur as euhedral phenocrysts along with smaller phenocrysts (0.3 mm) of albitised plagioclase and chloritised olivine. The clinopyroxenes are zoned with broad colourless cores and narrow (1 mm wide) oscillatory-zoned pale green rims. The rims have extinction angles ($Z^\wedge c$) a few degrees higher than the cores. This trend towards greenish clinopyroxenes is very common in the Nine Mile Volcanics and Temperance Formation, particularly in arenites in Ott at Dairymans Plain, where some clinopyroxenes are noticeably pleochroic with X = pale yellow-green, Y = pale green, and Z = pale yellow-green. It is even more striking in an arenite at grid reference 474414, where some of the clinopyroxene grains are clear, others are pale green, and a few are euhedral crystals that have X = pale emerald green, Y = pale green, and Z = pale brownish green with $Z^\wedge c = 52^\circ$. These pleochroic clinopyroxenes have optical properties which suggest that they contain a high proportion of acmite in their composition and are probably sodian augites.

Hornblende is a common mineral in arenites and rock fragments in the Temperance Formation. Rarely, such as in the arenite which contains the ?acmitic pyroxenes at grid reference 474414, hornblende dominates over clinopyroxene as the major mafic mineral, but more commonly it is subordinate. Basaltic rock fragments commonly contain both clinopyroxene and hornblende as phenocryst minerals, and one agglomerate rock fragment 20 cm in diameter from grid reference 409386 is a basaltic lava with about 25% euhedral phenocrysts of hornblende up to 6 x 1.5 mm, 5% euhedral phenocrysts of clinopyroxene, and 5% euhedral phenocrysts of sericitised plagioclase. The Temperance Formation hornblendes are commonly zoned from greenish to brownish. Some have greenish cores and more-brownish rims; others are the reverse. The two end-members have pleochroic schemes:

green: X = very pale brown
Y = brownish green
Z = green

brown: X = very pale brown
Y = Z = brown with a reddish tinge

Hornblendes are mostly between these two extremes. Some of them (mostly the brownish ones) are surrounded by reaction rims of nearly opaque material. Such 'opacite rims' are common round hornblendes in calcalkaline volcanic rocks (Yoder 1969; Jakeš & White, 1972b). An important feature of some arenites is the uniformity of hornblendes from the one bed: for example, if detrital hornblende grains are brown, the hornblende in the basaltic rock fragments from the same bed is also brown; also, if detrital hornblende is common, hornblende is also common as a phenocryst phase in the accompanying basaltic rock fragments. This suggests that much of the source material for a single volcanic arenite bed came from a single lava flow - that is, fluviatile transport of the detritus was minimal. Disintegration and transport must have been largely submarine in origin, and effected by the gravitational collapse of submarine pyroclastics on steep slopes.

The Nine Mile Volcanics and related intrusions contain abundant potash feldspar in the groundmass. This is also true for many of the lava rock fragments in the Temperance Formation (proved by staining), but volcanic arenites from very low in the Temperance Formation (e.g., at grid refs. 382282 and 364271) contain lava rock fragments without potash feldspar.

Definite lava flows have not been found in the Temperance Formation. The only outcrop which could be a lava is at grid reference 379290, but this is more likely to be a dyke. The rock is composed of about 20% greenish brown hornblende up to 4 x 1 mm, 15% very pale green clinopyroxene up to 2 mm, and minor sericitised plagioclase phenocrysts about 0.5 mm in a felted groundmass of feldspar microlites, amphibole, biotite, and opaques. The rock has been thermally metamorphosed by the Boggy Plain Adamellite (see METAMORPHISM OF THE KIANDRA GROUP AND GOOANDRA VOLCANICS), and most of the clinopyroxene has been altered to actinolite and biotite, but the hornblende is unaltered. In terms of its primary igneous mineralogy the rock is similar to the previously described hornblende-rich lava fragment from the agglomerate at grid reference 409386.

Chert within the Temperance Formation is formed from cryptocrystalline quartz, and when pure has little clay material; however, it often contains a small amount of fine silt-grade plagioclase or albite, or is recrystallised to a microcrystalline quartz mosaic by metamorphism. Pure chert commonly contains remains of radiolarian tests, and is mainly restricted to the chert unit (Otc). Within the interbedded chert and tuff unit (Otd) most beds of chert contain at least some volcanic material in the form of plagioclase and clinopyroxene crystal fragments less than 0.05 mm. A complete gradation may be seen from almost pure chert through tuffaceous chert and cherty tuff into tuff or volcanic arenite. Impure cherts are often finely laminated; the laminae, 1 to 5 mm thick, are alternately rich and poor in detritus. As the proportion of detrital material increases, the grainsize tends to increase: slightly impure cherts rarely have detritus more than 0.05 mm in diameter, whereas cherty tuffs commonly have grains around 0.5 mm.

Environment of deposition

The Temperance Formation is thought to have been deposited in a marine environment on the flank of the Molong Volcanic Arc, on the edge of the Monaro Slope and Basin (terminology after Scheibner, 1973). During much of its period of deposition, volcanic activity was mainly submarine, since most of the volcanic rocks are volcanic litharenites that are associated with chert and show evidence of submarine reworking but little or no fluviatile reworking. The widespread occurrence of bedded chert is taken to indicate deposition in moderately deep water. The lack of lavas in the Temperance Formation suggests that the marine volcanic centres providing the large amounts of tuffaceous material were outside the mapped outcrop area of the formation. The volcanic centres probably lay to the west, perhaps concealed by the present outcrop of the Nine Mile and Gooandra Volcanics. A preferred alternative interpretation is that the Nine Mile Volcanics at Peppercorn Creek in the north and Tumut Ponds (YARRANGOBILLY) in the south were volcanic centres of about the same age as the Temperance Formation (or at least the upper part of it), which they supplied with detritus. the Temperance Formation would then be regarded as a deeper-water facies lateral equivalent of the Nine Mile Volcanics. The presence of graded bedding, and the common occurrence of angular clasts of chert in the volcanic arenites, indicate that they have been deposited by slumping and turbidity currents off the edge of volcanoes. According to Menard (1956) and Jones (1967), submarine pyroclastic and epiclastic (mainly gravitational collapse) fragmentation followed both by rubble flow and by turbidity-current transport of material down the palaeoslope results in the development of a broad 'archipelagic apron' around volcanic centres. As Jones pointed out, these clastic aprons are in some instances two or three times more voluminous than the volcanic centres themselves, and this is probably so for the Temperance Formation.

Thickness

The thickness of the Temperance Formation is difficult to estimate, since outcrop is poor and structure complex. Using the information provided by Gardner (<u>in</u> Owen & others, 1974b), we estimate that the formation is about 2000 m thick in its type area in Temperance Creek, and may thicken to around 5000 m in the Long Plain area. Much of this increase in thickness is caused by the abundant development of chert in that area.

Relations

The Temperance Formation rests conformably on the Boltons beds with a gradational boundary. Thin chert beds occur in the uppermost part of the Boltons beds, and fine quartz arenite similar to that in the Boltons beds is present in the basal part of the Temperance Formation. The boundary is placed at the base of the first clinopyroxene-bearing volcanic arenite in the succession. It has been suggested that the Boltons beds may be younger than the Temperance Formation (Crook & others, 1973). As discussed earlier, a number of intrusive equivalents to the volcanic rocks in the Temperance Formation and Nine Mile Volcanics have been found intruding the Boltons beds, thus demonstrating that the Boltons beds cannot be younger than the Temperance Formation.

The boundary between the Temperance Formation and overlying Nine Mile Volcanics is placed at the level where clinopyroxene-bearing lava and tuff dominate the sequence. This too is a gradational boundary, and probably involves as well a lateral facies change. As discussed previously, the Temperance Formation is considered to be a clastic apron around volcanic centres; the Nine Mile Volcanics probably were the volcanic centres for the upper part of the Temperance Formation.

The relation between the Temperance Formation and the Gooandra Volcanics is not clear. Some lava rock fragments in the Temperance Formation may be derived from the Gooandra Volcanics, but, although mafic grains are present throughout the Temperance Formation, mafic phenocrysts have not been observed in the Gooandra Volcanics. Staining of volcanic arenites from low in the Temperance Formation has indicated that the lava rock fragments are low in K_2O; this feature is in common with the Gooandra Volcanics.

The Temperance Formation is considered to pass laterally eastwards into the Nungar beds.

Age

Only one fossil occurrence is known from the Temperance Formation. Crook & others (1973) reported the occurrence, in the chert on Dairymans Plain, of three poorly preserved inarticulate brachiopods referred to the family Obolidae. This family is restricted to the Cambrian and Ordovician.

Since the Temperance Formation in part underlies and in part is probably laterally equivalent to the Nine Mile Volcanics, which have yielded a late Gisbornian assemblage near their top, a late Darriwilian to ?late Gisbornian age is suggested for the formation.

Nine Mile Volcanics

Nomenclature

Fairbridge & others (1951) gave the name 'Nine Mile Shale' to a sequence of tuffaceous shale, chert, minor quartzite, and andesite overlying the Temperance Formation in the Tumut River and Nine Mile Creek areas. The name was first published by Fairbridge (1953). Moye (1953) renamed the unit the Nine Mile Volcanics, noting that andesitic tuff, lava, and agglomerate are important constituents of the unit. In this Bulletin, we use the name Nine Mile Volcanics, since lava and volcaniclastic sediments form the bulk of the unit, and the presence of lavas distinguishes it from the Temperance Formation.

Derivation of name

The name is derived from Nine Mile Creek, which flows into the Tumut River 2.7 km north-northwest of the mouth of Happy Jacks Pondage (YARRANGOBILLY).

Type section

Fairbridge & others (1951) designated, but did not describe, the type section as along the valley of the Tumut River above and below the mouth of Nine Mile Creek. Moye (1953) drew the boundary with the Temperance Formation across the Tumut River at the mouth of Temperance Creek. With the aid of a small boat, we re-examined the type section (Fig. M5, Table M4) when Tumut Ponds Reservoir was low. We have taken the base of the Nine Mile Volcanics as the point where chert and cherty tuff become minor components of the sequence, at grid reference 966632 (Cabramurra SMA 1-Mile Series Sheet area). This point along strike is close to Moye's base at Temperance Creek junction. The section continues down river to the Long Plain Fault at grid reference 961642. The total thickness of the section is estimated to be 1050 m. Repetition of the sequence by folding is not evident; all facing directions are to the west, and dips range from 65° west to vertical. Only 400 m of the section is dominated by lavas; this is similar to the thickness given by Moye (1953) for the lava belt along the Eucumbene-Tumut Tunnel line (KOSCIUSKO and BERRIDALE). The part of the sequence overlying the lava belt in the type section is cut out by the Long Plain Fault on the Eucumbene-Tumut tunnel line. Farther south, on the Happy Jacks Road, almost all the lava belt is cut out as well.

Distribution

Our interpretation of the distribution of basic volcanics in the Long Plain area differs from that of Owen & others (1974b) in that the tuffs and lavas cropping out at the northern end of Long Plain have been included in the Nine Mile Volcanics, whereas the lavas at the southern end of Long Plain and extending south through Gooandra to Kiandra have been called the Gooandra Volcanics. This interpretation is based on the similarity between the northern Long Plain outcrops and those at the Nine Mile Volcanics type area; the dissimilarity between the northern and southern Long Plain outcrops; and the recognition of a major fault, here called the Kiandra Fault, east of the Gooandra Volcanics.

The boundary between the Temperance Formation and Nine Mile Volcanics has been defined as where lavas and tuffs predominate over cherts and cherty tuffs. This occurs in only two areas - at the type area on Tumut River and at the northern end of Long Plain - though smaller occurrences of lavas interbedded with tuff are to be found along strike southward as far as the upper Murray River in JACOBS RIVER (L.A.I. Wyborn, 1977). To the north the Nine Mile Volcanics dip under Silurian and Devonian rocks near Little Peppercorn Creek. Rocks of similar age emerge regionally along strike from beneath

TABLE M4. TYPE SECTION OF THE NINE MILE VOLCANICS

Location: Cabramurra SMA 1-Mile Series Sheet area (Fig. M5)

Approximate distance (m)	Geographical description	Geological description	Approximate thickness of section (m)
0	Start of section; on south side of Tumut River about 50 m west of bend in river at grid ref. 966632, Cabramurra SMA 1-Mile Series Sheet. Section runs downstream along river	Base of Nine Mile Volcanics. Taken as point where albite tuff and arenite predominate over chert and cherty tuff of the Temperance Formation	160
180	Bluff on true* left bank of river	First lava flow in sequence. Porphyritic lavas 10-20 m thick interbedded with tuff and cherty tuff. Tuffs commonly graded-bedded. Dips 65-80° W, facing west	50
240		Albitised plagioclase porphyry (?intrusion)	20
260		Interbedded lava, tuff, and cherty tuff	140
320	River bends to north		
490	Nine Mile Creek enters from right	Bedding strike 174°, dip 64°W, facing west	
640		Massive medium-grained diorite intrusion (Lower Devonian type)	Not applicable
760		End of diorite intrusion. Interbedded lava, tuff, and cherty tuff	50
860	River bends northwest	Section repeated. Devonian intrusion absent	
1150	River again bends northwest	Albitised pyroxene-plagioclase porphyry (?intrusion) in prominent bluff on point on true left bank of river	
1400		Approximate end of repeated section. Interbedded lava, tuff, and tuffaceous chert	150
1600		Lavas absent. Interbedded tuff and cherty tuff	200
1900		Lava flow	20
1920		Tuff and cherty tuff	80
2000	River bends north	Prominent bluff of tuff on point on true right bank	30
2040		Section on true right bank. Tuff grades into brown and grey silty shale. Shale is along strike with graptolitic black shale at grid ref. 956633. Dip vertical, facing west	150
2300	River bends west, gully enters from north		
2330	End of section at bluff	Large quartz reef marking position of Long Plain Fault	

Total thickness of section 1050 m; lavas dominate in 400 m of it.
* True left bank refers to the river before submergence.

Silurian and Devonian cover north of Boorowa, about 130 km north of Little Peppercorn Creek; these rocks are basic tuffs and lavas of the Kenyu Formation, but their correlation with the Nine Mile Volcanics is rather speculative.

The distribution of the Nine Mile Volcanics near the type section is not completely known. They probably extend north to Clear Creek, where they would be faulted out by the Long Plain Fault and possibly the Kiandra Fault. To the south they are covered by Tertiary basalt on Fifteen Mile Spur, but just before dipping beneath the basalt their strike bends from south to southwest, so they are probably faulted out by the Long Plain Fault. They are certainly not present on the Tumut River at the northern end of Farm Ridge.

At the northern end of Long Plain most of the flat country is occupied by the Nine Mile Volcanics. The rocks extend northeast along Peppercorn Creek to its junction with Little Peppercorn Creek, where they are in part unconformably overlain by and in part faulted against the Peppercorn Formation.

The total area of outcrop of the volcanics at the northern end of Long Plain is about 15 km^2, and, near the type section, probably about 10 km^2.

Lithology

As the two areas of outcrop of Nine Mile Volcanics are over 35 km apart and have suffered from different degrees of metamorphism, they are described separately.

1. Tumut River area

General description. The Nine Mile Volcanics in the Tumut River area consist of well-exposed interbedded lava, tuff, and tuffaceous chert, which form virtually 100% exposure along the river and bluffs and scree on the steep slopes above the river. All rock types including chert and siltstone are greyish green because of the abundance of ferromagnesian minerals, mostly of secondary metamorphic origin. Lavas predominate in only the lower middle part of the sequence (see Table M4), and crop out on the river as massive bluffs. Individual flows are less than 20 m thick, and mostly contain abundant phenocrysts of plagioclase in random orientation. Many of the flows also contain equant mafic phenocrysts a few millimetres across, but these are never as abundant as the plagioclase. Several samples collected in the field as lavas with mafic phenocrysts may be intrusive even-grained dolerites (see Petrography, below).

Pale green feldspathic tuff and arenite are present between the lava flows. The coarser-grained beds are commonly graded and up to 60 cm thick (Fig. M7). Detritus in the graded beds is almost exclusively subhedral feldspar laths up to 5 x 3 mm at the base of a bed. These laths are similar in size to the phenocrysts in the lavas. As the detrital component in these clastic rocks becomes finer-grained, chert becomes a major constituent, and the rocks are then well bedded with bedding thickness mostly less than 5 cm.

At the top of the type section the tuff grades into about 150 m of greenish brown and grey silty shale whose top is cut by the Long Plain Fault. These shales are strongly cleaved and not well bedded, but on the ridge to the south at grid reference 956633 (Cabramurra SMA 1-Mile Series Sheet) the shales are darker, well bedded, and commonly cherty. Here they dip about 85^{o} west, face west, and contain common graptolite remains which have been described by Sherrard (1954).

West of the Long Plain Fault, rocks of the Tumut Trough succession (Kings Cross shales and Tumut Ponds beds) crop out for about 2 km down the Tumut River, until the Tumut Ponds Serpentinite crops out along the Gilmore Fault Zone. West of this fault, siltstone and shale with interbedded plagioclase tuff and minor lava crop out between Rough Creek and Fifteen Mile Creek, and on the Alpine Way at grid reference 944652 (Cabramurra SMA 1-Mile Series Sheet). These rocks are similar to those at the top of the Nine Mile Volcanics, have been called the Coppermine Creek Volcanics by Moye (1953), and were correlated with the Nine Mile Volcanics by Moye & others (1963).

Petrography. The lavas from the type section are all very similar in containing abundant (20-50%) phenocrysts of euhedral to subhedral albitised plagioclase up to 8 x 3 mm. Clinopyroxene phenocrysts are less abundant (0-10%), and are up to 3 mm; they are mostly completely altered to pale blue-

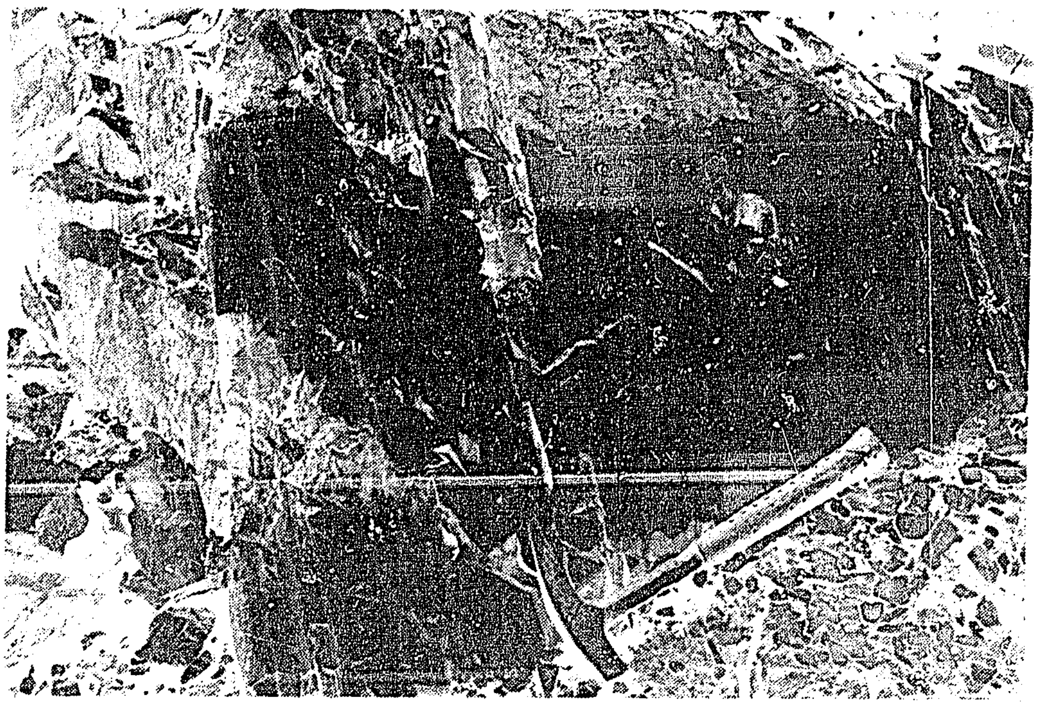


Fig. M6. Banded chert in the Temperance Formation on the Tumut River at Happy Jacks Pondage, grid reference 303143, KOSCIUSKO. The dark bands are richer in albite and volcanic debris than the lighter bands, which are relatively pure chert.
(GB/1830)

green actinolite, biotite, and chlorite, but a few scattered phenocrysts still contain relict cores of clinopyroxene. The groundmass of the lavas is a fine mat of aligned feldspar microlites, chlorite, biotite, actinolite, and opaques. Staining with sodium cobaltinitrite solution produced a positive result for potash feldspar in all the lava samples collected. Albite phenocrysts along and adjacent to fractures were also stained, possibly indicating that potash feldspar was at some stage partly mobilised into these fractures.

One lava sample collected from next to the dioritic intrusion of Early Devonian type mentioned in Table M4 is strongly hornfelsed. The albite and altered clinopyroxene are still present, but the groundmass is now a subgranoblastic assemblage of albite (50%), greenish brown biotite (35%), actinolite, chlorite, and opaques.

The presence of potash feldspar and biotite in these lavas strongly suggests that they were originally high in K_2O, the original potassic mineral being potash feldspar, which has now partly altered to metamorphic biotite in the groundmass. The presence of metamorphic biotite along with albite and actinolitised clinopyroxene indicates that the rocks in this area have been regionally metamorphosed to the upper greenschist facies. that the rocks appear to have retained much of their K_2O has been confirmed by L.A.I. Wyborn (1977), who reports K_2O contents of over 2% in her analyses. The basalts at the northern end of Long Plain, and those in basaltic rock fragments in the upper part of the Temperance Formation, are similarly high in K_2O. It is mainly this fact that leads us to include the lavas at the northern end of Long Plain in the Nine Mile Volcanics, whereas the lavas now termed Gooandra Volcanics are excluded, as they are low in K_2O, which appears to be a primary igneous feature.

The tuffs in the Nine Mile Volcanics are composed of subhedral to anhedral detrital albitised plagioclase and volcanic rock fragments up to 0.3 mm. The matrix consists mostly of epidote, calcite, chlorite, and finer-grained albite. In some samples epidote is abundant; in others, calcite. The tuffs collected from the type section differ from those in the Temperance Formation and in the northern Long Plain outcrop as they contain no detrital clinopyroxene or hornblende, but samples collected from Fifteen Mile Spur (1 km southeast of the graptolite locality, Fig. M5) are more typical: they contain abundant altered detrital clinopyroxene and unaltered detrital brown hornblende, as well as volcanic rock fragments with phenocrysts of those minerals.

Three samples of possibly intrusive rock were collected from the type section. One of these, a fine-grained dyke rock from grid reference 964635 (Cabramurra SMA 1-Mile Series Sheet), is composed of euhedral brownish green hornblende and subhedral sericitised plagioclase phenocrysts in a fine-grained groundmass that is half quartz and half zoned plagioclase (An_{60-30}). The absence of potash feldspar (revealed by staining), and the unalbitised plagioclase, suggest that the rock is not related to the Nine Mile Volcanics; it may be of Devonian age.

The other two samples were thought to be lavas in hand specimen, but thin sections show that they are composed almost entirely of euhedral plagioclase laths and lesser euhedral altered clinopyroxene crystals of 1 to 2 mm. They are strongly altered to albite, actinolite, epidote, and chlorite, though one (from grid ref. 964636, Cabramurra SMA 1-Mile Series Sheet) still contains relict An_{55} plagioclase and minor fresh clinopyroxene. The rocks appear to have no groundmass and therefore may be intrusive, but the extensive alteration may have masked small amounts of groundmass between larger crystals. Staining for potash feldspar showed the presence of small amounts between plagioclase grains in both samples. This - combined with the facts that the major phases are morphologically similar to the phenocrysts in the lavas, and that the rocks have suffered from the same upper greenschist facies metamorphism as the lavas - suggests that these possibly intrusive rocks are related to the lavas and represent some sort of cumulate concentration of the phenocryst phases present in the lavas. A likely alternative to the suggestion that the rocks are intrusive is that they represent crystal cumulates formed by in situ gravity settling toward the base of individual lava flows.

2. Northern Long Plain area

General description. In the northern Long Plain area the Nine Mile Volcanics have been divided into units of tuff, lava, and sediments. Despite the intense faulting, most of which postdates the overlying Silurian Peppercorn Formation but antedates the Devonian Kellys Plain Volcanics, we have established a general stratigraphic order. This consists of the

Temperance Formation conformably overlain by tuff (Okt), then lava (Okl), followed by more tuff (Okt), and finally volcanically derived sandstone and shale (Oks). We suggest that the lava unit is younger than the lower tuff unit, against which it is faulted. The sediments on the ridge west of Peppercorn Creek (and east of Little Peppercorn Hut) appear to lie in a syncline with underlying tuff on either side. To the south the lava unit appears to be faulted out, and the whole sequence is faulted out by the Long Plain Fault at grid reference 421540. The thickness and order of units in the sequence is quite similar to that in the type section.

Exposure is generally quite good. The tuffs and lavas form massive and cleaved rounded blocks protruding from grassy areas of mostly concealed outcrop. In a few places they form slabs and pavements up to 20 m wide. The sediments are only poorly exposed in road-cuttings, steep-sided streams, and on the slopes of the steeper hills.

The contact between the lower tuff unit and the Temperance Formation is gradational over about 20 m. The tuff is pale green, commonly cherty, and has chert interbeds up to 20 cm thick. The presumably overlying lavas are pale to dark green with a narrow light green weathering skin, and contain abundant pyroxene phenocrysts up to 5 mm. At some outcrops vesicles are abundant, and locally make up 30% of the rock. When vesicles are less abundant they are commonly filled with white calcite and pale pink feldspar, and are up to 10 mm. Elsewhere the lava unit has neither vesicles nor amygdales. At grid reference 465605 a well-preserved lava flow shows angular blocky structures and clinker-like surfaces, possibly indicating subaerial extrusion. The flow unit is in part faulted against and in part conformable beneath another (the upper) tuff unit. At both boundaries, a line of ferruginised outcrops is prominent along the northwest side of Peppercorn Creek north of grid reference 482622. A drillhole through this zone revealed underlying limestone, and at grid reference 486626 limestone crops out about 30 m west of the ferruginised zone. Apparently the limestone hr acted as a favourable horizon for the precipitation of iron from meteoric waters; the iron is derived from the weathering of the surrounding volcanic rock. The only fossil found in the limestone is a conodont specimen of genus Belodina (range middle to late Ordovician) identified by R. Nicoll (BMR). Legg (1968) recorded a poorly preserved streptelasmatid rugose coral (middle Ordovician to Middle Devonian) in a nearby limy tuff whose outcrop we could not find.

Fig. M7. Graded-bedded plagioclase-rich volcanic arenite in the Nine Mile Volcanics at the type section on the Tumut River. (GB/1831)

The presence of limestone interbedded with the Nine Mile Volcanics indicates a shallow-water environment, probably adjacent to a volcanic island.

The upper tuff unit, above the limestone, is similar to the lower tuff unit, but lavas are interbedded with it, especially on Long Plain adjacent to the Peppercorn Trail, where the lavas crop out as boulders up to 2 m in diameter.

The upper tuff unit is overlain by sediments, mainly fine-grained pale green sandstone and siltstone with lesser black chert, pyritic chert, and buff shale. D. Strusz (BMR, personal communication 1974) has identified poorly preserved graptolites from a dark grey siltstone at grid reference 483634 as Climacograptus and Orthograptus. The top of the sequence is faulted out by the Long Plain Fault.

Petrography. All the lavas in the Nine Mile Volcanics in the northern Long Plain area are extremely porphyritic, containing between 30% and 60% euhedral phenocrysts. Phenocryst minerals that have been identified are clinopyroxene, plagioclase, olivine, hornblende, biotite, magnetite, and apatite. The relative proportions of the phenocryst minerals vary, and one or two of them are commonly absent.

Clinopyroxene, the most abundant phenocryst mineral, is mostly completely unaltered, except for incipient marginal alteration to actinolite in the zone of greenschist metamorphism, and, rarely, where carbonate is abundant (e.g., at grid ref. 461601) the clinopyroxene is completely altered to a mixture of calcite and chlorite. Fresh clinopyroxene occurs as euhedral crystals up to 4 mm with $2V_z$ =45 to 50° and $Z \wedge c$ = 44°. The crystals are mostly pale green and non-pleochroic, and are probably diopsidic augite, but some show weak pleochroism with X = Z = pale yellowish green and Y = pale green. Others are zoned with pale non-pleochroic cores and darker pleochroic rims. The pleochroic variety has $Z \wedge c$ up to 47°.

Plagioclase, the next most common phenocryst mineral after clinopyroxene, occurs as euhedral laths up to 4 x 2 mm. All of it has been altered to albite, in which epidote, prehnite, and less commonly pumpellyite and sericite form inclusions. The presence or absence of a particular included mineral depends on the grade of metamorphism.

Olivine forms euhedral phenocrysts up to 4 mm. It is completely altered to chlorite, and less often chlorite with a core of composite quartz. In the lower metamorphic grades, minor prehnite accompanies the chlorite, whereas, at higher grades, needles of actinolite radiate inwards from the margins of the pseudomorph. Minor calcite and epidote are also present in some grains. Despite the complete alteration there is no difficulty in recognising that the crystals were once olivine, as they are stumpy prisms with the characteristic acute-angled double termination.

Biotite is rare in the lavas, but is more abundant in their intrusive equivalents (see Intrusions related to the Nine Mile Volcanics), possibly because alteration effects are less in the intrusions. One lava sample (from grid ref. 455602), however, contains about 5% biotite as equant phenocrysts up to 0.5 mm. The biotite is almost completely altered to chlorite, prehnite, opaques, and epidote, which are arranged in layers parallel to the original cleavage. Unaltered brown biotite is present in some of the phenocrysts, mostly surrounded by chlorite.

Hornblende, rare in the lavas from the northern end of Long Plain, forms scattered elongate prisms and needles. It is much more abundant in volcanic arenites in the Temperance Formation, implying that the exposed area of Nine Mile Volcanics is depleted in hornblende relative to the whole volcanic pile. The hornblende in the lavas is greenish brown and surrounded by a reaction rim which is almost opaque and of unknown mineralogy. These rims are present around many of the hornblendes in rock fragments in the Temperance Formation, and tend to be more common around brownish than greenish varieties, but most hornblendes in the Temperance Formation do not have the reaction rim.

Apatite and magnetite are ubiquitous accessory microphenocrysts in the lavas, occurring as euhedral crystals less than 0.5 mm. The apatite is equally abundant (about 1%) in all samples but magnetite is much more variable, with as much as 5% in some samples.

The phenocryst mineralogy correlates well with the MgO content of the rock (Table M5), and apparently indicates a well-defined differentiation trend. Lavas with the highest MgO content contain olivine and clinopyroxene phenocrysts only. Those with slightly lower MgO also contain plagioclase.

TABLE M5. PHENOCRYST MINERALOGY OF NINE MILE VOLCANICS LAVAS AND SOME RELATED ROCKS

Sample no. and grid ref. (TANTANGARA)	Phenocryst mineral	Percent in rock	Maximum size (mm)	Rock type*	MgO content (%) of rock
71840240 (421363)	clinopyroxene	45	2	olivine monzonite	9.9
	olivine	5	1		
	red-brown biotite	3	0.5		
	magnetite	1	0.5		
71840498 (491624)	clinopyroxene	40	4	olivine monzodiorite porphyry	9.35
	olivine	5	4		
71840492 (471614)	clinopyroxene	35	2	absarokite	8.88
	olivine	15	1		
	plagioclase	5	1		
	opaques	3	0.5		
70840037 (428547)	clinopyroxene	35	2	olivine monzonite	7.63
	olivine	5	2		
	plagioclase	5	1		
	magnetite	5	0.8		
	brown biotite	0.5	0.3		
	very dark brown hornblende	0.5	0.3		
71840490 (479610)	clinopyroxene	25	3	olivine monzonite porphyry	6.85
	plagioclase	10	1		
	olivine	5	1		
	biotite	2	0.5		
71840485 (457601)	plagioclase	30	2 x 1	shoshonite	6.30
	clinopyroxene	25	2		
	magnetite	4	0.3		
	hornblende	1	1.5 x 0.3		
71840296 (409386)	hornblende	25	6 x 1.5	shoshonite boulder from agglomerate	4.56
	plagioclase	15	4 x 2		
	clinopyroxene	5	3		
	opaques	2	0.3		
	apatite	1	0.2		
71840390 (455602)	plagioclase	35	4 x 2	biotite shoshonite	4.15
	clinopyroxene	15	2		
	biotite	5	0.5		
	magnetite	4	0.4		
	apatite	1	0.5		
72840264 (991672, Cabramurra SMA 1-Mile Series Sheet)	plagioclase	35	4 x 2	quartz monzodiorite	2.61
	hornblende	20	2 x 1		
	biotite	3	0.5		
	apatite	1	1.5 x 0.5		

With still lower MgO, plagioclase is more abundant and olivine is absent. Rocks with the lowest MgO contents contain hornblende as well as clinopyroxene and plagioclase. Biotite, apatite, and opaques do not seem to follow any pattern; by combining evidence from the Nine Mile Volcanics, Temperance Formation, and intrusions equivalent to the Nine Mile Volcanics lavas, it appears that biotite and opaques phenocrysts may or may not be present at any stage in the differentiation sequence, whereas apatite is equally abundant right through the sequence. Table M5 gives some examples of the phenocryst mineralogy of the lavas, and also of a lava fragment from the Temperance Formation and of some intrusive rocks.

The groundmass of the lavas is similar in all samples. It is a felted mass of feldspar microlites up to 0.3 x 0.05 mm (but mostly much smaller), and interstitial chlorite, opaques, granular iron-rich epidote, and minor amounts of other Ca-rich low-grade metamorphic minerals. In many samples the microlites are partly aligned parallel to a primary flow foliation. Staining with sodium cobaltinitrite reveals that most of the feldspar is potash feldspar, but the larger microlites are mostly albitised plagioclase. Potash feldspar is occasionally identifiable under the microscope by the presence of Carlsbad rather than albite twinning: the Carlsbad twin plane does not disappear in the 45^{o} position, whereas that of a single albite twin does. Lavas with a coarser-grained groundmass commonly show albitised plagioclase microlites surrounded by a narrow rim of pale pink potash feldspar. One sample was X-rayed, and the structural state of the potash feldspar determined by the 2θ values for the 060 and $\bar{2}04$ reflections (Wright, 1968): it was close to maximum microcline, though originally it would probably have been sanidine or orthoclase that has since been ordered by low-grade metamorphism.

Two types of amygdales have been found in lavas in the Nine Mile Volcanics. The more common type contains calcite, albite, and minor chlorite and is up to 1 cm across. A less common type from a lava at grid reference 464603 contains calcite, potash feldspar, and minor chlorite; the structural state of the potash feldspar was determined to be intermediate between orthoclase and microcline.

Thickness

The estimated thickness of the Nine Mile Volcanics in the type section on the Tumut River is 1050 m, and a similar thickness is likely in the Peppercorn area. This, however, is a minimum thickness, since an unknown amount is missing from the faulted upper contacts of the unit.

Relations

As discussed earlier the Nine Mile Volcanics are considered to have formed as volcanic centres surrounded by clastic aprons represented by the Temperance Formation. The Nine Mile Volcanics must therefore, at least in part, pass laterally into the Temperance Formation. Locally, however, as in the Little Peppercorn Creek area, the Nine Mile Volcanics are exposed resting on top of the Temperance Formation; thus, as the volcanic centres built up, the lava and tuff forming each centre probably prograded outwards to rest on clastic sediments derived from earlier eruptions.

The relation between the Nine Mile Volcanics and the Gooandra Volcanics is less certain, since the two are always in faulted contact. The presence of K_2O-poor lava fragments, typical of the Gooandra Volcanics, only in the lower part of the Temperance Formation may be taken as circumstantial evidence that the Gooandra Volcanics antedate the upper part of the Temperance Formation and, therefore, much of the Nine Mile Volcanics. Yet the two suites of volcanics may be the products of different, partly contemporaneous volcanic centres.

Fossils and age

Graptolites are known from two localities in the Nine Mile Volcanics: south of Tumut Ponds and near Little Peppercorn Creek. The Tumut Ponds locality (Fig. M5) is a black slaty shale near the top of the exposed Nine Mile Volcanics close to the Long Plain Fault. A varied though poorly preserved fauna listed by Sherrard (1954) includes *Dicellograptus divaricatus* var. *salopiensis*, *Climacograptus scharenbergi*, *Mesograptus multidens*, *Glyptograptus teretiusculus*, *Amplexograptus arctus*, ?*Retiograptus geinitzianus*, *Lasiograptus mucronatus*, and *L. mucronatus* var. *bimucronatus*. Sherrard derived a Gisbornian age for this fauna. The other locality, near

Little Peppercorn Creek at grid reference 483634 (Fig.M12), is in a grey siltstone, again near the top of the volcanics. The fauna is too poorly preserved to identify it specifically, but again it suggests a Gisbornian age.

In the Peppercorn Plain area (460600), small limestone lenses in the volcanics stratigraphically below the graptolite-bearing strata have yielded poorly preserved streptalasmatid corals (Legg, 1968), and the conodont Belodina (R.S. Nicoll, BMR, personal communication 1974), which has a middle to Late Ordovician range.

The upper part of the Nine Mile Volcanics is therefore of Gisbornian (Late Ordovician) age. As the Gisbornian graptolites are at a stratigraphically much higher level than detritus derived from the Nine Mile Volcanics in the Temperance Formation, volcanism may have started as early as the Darriwilian.

Intrusions related to the Nine Mile Volcanics

Throughout the Temperance Formation and Boltons beds, abundant stocks, dykes, and sills of basic composition appear on petrographic, geochemical, and stratigraphic grounds to have been feeders and high-level magma chambers related to the Nine Mile Volcanics. They are particularly abundant west of Blanket Plain, and in the valleys of the Murrumbidgee River and Tantangara Creek upstream from their junction. The larger bodies, mostly over 50 m wide, have been indicated on the TANTANGARA geological map with the symbol Oki.

These intrusions are of three petrographic varieties, and they show variation consistent with the differentiation observed in the Nine Mile Volcanics lavas, and lava clasts in the Temperance Formation. These three varieties are: large sill-like bodies which have been differentiated in situ and show well-developed cumulate textures; clinopyroxene porphyry dykes and stocks which appear to be the intrusive equivalent of the Nine Mile Volcanics lavas from the northern end of Long Plain; and hornblende-rich dykes and stocks which are more highly fractionated than the lavas from the northern end of Long Plain.

Cumulate sills

Cumulate intrusions in TANTANGARA form a small outcrop in the Boltons beds at grid reference 430361 (on the western edge of Blanket Plain), and an elongate sill about 2.3 x 0.3 km on both sides of the Snowy Mountains Highway northwest of Sawyers Hill. The first of these bodies may be part of a larger intrusion, as it is cut off to the east by a major fault. Joplin (1958) briefly studied two other, larger sills of similar composition and texture west and southwest of TANTANGARA, and included them in the Jagungal-Nine Mile Complex, which we now believe to be composed of three distinct rock suites:

(1) the Jagungal volcanics, which form the oldest outcropping rocks in the Kiandra area;
(2) intrusives related to the Nine Mile Volcanics;
(3) the Lower Devonian Boggy Plain Suite of I-type granitoids, to which the diorite at Junction Shaft quarry in KOSCIUSKO (Joplin, 1958) and the olivine-bearing quartz monzonite at Kiandra (Browne & Greig, 1923) belong.

The southernmost of the two sills has been studied more recently by Williams (1974), who mapped the body as an irregularly shaped sill about 10 km long and up to 1.5 km wide, and named it the Doubtful River Gabbro. The northern sill is of similar dimensions and has been studied by L.A.I. Wyborn (1977), who has called it the Gordies Spur Gabbro. Both these bodies are similar, comprising clinopyroxene, olivine, magnetite, plagioclase, and apatite cumulate grains surrounded by intercumulus poikilitic greenish brown hornblende. In some samples the cumulate grains are relatively minor and the rock is composed of about 70-80% hornblende. These rocks have been called perknites and hornblendites by Joplin (1971). Samples from the western sides of these sills contain more abundant feldspar, which is mostly altered to clinozoisite as the bodies have been metamorphosed to greenschist facies. Pegmatoid aggregations of hornblende and altered feldspar are also common towards the west, where hornblende crystals up to 10 x 2 cm are present in the Doubtful River Gabbro at grid reference 301118 (KOSCIUSKO). Immediately west of this locality the contact of the gabbro with the Temperance Formation is irregular, and cherty tuff and fine-grained gabbro are intimately mixed (peperite), suggesting that the sill intruded only partly lithified sediments. These sediments face west but dip steeply east. Gravitational stratification of the body produced a more felsic top which now faces west, the same direction of facing as the enclosing sediments. The Gordies Spur Gabbro has a similar stratification with a more felsic western side (top), which is best seen in a section along Nine Mile Creek west of Nine Mile Diggings.

The outcrop of cumulate rock on the western edge of Blanket Plain is highly altered and composed of epidotised feldspar, chloritised pyroxene, and minor biotite, apatite, and magnetite, all embedded in poikilitic greenish brown hornblende crystals up to 5 mm. Intergranular epidote is abundant and the rock is cut by prehnite veins.

The sill to the northwest of Sawyers Hill is less altered and ranges in composition from biotite-bearing pyroxene hornblendite to hornblende monzonite. The hornblendite has a cumulate texture of euhedral clinopyroxene partly altered to green hornblende, brown biotite, apatite, magnetite, and sericitised feldspar, embedded in poikilitic brownish-green hornblende ($2V_x = 60^o$) up to 4 mm. Parts of the sill (e.g., at grid ref. 375276) have been hornfelsed by the adjacent Lower Devonian Boggy Plain Adamellite, resulting in the recrystallisation of hornblende along grain margins. The more felsic rocks in the sill crop out southwest of the Snowy Mountains Highway, and are more even-grained than the pyroxene hornblendites; they are composed of about equal proportions of microcline, sericitised plagioclase, and green hornblende - all about 1 mm - and minor chloritised biotite, opaques, and clinopyroxene (in the cores of hornblende), and rare quartz.

These large high-level sills may have played a part in producing the chemical and mineralogical variation in the Nine Mile Volcanics, since low-pressure crystal fractionation of amphibole, clinopyroxene, and especially olivine - present in the sills southwest (Williams, 1974) and west (L.A.I. Wyborn, 1977) of TANTANGARA - is capable of producing the fractionation trend observed in the Nine Mile Volcanics.

Clinopyroxene porphyry intrusions

This petrographic group is the most common, occurring throughout the Temperance Formation and the upper parts of the Boltons beds west but apparently not east of the Boggy Plain Fault. The intrusions are mostly dykes or sills only a few metres wide, but some, such as those west of Blanket

Plain, are stock-like and up to 200 m in diameter. Altogether about 25 separate bodies have been mapped and sampled, and all are remarkably similar in texture and composition.

The most striking feature of these intrusions is their abundance of clinopyroxene phenocrysts: they contain between 25% and 45% of euhedral clinopyroxene up to 4 mm. This is commonly zoned (best seen on 001 sections) with colourless cores and pale green weakly pleochroic rims ($2V_z = 45-50^o$ and $Z\hat{}c = 44^o$), of which the green rims have a slightly larger extinction angle. In some samples (e.g., a dyke at grid ref. 466608) the clinopyroxene commonly forms glomeroporphyritic groups.

Olivine pseudomorphed by chlorite is present in some samples, in which it mostly forms about 5% of the rock. It forms euhedral bipyramidal grains of about 1 mm, though in a sill about 10 m thick at grid reference 491624 it forms phenocrysts up to 5 mm, which are distinctive in hand specimen as they are much darker than the pale green clinopyroxene phenocrysts. Another dyke rock from nearby (grid ref. 496623) contains about 15% olivine up to 1 mm, mostly altered to chlorite but commonly with cores composed of a recrystallised mass of quartz; as the alteration of olivine to chlorite requires the introduction of alumina and the removal of silica, apparently not all the excess silica was removed from the olivine in this sample.

Apart from the clinopyroxene and olivine these intrusions contain primary orthoclase, plagioclase, hornblende, biotite, opaques, and apatite.

Orthoclase is always more abundant than plagioclase, but not by a large amount, and the rocks are classified as monzonites and olivine monzonites. The orthoclase occurs as anhedral to subhedral grains up to 1 x 0.3 mm, elongated along the x-crystallographic axis. It commonly encloses plagioclase grains to give a monzonitic texture, but in porphyries with a finer-grained groundmass it forms narrow rims (less than 0.05 mm) around plagioclase grains, as well as separate laths. Perthite lamellae have not been observed. Carlsbad twinning is present in almost all crystals, and is useful for distinguishing between orthoclase and albite microlites when the grains are too small for their optic sign to be determined. $2V_x$ is about 60^o for larger grains.

Plagioclase is present as euhedral laths up to 2 mm long, but mostly it is the same size as the accompanying orthoclase. Smaller grains are commonly embedded in or surrounded by orthoclase. Unlike the orthoclase, which was not altered by the metamorphism in TANTANGARA, the plagioclase is either highly sericitised or altered to clear albite. Secondary calcium-bearing metamorphic minerals commonly occur as inclusions in the altered plagioclase, but most of the original calcium present in the grains has been completely lost, and is now present in intergranular epidote, prehnite, pumpellyite, and calcite, or in veins containing these minerals.

An important feature of the plagioclase and orthoclase, which comprise the bulk of the groundmass in these intrusions, is their grainsize relative to the position in the stratigraphic succession of the intruded rocks: the intrusions in the Boltons beds and most of the Temperance Formation have a relatively coarse-grained feldspathic groundmass, but the intrusions in the Nine Mile Volcanics and high in the Temperance Formation near the Nine Mile Volcanics have a much finer-grained groundmass, and must have crystallised at much shallower depths. This, along with their mineralogy and chemistry, is good supporting evidence that the clinopyroxene porphyry intrusions were the feeders for the Nine Mile Volcanics lavas.

Hornblende is a common accessory mineral in some of the clinopyroxene porphyry intrusions, particularly in the rocks with olivine phenocrysts (e.g., at grid refs. 417358 and 411426). The hornblende differs from that in the cumulate intrusions and the extrusive rocks in that it has much stronger absorption: X = yellowish brown, Y = dark olive green, Z = very dark bluish green, birefringence $\doteqdot 0.027$, and $2V_x = 20^{\circ}$; the optical properties correspond to ferrohastingsite. The hornblende is commonly found around the margins of clinopyroxene phenocrysts and is anhedral against plagioclase laths, so it appears to have crystallised at a late stage, possibly at the same time as orthoclase.

Biotite is also a common accessory mineral, and is more widespread than hornblende, being present in almost all samples. It forms euhedral to rounded flakes up to 0.4 mm embedded in the feldspathic groundmass. It is mostly brown, but is reddish brown in some samples, and is invariably almost completely altered to chlorite.

Apatite is abundant in the feldspathic groundmass of many of the intrusions. It occurs as greatly elongate needles up to 2 mm long which completely cut through grains of orthoclase and plagioclase, so must have crystallised before these minerals.

Granular opaques of about 0.3 mm form up to 4% of the rock and are embedded in the feldspathic groundmass.

Hornblende-rich intrusions

Hornblende-rich intrusions not displaying the cumulate texture of the sills previously described are relatively rare, and apparently represent the most fractionated rocks present in the magma series of which the Nine Mile Volcanics is a part. They are highest in SiO_2 and lowest in MgO. They were mapped at six localities, of which three are in the more felsic parts of the previously described intrusive types. One of them (at grid ref. 991672, Cabramurra SMA 1-Mile Series Sheet) is part of the cumulate sill west of TANTANGARA (Geordies Spur Gabbro of L.A.I. Wyborn, 1977), and another two (at grid refs. 412423 and 407393) are parts of clinopyroxene porphyry stocks. The other three (at grid refs. 398425, 380290, and 402329) are dykes less than 1 m wide remote from any other intrusive types.

Samples from all of them have abundant phenocrysts of euhedral brownish green hornblende up to 4 mm long and less common albitised plagioclase in a groundmass of potash feldspar, plagioclase, chlorite, quartz, hornblende, calcite, and opaques. The sample from grid reference, 407393 contains clinopyroxene phenocrysts as well as hornblende, and there is no evidence of the clinopyroxene altering to hornblende. The hornblende porphyries appear to be similar to some of the lamprophyres described by Joplin (1971, pp. 197-199).

Nungar beds

Nomenclature

Newberry (1956) referred to a series of Upper Ordovician slate, shale, siltstone, sandstone, and quartzite exposed in the Nungar Creek gorge as the Nungar beds. Stevens (1958a) described them in more detail, and mapped various lithological subdivisions between Mount Nungar and Providence Portal. He also described a type section along Shaft Road, in the Nungar Creek gorge, and presented a detailed map of the section. Poorly preserved graptolites found by Stevens indicate a Late Ordovician age for the Nungar beds.

Stevens (1958b, p.252) first published the name Nungar beds in a description of the geology of the Cooleman Plain district. The beds he referred to as Nungar beds in this area are now considered to be part of the Lower Silurian Tantangara Formation. Walpole (1964) also referred to the Nungar beds in a summary of the engineering geology of the Murrumbidgee-Eucumbene Tunnel. Moye, Sharpe, & Stapledon (p. 92 in Packham, 1969) regarded the Nungar beds as the lateral equivalent of the Adaminaby beds, which crop out east of Adaminaby.

SMHA geologists (Newberry, 1956; Moye, 1957; Stevens, 1958a) and Crook & others (1973) assumed that the Nungar beds form extensive outcrops on Nungar Ridge and on the ridge between Tantangara Dam and the Pocket Saddle area. The present study has demonstrated that much of the assumed Upper Ordovician strata in this area is Lower Silurian, and this has led to the following reinterpretation of the Nungar beds.

The name has been retained informally because the sections are incomplete and the relations between the Nungar beds and other Ordovician units in the area are uncertain. The Nungar beds and Boltons beds may be equivalents; if so the name Boltons beds would have precedence if the two units were combined into the one formation.

Derivation of name

The unit is named from Nungar Creek (Newberry, 1956, p.4), along whose gorge lies the type section.

Type section

The type section (Stevens, 1958a) is along Shaft Road, which extends from the Tantangara Road (at grid ref. 469293) eastward for 2000 m - through the length of the Nungar Creek gorge - to a former SMHA drill site (at grid ref. 484295). Stevens (1958a) thought that the rocks cropping out in this section were wholly Nungar beds, but we consider that much of this succession should be referred to the Tantangara Formation, and that the Nungar beds are present in only two short sections - at the eastern end and in the centre. The present interpretation of the geology is shown in Figure M8.

Stevens (1958a, p.2) recognised ten lithological units from west to east along Shaft Road:

10. Fine-grained buff to green sandstone
9. Interbedded slate and quartzite
8. Interbedded siltstone and shale
7. Brown siltstone
6. Black slate
5. Grey slate or shale
4. Interbedded slate and quartzite
3. Chiefly quartzite
2. Spotted, finely bedded hornfels with some quartzite
1. Dark grey quartzite

Granodiorite intrusion

We consider that only units 1, 2, 5, and 6 are Nungar beds, and that the remaining units are part of the Tantangara Formation. The rocks in units 3, 4, and 9, called quartzite by Stevens, are not true quartzites but strongly lithified coarse sandstones typical of much of the Tantangara Formation. Units 1 and 2 are exposed at the eastern end of Shaft Road from the contact with a granodiorite intrusion (at grid ref. 484295) westward for 390 m along the road (to grid ref. 481292); units 5 and 6 are exposed along the road for 140 m from grid reference 479291 (810 m west of the intrusion) to grid reference 477292. Between these two parts of the type section, the Tantangara Formation is poorly exposed in a narrow downfaulted block whose inferred arcuate easterly bounding fault converges on and meets the westerly bounding fault a few hundred metres north and south of the type section. The westerly bounding fault is exposed at grid reference 479291.

Although the nominated type section of the Nungar beds is incomplete, it is the only locality in the type area where the beds are well exposed and so must suffice. Its incompleteness, and the uncertain relations between the Nungar beds and the other Ordovician units, are arguments in favour of the Nungar beds remaining an informal unit.

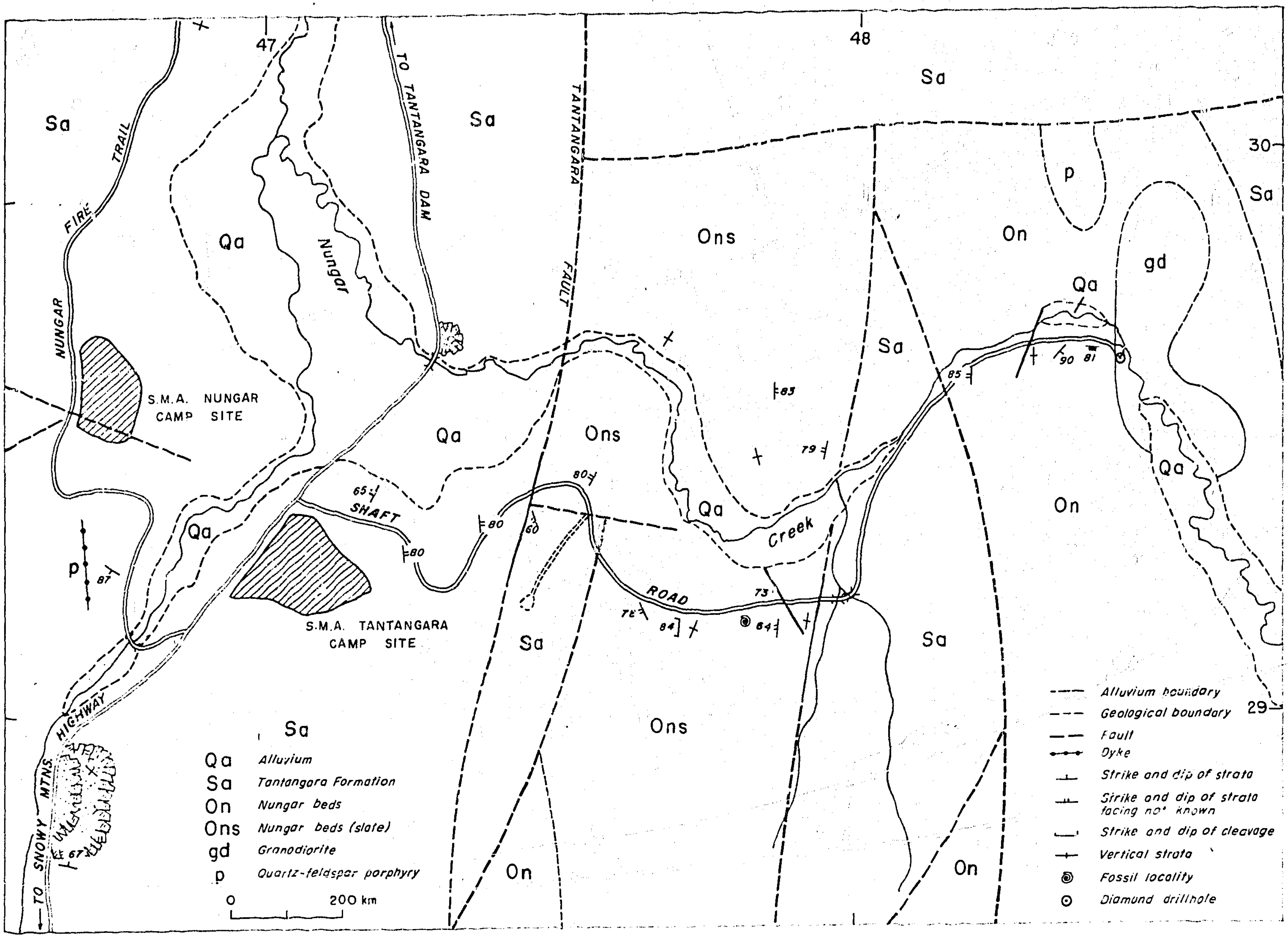


Fig. M8 Type locality of the Nungar beds

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M55

Distribution

The Nungar beds crop out over much of the range between Providence Portal and Nungar Creek. They form several irregular outcrops farther north on Nungar ridge, on the eastern side of Nungar Plain, and on the ridge extending from north of Bulgar Hill south to the Goorudee rivulet and Mudhole Creek valleys and to the Snowy Mountains Highway. A black graptolitic slate at Tantangara Dam, and areas of quartzite and slate east of Paytens Creek, are all considered to be part of the Nungar beds. the unit is also present around the headwaters of Burgess Creek, in southwest TANTANGARA, and in the Brindabella Range, where it crops out on the higher parts in a north-south-elongate fault-bounded block.

The Nungar beds also crop out extensively in the western part of BERRIDALE, (White, 1976) Chappell, & Williams, 1976) - for example, on Bald id Hill (grid ref. 402031, BERRIDALE).

Exposure of the Nungar beds is commonly poor, but is good in some areas of the Monaro Range. Quartzite forms low tors not only on ridge tops but also on valley floors and sides, and is common as float. Slate crops out more rarely; the two slate beds depicted on the TANTANGARA map in the Monaro Range are unusual in that they form prominent outcrops up to 4 m high. Float from the slate beds is generally common, but where the slate is interbedded with quartzite its debris is obscured by the quartzite float.

Lithology and petrography

The Nungar beds are a succession of interbedded fine arenite, siltstone, and slate representing a distal flysch sequence. Chert and tuffaceous sediments are rare. Sedimentary structures are abundant in most sections.

The fine arenite, invariably altered to quartzite, consists almost entirely of equigranular quartz grains about 0.1 to 0.2 mm with interpenetrative boundaries. In the less metamorphosed arenites the quartz is generally subangular. Rare coarser arenites have a bimodal size distribution of quartz grains similar to that described for the Boltons beds.

Accessory zircon and tourmaline are common, and metamorphic biotite, sericite, and chlorite are also present. Lithic fragments are absent, apart from very rare mud clasts in the coarser arenites.

The siltstone is often finely laminated, and has a variety of sedimentary structures. It is formed of alternating layers, 0.5 to 4.0 mm thick, of fine silt grains of detrital quartz and phyllosilicate. Boundaries between quartz grains are often interpenetrative, and a little metamorphic biotite is generally present. Chlorite and sericite are common, particularly in the finer laminae. Where hornfelsed by intrusive igneous rocks, large porphyroblastic cordierite with abundant inclusions is extensively developed.

Bedding in black to dark grey slate is generally obscure or lacking, but cleavage is well developed. Pyrite is common, both scattered through the rock and locally concentrated in layers up to 0.5 mm thick which may indicate bedding. Little can be seen in thin sections of the slate: the bulk of the rock has a black to very dark grey matrix with rare fine silt-size detrital quartz, and fine elongate sericite aligned parallel to the cleavage, scattered through the rock.

Dark grey to black chert beds up to 20 mm thick are sometimes associated with the dark slate; at one place at the western edge of the type locality on Nungar Creek (grid ref. 476295) an isolated 10-metre-thick sequence of well-bedded chert, in beds 5-20 cm thick, is similar to chert in the Temperance Formation, particularly that at Dairymans Plain.

The rare tuffaceous sediments in the Nungar beds consist of a few deeply weathered dark greenish grey rocks exposed as float on the northwest slopes of Gang Gang Mountain. The rock appears to be a basic tuff, possibly waterlaid, but is too weathered for firm identification.

Sedimentary structures and environment of deposition

The sedimentary structures in the Nungar beds include parallel lamination, ripple cross-bedding, convolute bedding, and rare graded bedding. Load and flute marks on bedding surfaces are not evident, largely because of the widespread occurrence of interbed shearing.

This assemblage of sedimentary structures indicates distal flysch; only rare deposits are of a more proximal nature. Although no detailed logs have been made, most turbidite units seem to be missing divisions A and B of Bouma's (1962) ideal sequence, and the proximality index of Walker (1967) is probably about 25%.

Thickness

We have not attempted to estimate the thickness of the Nungar beds because they are intensely deformed. They are probably of the order of thousands, rather than hundreds, of metres thick.

Age

Stevens (1958a) noted the occurrence of poorly preserved Late Ordovician graptolites in the Monaro Range between Gang Gang Mountain and Nungar Creek. Later, during the construction of Tantangara Dam, graptolites were found in a black pyritic slate cropping out in the foundations of the northern half of the dam site. The graptolites were in the SMHA collections, in Cooma, but have now been deposited in the Commonwealth Palaeontological Collection, held by BMR. Most specimens are too poorly preserved to be identified, but we identified a specimen on one sample (SMHA sample T6022) as *Orthograptus calcaratus* var. *tenuicornis*, which ranges through the Gisbornian and Eastonian according to Thomas (1960). Elsewhere in southeastern New South Wales, graptolites ranging in age from Darriwilian to Eastonian are present in similar distal flysch successions; the Nungar beds may have a similar range. To our knowledge, no graptolites younger than Eastonian are known from distal flysch successions elsewhere in this region, and so the Nungar beds are unlikely to be younger than Eastonian.

Relations

We regard the Nungar beds as a distal flysch wedge developed to the east of the island arc formed by the Nine Mile and Gooandra Volcanics, and deposited essentially contemporaneously with these volcanic units. This implies that in the area now intruded by the Boggy Plain and Gang Gang Adamellites and covered by the Tantangara Formation, the Nungar beds pass laterally westward into volcanogenic sediments, though the evidence for this is circumstantial: firstly, the age of the Nungar beds and their equivalents is essentially Gisbornian to Eastonian, similar in part to that of the Kiandra Group; and secondly, some thin tuffaceous rocks and bedded chert in the Nungar Creek gorge and Gang Gang Mountain area are similar to lithologies in the Kiandra Group, and may indicate an interfingering of the two units.

The Boltons beds are considered to be equivalent to the oldest part of the Nungar beds; the two are virtually identical in field appearance and petrography, and, in BERRIDALE, are separated only by a brecciated fault zone (White & others, 1976a). However, their complete synonymy cannot be demonstrated at present, but must await further detailed mapping in KOSCIUSKO.

The Nungar beds are thought to be overlain conformably by the Adaminaby beds and unconformably by the Tantangara Formation.

Adaminaby beds

Nomenclature

The name Adaminaby beds was first published by Fairbridge (1953, p.III/3), and had been used previously by Adamson (1951). Later, Adamson (1956, p.141) published the name for Ordovician sediments at the site of the Eucumbene Dam (BERRIDALE), though he failed to use it in an earlier report (Adamson, 1955) describing the regional geology of the area. Authors who later referred to the Adaminaby beds include Öpik (1958) and Moye, Sharp, & Stapledon (in Packham, 1969).

None of these authors has satisfactorily described the unit, and neither type section nor area has been designated. The unit is assumed to be named after the old township of Adaminaby, now flooded by Lake Eucumbene. Since the relations of the Adaminaby beds to other Ordovician units in the are and to the Lower Silurian Tantangara Formation cannot be clearly demonstrated, the name is retained as an informal one.

Distribution

The Adaminaby beds crop out over a large area in the eastern half of TANTANGARA and BRINDABELLA. The main outcrop extends north from the southern edge of TANTANGARA, where it occupies a belt 5 to 6 km wide between the Murrumbidgee Batholith to the east and the Cotter Fault to the west. Northwards this belt narrows, and is interrupted by the Stewartsfield Granodiorite intrusion and overlying Cainozoic sediments near Yaouk. From Yaouk northwards, the Adaminaby beds crop out on both sides of the Cotter Fault: in the west they are pinched out between the Gingera Batholith and the Cotter Fault 6 km north of Adaminaby; and on the eastern side they continue north into BRINDABELLA between the Cotter Fault and the Murrumbidgee Batholith, and are faulted out by the Winslade Fault in the Cotter valley above Cotter Dam. Several small areas of sedimentary rock within the Murrumbidgee Batholith in the Paddys River area are correlated with the Adaminaby beds, and so is a belt of similar rocks forming the Bullen Range. A further belt of Adaminaby beds lies between the Goodradigbee and Bimberi Faults from Rolling Ground Ridge northwards, ending where the two faults join west of Mount Aggie. A belt of the Adaminaby beds forms a sedimentary screen between the Shannons Flat Adamellite and Clear Range Granodiorite from the Orroral valley south to the southeast corner of TANTANGARA.

Reference section

Owen & others (1974b) suggested that the type area should be around Eucumbene Dam, but subsequent examination has shown that it is unsuitable for a reference section: the Jindabyne Fault, from which the Tantangara and Boggy Plain Faults appear to branch near the northern edge of BERRIDALE, strikes roughly north-south close to the eastern side of the dam (White & others, 1976b), where it separates the Adaminaby beds to the east from the Nungar beds to the west; the Adaminaby beds are too poorly exposed or disrupted by the Berridale and Kosciusko Batholiths for a representative section to be designated. The site of old Adaminaby is now flooded by Lake Eucumbene, but even the exposures close to the shore are too poor for a reference section to be described. However, farther northeast, a section through the Adaminaby beds is well exposed along a track on the south side of the Murrumbidgee River at Rosedale, about 6 km east of Adaminaby (grid ref. 658152 to 661153, TANTANGARA), and we have described it as a reference section, which we recommend be considered as the type section if the unit is formally defined at a later date; it comprises about 150 m of continuously exposed interbedded sandstone and shale representing a typical proximal flysch sequence, and dips east at about 60°. Additional excellent sections are exposed on the access road for the water pipeline from Bendora Dam to the Cotter Pumping Station (between grid refs. 692824 and 716857, BRINDABELLA).

Lithology

The main lithology of the Adaminaby beds is a medium to fine-grained impure sandstone, with interbedded siltstone and shale, and minor amounts of coarse sandstone, black slate, and bedded chert. Limestone and tuffaceous beds are absent.

Most of the succession represents a proximal flysch sequence, and is similar in field appearance to the eastern part of the Tantangara Formation, a feature which has led to problems in distinguishing them in the field.

The main rock type appears in the field to be a light to medium brown sandstone, though outcrops are rare. Individual beds - in which the sandstone commonly grades upwards into siltstone and shale, and contains load casts - are up to 10 m thick, but seldom exceed 2 m. The sandstone is composed of moderately rounded to angular quartz grains, generally less than 0.3 mm diameter, in a matrix of fine silt and clay; sorting is commonly poor. Rock fragments and feldspar grains are virtually absent. The siltstone and shale rarely crop out, though road-cuttings indicate that they form an important element within the unit. They are generally light grey to brown, commonly show parallel laminations or small-scale cross-bedding, and contain small slump structures.

In the north, particularly in the Goodradigbee and Cotter valleys, beds of coarse sandstone are an important part of the succession. The sandstone is poorly sorted, massive, generally brown, with quartz grains up to 1.5 mm in diameter visible in hand specimen. Rock and feldspar grains are rare, except east of Corin Dam, and rock clasts have been seen only immediately west of Corin Dam (Fig. M9), where the bases of thick sandstone units commonly contain clasts of black mudstone up to 50 mm long and rare clasts of weathered sulphides, possibly pyrite with minor chalcopyrite; the rock may represent a 'slurry deposit' type of flysch sedimentation.

In thin section the coarse sandstone comprises well-rounded spherical quartz grains up to 1.5 mm diameter in a matrix of less rounded quartz and rare feldspar grains less than 0.25 mm and fine phyllosilicate material. The proportion of large rounded grains ranges from more than 75% in some specimens to less than 5% in others. When present, rock fragments are usually black mudstone or rarely chert, highly weathered volcanic rock, or quartzite. Coarse sandstone from the Adaminaby beds is similar to that in the Tantangara Formation (particularly near Tantangara Dam), but mostly has fewer lithic and more feldspar fragments.

Black shale or mudstone interbedded with the brown sandstone sequence at several localities forms beds from two to several tens of metres thick. Cleavage may be sufficiently well developed to form slate. In several localities (e.g., grid ref. 802394) the Shannons Flat Adamellite has strongly hornfelsed the adjacent black siltstone to a quartz-muscovite-biotite-cordierite rock in which prismatic andalusite has locally developed. Two black shale beds up to 25 m thick (Og_1, Og_2) are particularly well developed in the gently dipping Adaminaby beds in the Tidbinbilla Range. Graptolites are fairly common at several localities, especially where the rock has been hornfelsed by intrusions of the Murrumbidgee Batholith, though specimens have also been collected in regionally metamorphosed rock (where cleavage and bedding coincide) and in the undeformed shales west of Tidbinbilla Range.

Bedded chert is exposed at Alum Creek (grid ref. 772153), where dark grey to black chert in beds from 10 to 25 cm thick crops out for 150 m along the creek and appears to be about 30 m thick. The relation between the chert and the surrounding brown sandstone is unknown, but is assumed to be conformable within the sandstone. The chert is similar in appearance to that in the Temperance Formation, but does not show the slump-folds common in the latter.

Sedimentary structures and environment of deposition

The Adaminaby beds contain abundant sedimentary structures that indicate deposition in a proximal flysch environment. These include graded bedding in medium to coarse sandstone, parallel lamination, current ripple lamination, convolute bedding, and, where folding has been less intense, load casts and flute marks. Although no detailed logs have been made, the proximality index (Walker, 1967) in most areas is estimated to be more than 75%. However, the Adaminaby beds are not uniformly proximal flysch because they include sequences deposited in a more distal environment - for example, on the Corin Dam road at grid reference 676655 - but these are of limited occurrence, and the bulk of the Adaminaby beds was deposited in a proximal flysch environment.

Trace fossils have been seen only at one locality, in the bed of the Cotter River about 5 km downstream of Bendora Dam (grid ref. 677797). The trace fossils occupy bedding surfaces in a dark grey siltstone, and represent browsing traces of a surface-feeding organism. They belong to the deep-water Nereites facies of Seilacher (1967).

The sandstone exposed on the west abutment of Corin Dam (grid ref. 661659) shows several unusual features. It is well bedded in units 20 to 100 cm thick (Fig. M10), is coarse-grained, contains abundant black shale clasts, rarely shows graded bedding, has sharp tops and bottoms, and lacks scouring; some beds, however, do show graded bedding upwards into plane-parallel laminated siltstone, before being cut off by the next sandstone bed. Such a deposit typically forms in a proximal flysch environment, and these beds may represent a traction-carpet deposit (Dzulynski & Sanders, 1962; Bagnold 1956), which in a proximal flysch environment may develop a sharp top and be ungraded (Walker, 1967); it most typically occurs in the upper part of a submarine fan.

Age

Graptolites are known from several localities in the two Sheet areas. A hornfelsed black mudstone on a ridge about 3.5 km south-southeast of Gudgenby (grid ref. 804394) has yielded Climacograptus bicornis, Dicranograptus cf. ramosus, and D. hians, indicating a late Eastonian age;

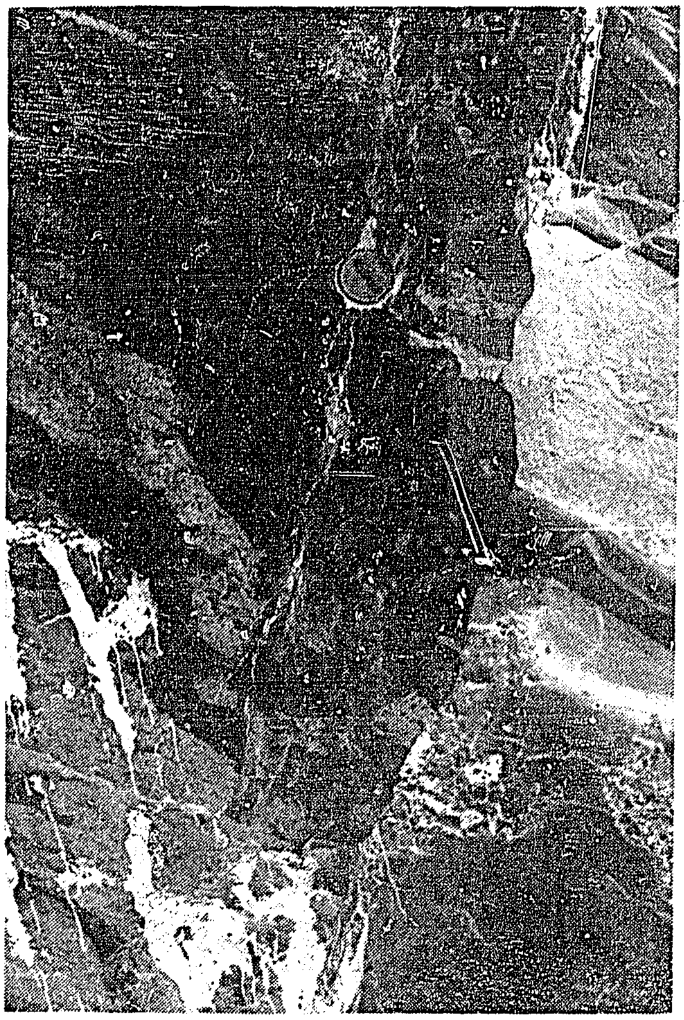

Fig. M9. Elongate mudstone clasts at the base of a turbidite unit in the Adaminaby beds on the west abutment of Corin Dam.
(GA/8092)

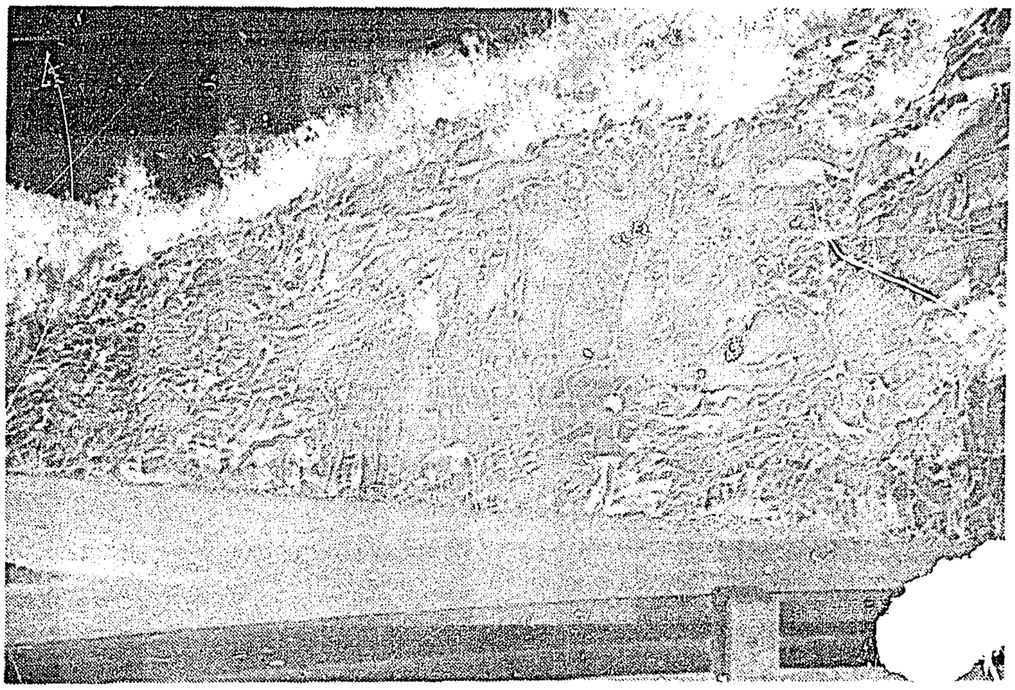

Fig. M10. Well-bedded arenite in the Adaminaby beds on the west abutment of Corin Dam. They are thought to have been deposited by a traction-carpet process in an upper fan environment.
(GA/8100)

a similar fauna has been found near Jones Plain (grid ref. 746158). The best preserved and most prolific faunas have come from the black shale bands in the Tidbinbilla Range, particularly at grid reference 724796. The forms identified from this locality include Dicellograptus cf. complanatus, D. complanatus var. ornatus, D. morrissi, D. caduceus, Dicranograptus hians, Orthograptus calcaratus var. acutus, O. pageanus var. ?spinosus, O. cf. truncatus, Climacograptus bicornis, C. caudatus, and Hallograptus bimucronatus; the indicated age is latest Eastonian. Elsewhere, both Eastonian and Bolindian ages have been reported from units correlated with the Adaminaby beds (Hopwood, in Packham, 1969; and White & others, 1976a).

The age of the Adaminaby beds is therefore taken to be late Eastonian to early Bolindian.

Relations

The Nungar beds are thought to pass upwards conformably into the Adaminaby beds, representing a probably gradational change from distal to proximal flysch sedimentation in the middle part of the Eastonian.

The Adaminaby beds are similar lithologically to the Lower Silurian Tantangara Formation, and distinguishing the two in the field is difficult in the absence of fossil evidence; so one may have been mapped for the other in places.

The main difference between the two units is that black graptolitic shale is present in the Adaminaby beds, but absent from the Tantangara Formation. In addition, sandstone (particularly coarse sandstone) of the Tantangara Formation tends to contain a higher proportion of rock fragments than the Adaminaby beds, though sandstone rich in mudstone fragments near Corin Dam has been assigned to the Adaminaby beds on the evidence of graptolite faunas found just to the north - in the Tidbinbilla Range.

Apart from the unconformable contact between the Adaminaby beds and the Tidbinbilla Quartzite, all contacts between the Adaminaby beds and other Palaeozoic sedimentary rock formations are faulted in the two Sheet areas. The Adaminaby beds have yielded no latest Ordovician faunas, and so are assumed to be unconformable below the Lower Silurian Tantangara Formation, which overlies other Ordovician formations unconformably.

Thickness

The thickness of the Adaminaby beds is unknown owing to the complex structure and the lack of marker beds. It is almost certainly more than 1000 m, and may be several thousand metres.

SILURIAN SEDIMENTARY UNITS

Although much of the two Sheet areas was land through most of the Silurian, and felsic volcanism predominated, nine Silurian, mainly sedimentary units have been recognised. The oldest unit, the Tantangara Formation of early Llandoverian age, is a thick sequence of turbidites which marks the final phase of flysch sedimentation in the two Sheet areas. After a fold episode in the middle Llandoverian, exclusively shallow-water shelf sediments were deposited in restricted areas through the remainder of the Silurian. Marine sedimentation persisted from the late Llandoverian to the Pridolian in the Cooleman Plains area (Cooleman Plains Group), but elsewhere it was restricted to the late Llandoverian-early Wenlockian in the Cotter valley (Tidbinbilla Quartzite), the Ludlovian near Wee Jasper (Micalong Creek Beds), and the early Ludlovian in northeast BRINDABELLA (Glen Bower and Yass Formations).

Tantangara Formation

Nomenclature

Best & others (1964) gave the name 'Tantangara Beds' to sediments that crop out on Nungar Ridge, north and south of Tantangara Dam, and described them as 'shales, sandstones, greywackes and volcanics' of undifferentiated Silurian age, although they gave no evidence for the age.

Bein (1968) and Crook & others (1973) concluded from a study of graptolites from the foundations of Tantangara Dam that the 'Tantangara Beds' were Late Ordovician, and that there was no reason to separate them from the Nungar beds. During the 1971-72 field season, Silurian fossils were found at localities on Nungar Ridge, and major lithological differences were noted between the Nungar beds and 'Tantangara Beds'. For these reasons the validity of the 'Tantangara Beds' as a separate unit is upheld - although its status is changed to that of formation - and a definition of the unit follows.

Derivation of name

Best & others (1964) did not say how the unit derives its name, but we assume it is from Tantangara Dam (grid ref. 502372).

Type section

The type section is designated as starting along the road-cutting on the south side of the Murrumbidgee River east from the tunnel inlet valve station above Tantangara Dam (grid ref. 500371) to the bridge over the Murrumbidgee River, and continuing across a series of natural exposures along the hillside on the south side of Gulf Bend to grid reference 520369, a total distance of 2 km (Fig. M11). The western part of the road-cutting exposes a continuous section of massive coarse dark arenite with interbedded siltstone and shale; the eastern part has discontinuous exposures of softer fine brown arenite. The natural exposures formed by severe soil erosion on the south side of Gulf Bend are interbedded fine arenite, siltstone, and shale. Dips in the type section are generally between 70 and 80^{o} to the west-northwest.

An additional reference section is a road-cutting on the Snowy Mountains Highway between grid references 487218 and 496220, on the eastern side of the Monaro Range. It consists of a series of brown interbedded fine arenite, siltstone, and cleaved shale, in beds 0.5 to 30 m thick. The beds, some of which show graded bedding, dip to the southeast at 65 to 80^{o}.

Distribution

The Tantangara Formation is thought to crop out over a large area between the Snowy Mountains Highway and Lake Eucumbene, and most of this area is shown as such on the TANTANGARA map. However, a review of the geology of this area, and a comparison with BERRIDALE (White & others, 1976a), to the south, suggests that at least some of the area is probably underlain by Adaminaby beds, since fossiliferous Ordovician rocks crop out only a few kilometres south of TANTANGARA. In particular the area around Anglers Reach

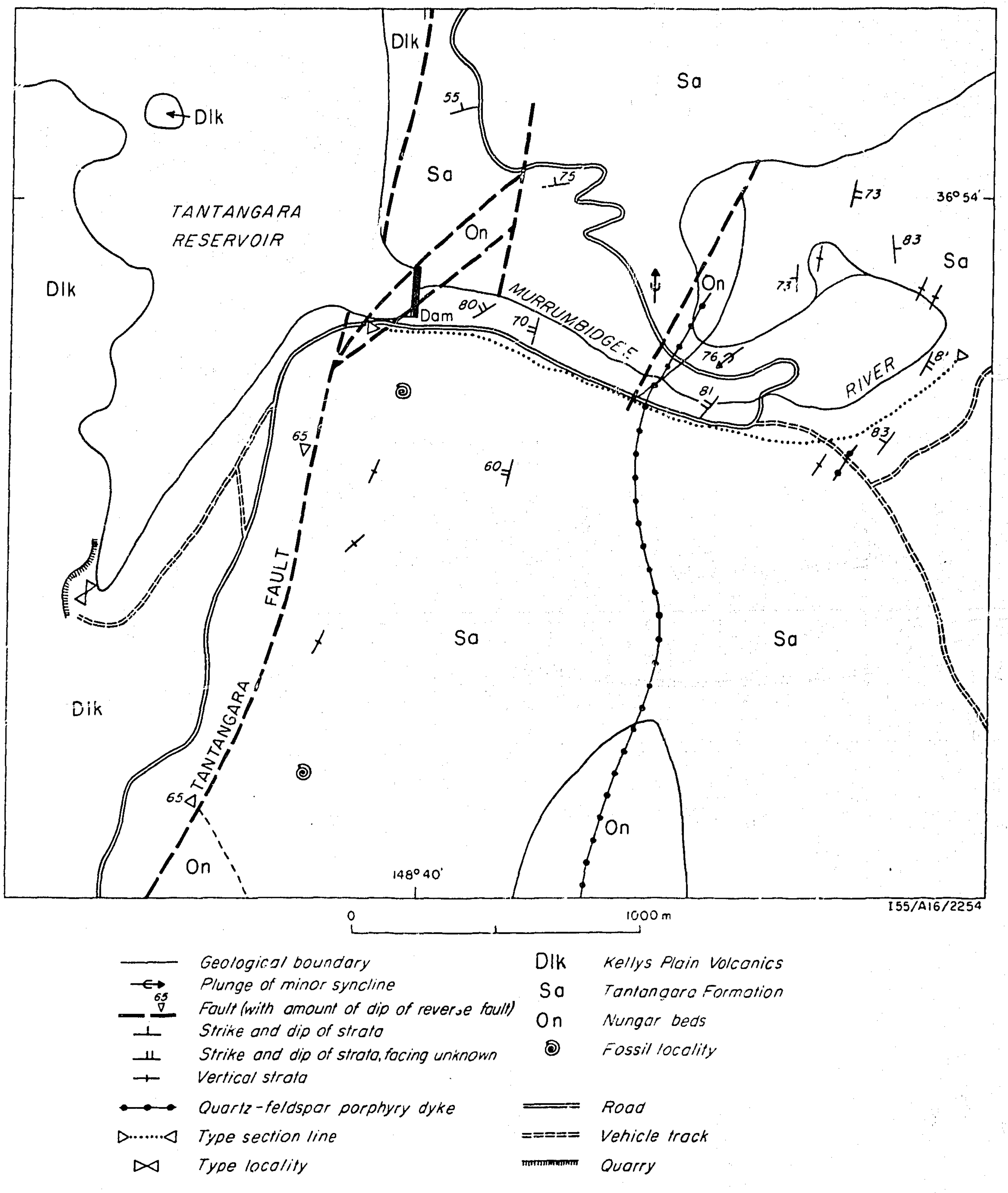

Fig MI I. Location of type section of Tantangara Formation and type locality of Kellys Plain Volcanics is now thought to be Adaminaby beds, but since the relation - and indeed the position of the boundary - between the Tantangara Formation and Adaminaby beds is unknown in this area they are not separated on that part of the map. In the absence of fossils, or in areas of poor outcrop, only thin sections can help to distinguish between the two.

North of the Snowy Mountains Highway, the Tantangara Formation crops out in a wide belt, though with several inliers of Nungar beds, as far as the Murrumbidgee River east of Tantangara Dam. The width of outcrop is about 11 km east of Tantangara Dam, but narrows northwards and is faulted out 4 km northeast of Pocket Saddle.

West of Tantangara Dam the formation crops out in a belt about 5 km wide, extending south from Mount Nattung through Peak Back Ridge and Zinc Ridge to Blanket Hill and south along Gang Gang Creek and Little Swamp Creek to the southern edge of TANTANGARA.

The Tantangara Formation is generally poorly exposed, with the exception of massive coarse arenite beds which form prominent tor-like outcrops on Nungar Ridge. These resistant beds generally crop out along ridge tops and less commonly along the flanks of hills and in valley bottoms. Float from them has formed extensive colluvial deposits which obscure much of the underlying geology. In a few places large scree slopes have developed, for example on the south side of Mount Nungar.

The softer fine-grained arenite, siltstone, and shale which are interbedded with the coarse arenite rarely crop out, except where soil erosion is severe - as at Gulf Bend.

Lithology

Three lithological associations are apparent: (1) dark grey coarse-grained massive sublitharenite, dark brown to grey siltstone, and shale, in which graded bedding from coarse arenite to siltstone and shale is common; (2) light to medium brown fine arenite, siltstone, and shale, with less common graded bedding; and (3) medium to fine arenite with few finer interbeds.

The massive coarse sublitharenite-siltstone-shale association predominates in the western outcrops of the Tantangara Formation east of the Tantangara Fault - particularly on Nungar Ridge - but is also sporadically interbedded with the fine arenite-siltstone-shale association farther east. The distinctive rock type is a coarse to very coarse sublitharenite or quartz arenite in beds up to 20 m thick, commonly showing graded bedding. Individual beds are lenticular, generally less than 1 km in extent; the lensing may be a tectonic feature, but a sedimentary origin is more likely. The rock is extremely resistant and forms large tor-like outcrops that have well-developed joints and indistinct bedding.

In hand specimen the arenite comprises conspicous well-rounded quartz grains up to 2 mm in diameter, brownish rock fragments, and rare white feldspar grains. Fossil fragments, generally of a similar size to the larger grains, are present at three localities, but reach identifiable size (up to 10 mm) at only one (grid ref. 492299). The bottom layers of many of the graded units contain black mudstone clasts, generally 5 to 20 mm in diameter though exceptionally up to 250 mm long by 50 mm thick. The larger clasts are elongate and commonly distorted, whereas the smaller ones - less than 50 mm - range from elongate to nearly spherical. Rare clasts of grey chert are elongate and undeformed.

In thin section the rock is trimodal: large grains 0.5 to 2.0 mm in diameter make up the bulk of the rock; grains 0.05 to 0.15 mm form a second group; and fine phyllosilicates fill the interstices between the grains. The larger grains are mainly well rounded with a high sphericity, whereas the smaller grains are generally subangular and commonly have interpenetrative boundaries with adjacent grains. Quartz forms 80 to 98% of both granular modes; all grains show undulose extinction, and many show deformation lamellae. The finer granular mode includes rare detrital grains of potash feldspar, plagioclase, muscovite, zircon, and tourmaline.

Several types of rock fragment are present. The most common is black mudstone, which is brown in thin section and composed entirely of phyllosilicates with no silt-size grains. Bedding is generally not visible in these fragments, which are mostly elongate with length:width ratios of up to 3:1. Chert is present in minor amounts, and is formed of phyllosilicates and cryptocrystalline quartz. Volcanic rock fragments, though rare, are present in almost all samples, and in a few places are the main component; they comprise interlocked andesine laths averaging 0.15 mm long in a brown phyllosilicate matrix, and are similar to the volcanic rocks in the Nine Mile and Gooandra Volcanics.

The matrix of the rock is a pale brown network of fine phyllosilicate needles. Much is too fine-grained to be identified, though sericite and chlorite with anomalous 'Berlin blue' interference colours are present, and in some rocks red-brown biotite forms small clusters of fine needles.

According to the classification of Folk (1968), these rocks range from quartz arenite to sublitharenite.

Within a single turbidite unit the coarse arenite described above grades into fine arenite as the coarser mode diminishes and the ratio between the two other modes remains roughly the same. The fine arenite passes into siltstone as the proportion of the finer granular mode diminishes; the total elimination of this mode produces shale. The reduction in grainsize to siltstone and shale is usually accompanied by a change in colour from very dark grey to lighter grey or dark brown. The mineralogy of the finer-grained rocks is similar to that of the coarse arenite except that rock fragments are rare or absent. All fine arenites qualify as quartz arenites according to Folk's classification.

Although the fine arenite, siltstone, and shale which are associated with the coarse arenite commonly form the upper parts of graded-bedded units, they may also form such units without a coarse arenite at the base, or may occur as uniform individual beds up to 2 m thick. The finer-grained beds are commonly much softer than the massive coarse arenite; thus they rarely form natural exposures, and are generally seen only in road-cuttings.

The fine arenite-siltstone-shale association, exposed in the reference section on the Snowy Mountains Highway, differs from the association described above by the almost complete absence of thick beds of coarse arenite. It crops out over a large area east of the Monaro Range, from the Murrumbidgee River south through Nungar Plain to the southern edge of TANTANGARA. The common rock type is a medium to light brown fine arenite, which may grade up into brown siltstone and grey to brown cleaved shale. Graded bedding is less prominent than in the association described above, and both fine arenite and shale may form thick ungraded beds.

In outcrop the fine arenite is typically light to medium brown - rarely grey - soft, and deeply weathered. It occurs either as the basal part of turbidite units up to 1.5 m thick, or as uniform beds 0.5 to 30 m thick. Because it is soft, it is exposed only in road-cuttings - a feature of all rock types of this association. Thin sections show that it is bimodal: grains ranging in size from 0.05 to 0.25 mm form 50% to 70% of the rock, and fine silt to clay forms the matrix. Quartz grains form the bulk of the fine sand; chert and shale fragments - if present - form less than 5%. Sparse albite and muscovite appear to be of detrital origin. The matrix is generally indeterminable, but both chlorite and sericite have been identified. The siltstone is mineralogically similar to the arenite, and differs only in grainsize.

The shale is brown to grey, commonly finely laminated, and invariably strongly cleaved. It either forms the upper part of a graded-bedded unit, or occurs as individual beds up to 50 m thick. Thin sections show that the lamination is due to alternating fine-grade detrital quartz and phyllosilicate material. Laminae are 0.5 to 2.0 mm thick, the coarser material forming the thicker laminae. The phyllosilicate material forming the matrix of the fine siltstone and shale is generally indeterminable, but includes chlorite and sericite.

<u>The medium to fine arenite association</u>, which crops out over a wide area west of Tantangara Reservoir from Blanket Hill north to Port Phillip Gap, typically comprises medium to thickly bedded, fine to medium-grained arenite with minor shale. Crook & others (1973) referred these beds to the Ordovician Boltons beds, but our work has shown that they rest unconformably on Ordovician units north of Peak Back Ridge and are overlain by the Peppercorn Formation; hence we correlate them with the Tantangara Formation.

The medium to fine arenite of this association varies from light grey to greenish-grey or brown, or rarely dark grey. It forms beds from 2 cm to several metres thick which are generally devoid of sedimentary structures. The thinner-bedded arenite occurs mainly on Peak Back Ridge; elsewhere, to the north and south, the thickly bedded or massive arenite predominates. The arenite is similar to that in the massive coarse sublitharenite-siltstone-shale association, except that the large well-rounded grains are less common, and are rarely more than 1 mm in diameter; in many arenites these large grains are completely lacking. The smaller grains are commonly angular and poorly sorted, and phyllosilicate material is common. Metamorphism has converted the arenite to quartzite. A variety of rock fragments may be present, including chert, mudstone, quartzite, and possible volcanic rock. A feature of many arenites of this association is the abundance of well-rounded zircon and tourmaline grains. Siltstone and cleaved shale are common only on Peak Back Ridge. The siltstone may be finely laminated and show rare contorted bedding, but the cleavage has destroyed all sedimentary structures in the shale.

Environment of deposition

The Tantangara Formation contains many of the typical sedimentary structures of turbidite deposits, and the turbidite sequence of Bouma (1962) is widely developed. The common occurrence of Bouma's divisions A (basal graded bed) and B (plane-laminated arenite) indicates that much of the sediment was deposited in a proximal turbidite environment. Crook & others (1973) reported proximality values for three short sections at Tantangara Dam as 25%, 100%, and 83.3%. The juxtaposition of two very proximal with one rather distal value is puzzling, though Crook & others (p. 120) suggested four possible explanations without giving preference to any one. The proximality values, however, do confirm that much of the section at Tantangara Dam, which is within our massive coarse sublitharenite-siltstone-shale association, is a proximal turbidite.

The fine arenite-siltstone-shale association, which occurs generally east of the massive coarse sublitharenite-siltstone-shale association, similarly exhibits many of the features of proximal turbidite deposition, but, in contrast, shale is more common, the arenites are finer-grained, and individual turbidite beds are thinner. No detailed logs were measured, but proximality index is estimated to be commonly between 50% and 75%, with some parts below 50%. It is therefore considered to be a more-distal turbidite than the massive coarse sublitharenite-siltstone-shale association.

The concept of proximality cannot be applied to the sequences in the medium to fine arenite association, since virtually all their internal sedimentary structures have been destroyed during recrystallisation. However, since the arenites are similar microscopically to the remainder of the

Tantangara Formation, they presumably formed by a similar depositional process; in addition, shale is minor, and much of the arenite is in thick to massive beds. We therefore suggest that the medium to fine arenites were deposited in an area in which frequent rapid turbidity flows restricted the deposition of mud, and that they may represent traction-carpet deposits (Dzulynski & Sanders, 1962; Walker, 1967) formed in a more-proximal environment than the massive coarse sublitharenite-siltstone-shale association.

Based on the arguments given above, we suggest that the Tantangara Formation was deposited in a meridional trough which developed at the end of the Ordovician or early in the Silurian, and represents a series of submarine fans deriving their sediment from the west. The medium to fine arenite association would have been deposited in the upper part of one or more fans; the massive coarse sublitharenite-siltstone-shale association in the central parts of the fans; and the fine arenite-siltstone-shale association in the outer parts of the fans. The thinner-bedded arenite and minor shale around Peak Back Ridge may have been deposited between two adjacent fans represented by the thick arenites which crop out to the north and south on Mount Nattung and Zinc Ridge. Similarly the sequence of distal beds noted by Crook & others (1973) at Tantangara Dam may have been derived from a fan adjacent to that which supplied the Tantangara Dam area.

This hypothesis implies that the three associations are lateral equivalents, which is supported by the relations between the associations and the underlying units: in the west the medium to fine arenite association rests unconformably on the Kiandra Group west of Dairymans Plain; the massive coarse sublitharenite-siltstone-shale association rests unconformably on the Nungar beds on Nungar Ridge; and farther east, the fine arenite-siltstone-shale association also rests unconformably on the Nungar beds on Nungar Plain.

Relations

The contact of the Tantangara Formation with underlying units is an unconformity. It is well exposed west of Dairymans Plain in a stream bed (at grid ref. 447456) where the Tantangara Formation dipping 34°N and striking 165° overlies chert of the Kiandra Group steeply dipping on strike 010°; the base of the Tantangara Formation is a massive medium to coarse-grained arenite about 3 m thick with abundant well-rounded quartz up to 1.5 mm in diameter.

The Tantangara Formation is overlain with marked unconformity by the Peppercorn Formation (late Llandoverian to ?early Ludlovian), Pocket Formation (?late Llandoverian to ?early Ludlovian) and the Kellys Plain Volcanics (early Lochkovian).

Thickness

The thickness of the Tantangara Formation cannot be accurately estimated because of its poor exposure and the structural and stratigraphic complexity of its outcrop. The type section exposes about 1000 m of sediments, and so gives a lower limit to estimates. The total thickness of the unit may be 1500 to 2000 m.

Age

D.L. Strusz (BMR) has confirmed the Silurian age of a poorly preserved, fragmentary fauna collected from a coarse sublitharenite just inside the tree line on the northern edge of Nungar Plain (grid ref. 492299):

'Most of the fragments of tabulate corals, and many of the smaller shell fragments cannot be identified. However a series of brachiopod fragments can be assigned with reasonable confidence to Eospirifer. This spiriferid is first known in the Llandoverian, is common throughout the Silurian, and persists into the Early Devonian in central Europe.

'In addition, two specimens of a fasciculate species of Tryplasma are present. Although this genus appears in the Upper Ordovician, it is most common in the Silurian.

'Also, one of the tabulate coral fragments can be fairly confidently assigned to Angopora, which first appears in the Silurian according to Hill & Stumm (1956, p. F464)'.

Thus the fossil evidence indicates a Silurian or younger age for the Tantangara Formation. In the Nungar Creek valley, the strongly deformed Tantangara Formation is overlain unconformably by the more gently folded Peppercorn Formation, which conodonts date as late Llandoverian; on this evidence the Tantangara Formation must be no younger than early Llandoverian.

The possibility that part of the Tantangara Formation is latest Ordovician cannot be dismissed, but supporting fossil evidence is unlikely to be forthcoming.

COOLEMAN PLAINS GROUP

Peppercorn Formation, Pocket Formation, Cooleman Limestone, and Blue Waterhole Formation

The name Cooleman Plains Group is introduced to include the Peppercorn Formation, Pocket Formation, Cooleman Limestone, and Blue Waterhole Formation, which together represent a shallow-marine sequence cropping out between Tantangara Reservoir and Brindabella. In a previous account, Owen & others (1974b) did not formally describe these units, which - with the exception of the Peppercorn Formation - they included in their informally named 'Cooleman Plains sequence'. As a result of further mapping in BRINDABELLA and re-interpreting the Cooleman Plains area, we can now fully define the three units of the 'Cooleman Plains sequence'; demonstrate their close relation to the Peppercorn Formation; and define a group containing all four units.

Previous work

The Reverend W.B. Clarke (1860), who was the first to refer to the geology of the area in which the Cooleman Plains Group crops out, reported 80 to 100 km^2 of cavernous limestone, apparently metamorphosed by intrusive granites and porphyries, in the Cooleman Plains area. Leigh & Etheridge (1894) reported on the caves and on several aspects of the geology, used the name Cooleman Limestone for the first time, and distinguished it from a limestone (called Cave Limestone) underlain by calcareous shale at Cooleman Falls (grid ref. 542564).

No further investigations were made until Walpole (1952) mapped the area. He described the Cooleman Limestone in more detail but did not recognise the overlying siltstone and chert as a separate unit.

Staff of SMHA examined the area as part of a regional survey for the proposed Tantangara Reservoir. Newberry (1956) named the Pocket Beds near Pocket Saddle and in the upper Goodradigbee River valley. Stevens (1957, 1958b) presented the most detailed geological map of the area. He identified four units, introducing the name Wilkinson Limestone for the limestone cropping out downstream of the Cooleman Falls, and also recognised the existence of complex facies relations between the various units.

Walpole (1964) and Best & others (1964) introduced a completely different nomenclature for the Silurian rocks of the area, but did not publish a written account of the units. The names they introduced are synonymous with names introduced by Stevens (1958b): the Marys Hill Beds and Mount Murray Branch Formation of Walpole and Best & others are equivalent respectively to the Blue Waterhole Beds and Pocket Beds of Stevens. They also published the name Peppercorn Beds for the Silurian sediments on Long and Little Peppercorn Plains.

Legg (1968) largely concurred with Stevens in his mapping of the area, but recognised the similarity of the Cooleman Limestone to the limestone near the top of the Pocket Beds, and further refined Stevens's ideas of lateral facies relations. He also attempted to reconstruct the palaeogeography and depositional environment of the beds.

Peppercorn Formation

Nomenclature

Walpole (1952, p.9) gave the name Peppercorn Group to a series of possibly middle Silurian sediments exposed on Long Plain and around the headwaters of Little Peppercorn Creek. He derived the name from Peppercorn Hill, a prominent hill at the north end of Long Plain, but designated no type locality. According to the Australian Stratigraphic Code the unit cannot be considered a group as it does not comprise two or more formations, and later workers called it the Peppercorn Beds.

The name Peppercorn Beds first appeared in published work in 1964 on the second edition of the Canberra 1:250 000 geological map (Best & others, 1964), and was mentioned briefly by Walpole (1964, p.38). The 1:250 000 map shows the Peppercorn Beds west of the Long Plain Fault occupying a large area comprising acid volcanics which we now identify with the Goobarragandra Volcanics rather than the Peppercorn Beds. Walpole apparently realised this difference, for he differentiated them in a sketch map (Walpole, 1964, fig. 11).

Previously Stevens (1958a) had described outcrops of Silurian chert, conglomerate, and sandstone in the Nungar Creek valley, but did not name them. The present work has shown that the outcrops described by Stevens are part of the Peppercorn Beds.

Legg (1968) described the Peppercorn Beds from the Little Peppercorn Creek area, and Bein (1968) described them in the lower Nungar Creek valley and on Dairymans Plain. Bein introduced the name Currango Beds for the Nungar Creek occurrence of the Peppercorn Beds because of the then existing uncertainty about correlating the Silurian rocks in Nungar Creek and the Peppercorn area. The name Currango beds, defined by Crook & others (1973), is considered a junior synonym of Peppercorn Beds and is not used here.

The Brindabella Beds of Best & others (1964) are considered a synonym of the Peppercorn Beds. The lithology of the unit in the Brindabella valley is identical with the upper part of the Peppercorn Beds in Little Peppercorn Creek, and mapping has shown continuity between the two areas.

Sufficient information is now available to describe the relations of the unit with other units in the two Sheet areas, and it is defined herein and given formational status.

Derivation of name

The Peppercorn Formation was named by Walpole from Peppercorn Hill, a prominent hill capped by Tertiary basalt at the head of Long Plain.

Type section

The type section, designated here, is in the valley of Little Peppercorn Creek. It starts about 250 m east of the creek crossing of an old disused track from Little Peppercorn Plain to Little Peppercorn Hut (Fig. M12). From this point (grid ref. 482637) it extends northwest for about 800 m to the base of the overlying Kellys Plain Volcanics (grid ref.479643).

The contact of the formation with the underlying Nine Mile Volcanics is not exposed in the type section, but mapping in the area has shown it to be an unconformity. As the contact is traced northeastward, the Peppercorn Formation is found to rest on various units within the Nine Mile Volcanics. The basal unit within the Peppercorn Formation is a coarse sandstone bed about 5 m thick, which contains reworked fragments of tuffaceous material from the underlying volcanics; this unit is not exposed in the type section, where it is present only as float. In the type section it is followed by 65 m of poorly bedded conglomerate which, being resistant to weathering, has formed good exposures along a ridge about 25 m high. The conglomerate is mainly composed of well-rounded chert pebbles up to 3 cm in diameter, and has interbeds of coarse sandstone and pebbly sandstone, particularly towards the top. The beds appear to have a vertical dip, and strike 060°.

The conglomerate passes gradually up through coarse to fine sandstone which is poorly exposed; this sandstone unit is about 25 m thick. It in turn passes gradually up into strongly cleaved brown siltstone which lacks obvious bedding and again is poorly exposed. This rock type continues without interruption to the overlying Kellys Plain Volcanics. The thickness of the siltstone is uncertain because of the poor exposure and lack of dip readings, but is thought to be more than 500 m.

Distribution

The Peppercorn Formation is widespread, extending from Nungar Creek in the south to Little Peppercorn Creek and the Brindabella valley in the north. It crops out in several areas between the northern end of Long Plain - from Cooinbil homestead north along the eastern slope of Peppercorn Hill - and north of Little Peppercorn Creek in a series of faulted outcrops. Southeast of Cooinbil it is overlain by the Lower Devonian Kellys Plain

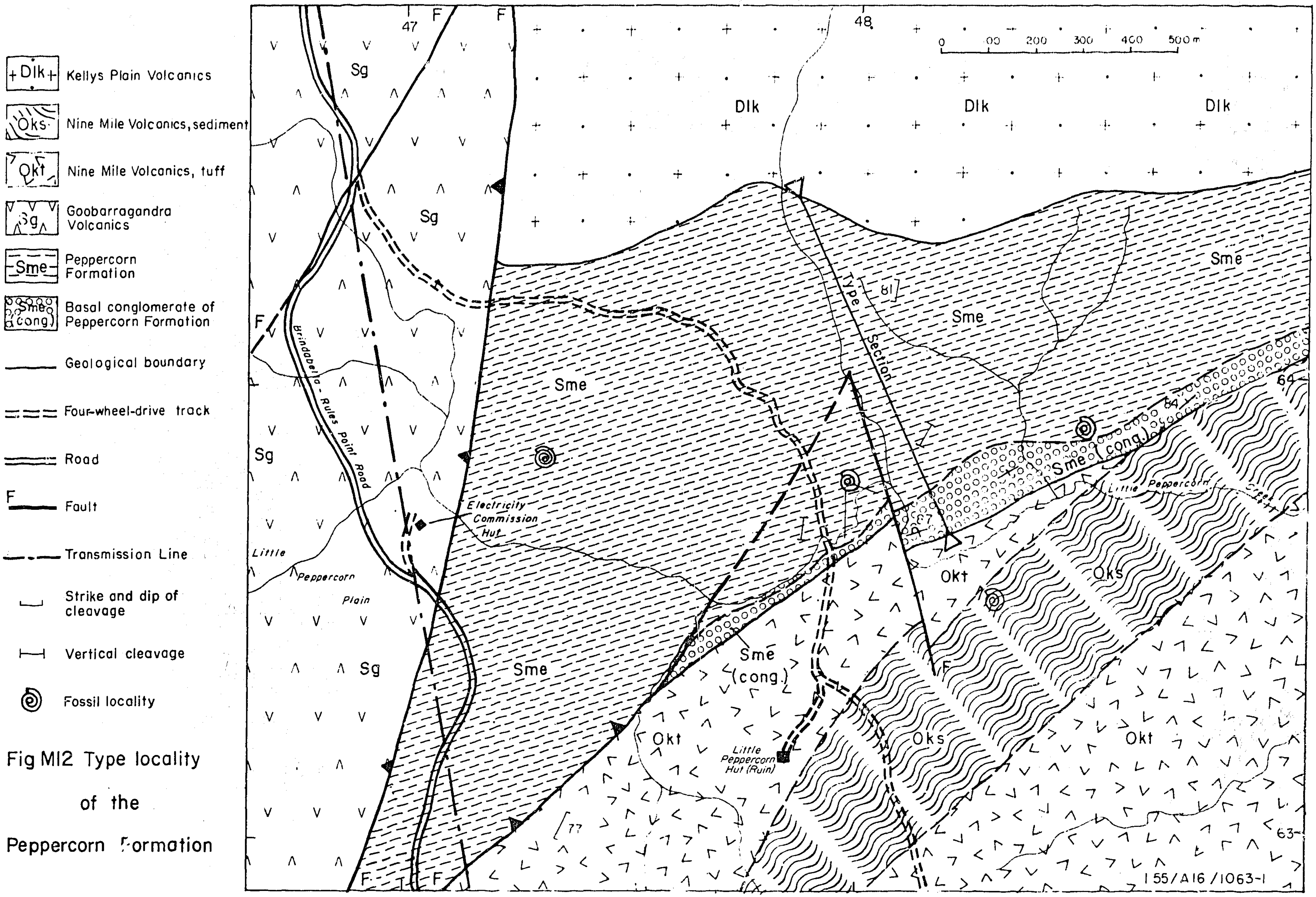

Fig M12 Type locality of the Peppercorn Formation

Volcanics, and forms only isolated inliers within the volcanics or small outcrops on their western boundary on Currango and Dairymans Plains. Farther south, in the Nungar Creek valley, it crops out almost continuously from the mouth of Nungar Creek to the Nungar Creek Trail Crossing, and from there - as small isolated outliers - to the eastern slopes of Blackfellows Hill. It extends northeast from Little Peppercorn Creek in a narrow faulted belt about 4 km long, then disappears beneath the overlying Kellys Plain Volcanics, and reappears to the north in the Tinpot Creek valley, from where it extends north into the Brindabella valley.

Lithology

The lithology of the Peppercorn Formation is constant over a wide area. It consists of a basal chert conglomerate overlain by coarse sandstone becoming fine, which is commonly fossiliferous immediately above the conglomerate; fine sandstone, siltstone, and mudstone are interbedded higher in the succession. Fossiliferous limestone and calcareous shale crop out on Long Plain near Cooinbil. Locally the basal conglomerate is underlain by a medium to coarse sublitharenite up to 10 m thick, as in the type section and in the Nungar Creek valley.

The basal chert conglomerate is the most distinctive part of the Peppercorn Formation. Wherever it crops out it forms prominent tors and ridges, as in the lower Nungar Creek valley where outcrops are up to 10 m high. The conglomerate is mostly formed of rounded to subangular chert and vein-quartz pebbles having a fairly high sphericity. The composition of the pebbles reflects to some extent the subjacent rock type: in addition to chert and vein-quartz, which always predominate, volcanic pebbles are present where the conglomerate overlies volcanic units in the Kiandra Group; and quartz arenite and sublitharenite pebbles are present where it overlies the Tantangara Formation. The size of the pebbles shows little variation from Little Peppercorn Creek to the lower Nungar Creek valley, where they range from 1 to 5 cm diameter, but farther south the average size increases to about 10 cm, and some pebbles are up to 20 cm diameter. The angularity of the pebbles also tends to increase towards the south.

The matrix of the conglomerate consists of well-rounded sand ranging from very fine to granule size. The sand-size material also occurs as small cross-bedded lenses within the conglomerate.

The thickness of the conglomerate varies over short distances. In places in the Little Peppercorn Creek area it is up to 70 m thick, though generally it is less than 25 m. South of Little Peppercorn Creek it is cut out completely by faulting, and when it reappears on Dairymans Plain it appears to be about 5 m thick, though the full extent may be hidden beneath the Kellys Plain Volcanics. In the Nungar Creek valley the thickness ranges from about 3 m in the north to about 30 m in the south.

The conglomerate grades up into light brown sandstone and sandy siltstone. Fossils are present at many localities in this siltstone, almost always within a few metres of the top of the conglomerate. Rare thin beds of conglomerate up to 50 cm thick are interbedded with the siltstone in the Long Plain area, and show many of the characteristics of the main conglomerate unit, although the pebbles rarely exceed 2 cm diameter. The sandy siltstone generally shows few sedimentary structures apart from minor lamination and small-scale cross-bedding; bioturbation is present and probably accounts for the lack of structure, but in the Nungar Creek valley at grid reference 473396 a bed about 80 cm thick shows well-developed slump-structures (Fig. M13).

Small lenses of limestone and calcareous shale are interbedded with sandy siltstone on Long Plain near Cooinbil. The limestone is partly recrystallised and sheared, generally light grey with pink patches, and contains crinoids, stromatoporoids, tabulate and rugose corals, and brachiopods (Hill, 1954). A small limestone lens is also exposed on Currango Plain at grid reference 507470.

The sandy siltstone grades upwards into poorly laminated and bioturbated medium brown to dark grey fine siltstone or mudstone which is moderately cleaved in the Peppercorn-Long Plain area and poorly exposed. This mudstone forms inliers in the Kellys Plain Volcanics on Currango Plain.

Environment of deposition

The Peppercorn Formation is considered to be a transgressive unit representing a return of the sea after the major folding which affected the Tantangara Formation and older units. The basal conglomerate of the Peppercorn Formation formed in a high-energy environment, probably as a beach deposit; marine conditions are indicated by fossils in a small sandy lens

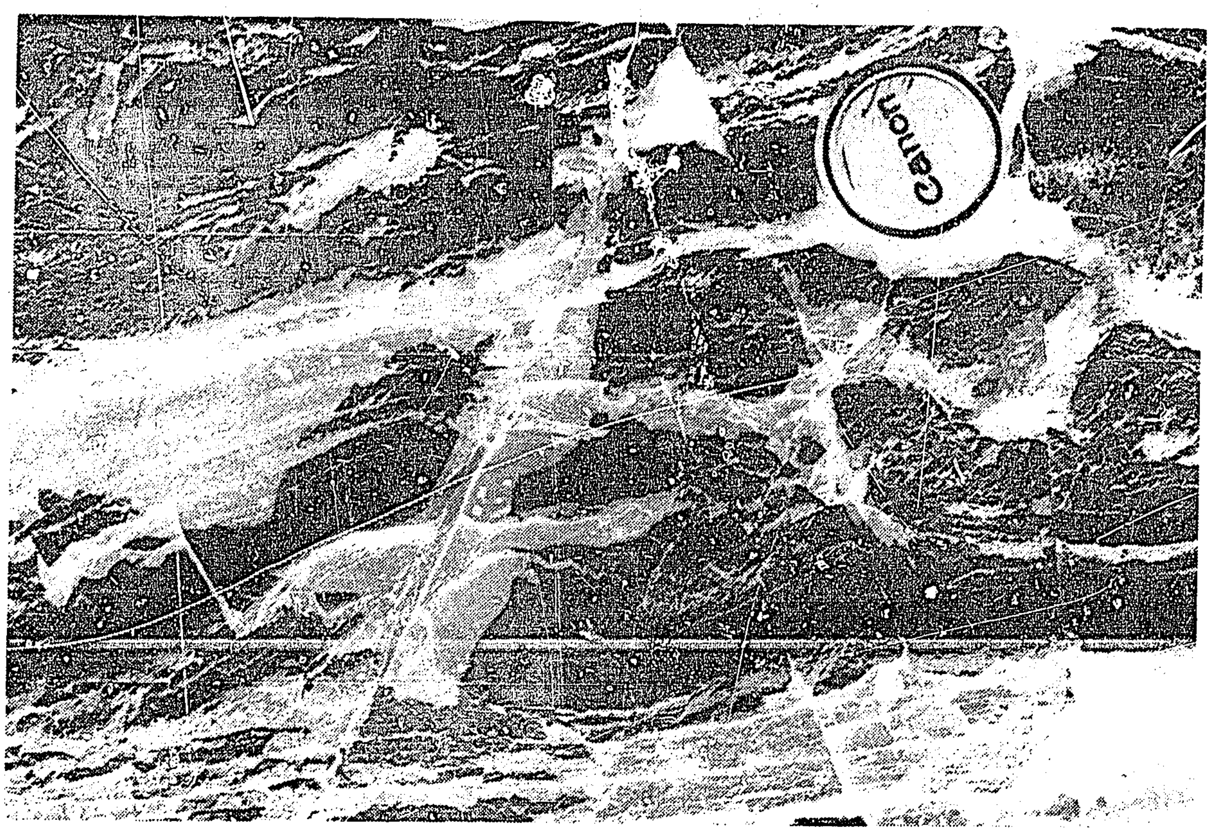

Fig. M13. Slumped siltstone bed in the Peppercorn Formation on Nungar Creek at grid reference 473396.
(GA/8107)

at the type locality. In the southern part of the Nungar Creek valley, clasts are fairly angular at some localities, indicating little reworking by wave action, and part of the conglomerate may have been deposited above sea level, probably as an alluvial fan.

At all localities a vertical transition upwards into sandstone, then siltstone, and finally mudstone indicates deepening water as the transgression progressed, and demonstrates in vertical section the lateral facies changes commonly occurring in a shallow-marine environment from a nearshore to offshore position. The rare limestone lenses, near Cooinbil and on the west bank of Tantangara Reservoir, indicate that, even in the offshore environment, water depths were still shallow.

Thickness

The Peppercorn Formation is about 600 m thick in its type section, whereas upwards of 1000 m of siltstone and mudstone from the upper part of the unit are exposed in the lower Peppercorn Creek valley.

Relations

The Peppercorn Formation unconformably overlies the Kiandra Group in the Little Peppercorn Creek area and near Dairymans Plain, and the Tantangara Formation in the Nungar Creek valley. The top of the formation passes up conformably and gradationally into the Blue Waterhole Formation in the lower Peppercorn Creek area, and into the Cooleman Limestone on the western edge of Cooleman Plain. The formation is unconformably overlain by the Lower Devonian Kellys Plain Volcanics from Nungar Creek north to Peppercorn Creek.

Fossils and age

Macrofossils are common in the Peppercorn Formation at many localities. They are present in three different rock types. The fossils are most common in the sandy siltstone immediately above, or more rarely within, the basal conglomerate, particularly in the Nungar Creek and Little Peppercorn Creek valleys, where they are preserved as moulds. Fossils are less abundant in the fine siltstone higher in the sequence, where they are preserved as moulds, both scattered through the rock and concentrated into particular beds. They also occur in the limestone lenses near Cooinbil.

Hill (1954) described corals from the limestone near Cooinbil and identified Halysites sp. cf. australis, H. brevicatenatus sp. nov., Halysites sp. indet., Coenites sf. seriatopora, and Diploepora sp. cf. grayi; she reported a Wenlockian or Ludlovian age for this fauna. D. Strusz (BMR, personal communication 1974) came to a similar rather indefinite conclusion about a fauna collected in the Nungar Creek valley (at grid ref. 471411); he identified Encrinurus cf. etheridgei, Rhizophyllum sp., and ?Nucleospira sp. More detailed work remains to be done on these faunas.

The limestone near Cooinbil has yielded a rich conodont fauna, of which the main elements have been identified by Nicoll & Rexroad (1974). Significant species are Ambalodus galerus, Apsidognathus tubercalatus, Astrognathus cf. tetractis, Neospathognathodus pennatus, Ozarkodina gaertneri, Pterospathodus amorphognathoides, and Pygodus lyra. This fauna indicates a correlation with the Telychian Stage (late Llandoverian) of the Welsh Borderlands (Aldridge, 1972).

The age of the Peppercorn Formation, at least near Cooinbil, is therefore late Llandoverian. The uppermost part of the formation may be early Ludlovian.

Pocket Formation

Nomenclature

Newberry (1956) introduced the name Pocket Beds for a sequence of quartzite, slate, phyllite, lenticular limestone, and tuff in the Pocket Saddle area, near the Goodradigbee River, and for about 5 km downstream in the Goodradigbee valley. Stevens (1958b) first published the name. The Mount Murray Branch Formation of Walpole (1964) and Best & others (1964) is a junior synonym of the Pocket Beds. The unit is now well enough known for formal naming and definition as the Pocket Formation.

Derivation of name

The unit derives its name from Pocket Saddle, on the divide between Pocket Creek - which drains north into the Goodradigbee River - and Gurrangorambla Creek - which drains southwest into the Murrumbidgee River.

Type section

The type section (Fig. M14, Table M6), designated here, is along the Goodradigbee River. The base of the section is taken where a sill of Gurrangorambla Granophyre intrudes the Pocket Formation at grid reference 553554, about 1.5 km above the junction of Cave Creek and the Goodradigbee River. The top of the section, at the junction of the Pocket Formation and the Blue Waterhole Formation, is about 0.4 km above the mouth of Cave Creek at grid reference 553563. The type section comprises about 750 m of exposed Pocket Formation in the bed of the Goodradigbee River, and shows the typical lithology of the unit: cleaved mudstone with interbeds of impure limestone, and coarser beds (some tuffaceous) near the base. Upstream of the granophyre sill, strata lower in the formation are strongly cleaved and poorly exposed.

Distribution

The Pocket Formation crops out in two areas separated by the intrusive Gurrangorambla Granophyre and the extrusive Kellys Plain Volcanics. The northern area lies between Mount Black (grid ref.540550) to the west and Rolling Ground Ridge to the east, and is bounded in the north by a prominent ridge immediately south of Cave Creek; southwards this area is bounded by the granophyre, of which a narrow sill also splits the area into two parts. The southern area in which the Pocket Formation crops out is an elongate faulted area, about 3.5 km by 0.5 km, trending north-south; its northern end occupies part of the Goodradigbee River valley, and its southern part crops out in the Pocket Creek valley.

The topography reflects the soft, deeply weathered lithologies of much of the unit: both outcrop areas are the sites of deeply incised tributaries of the Goodradigbee River, and waterfalls have formed where granophyre sills cutting the Pocket Formation cross the Goodradigbee River; the limestone lenses, however, may form ridges, (e.g., at grid ref. 569535).

Lithology

The Pocket Formation is mostly cleaved mudstone, with interbeds of impure limestone, and local thin sandy siltstone and tuffaceous beds. The mudstone is grey, weathering brown, and massive or with indistinct bedding;

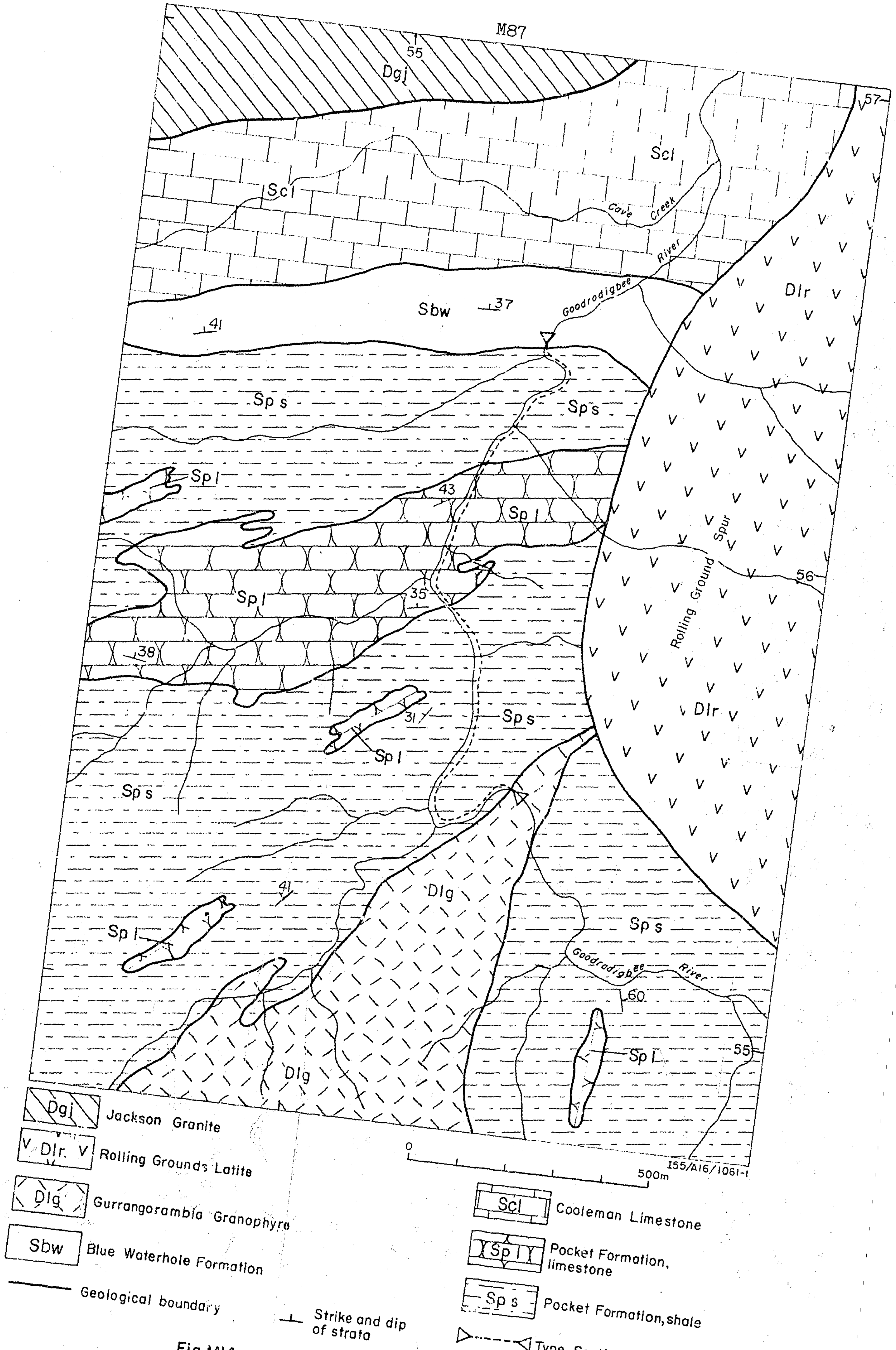

Fig MI4. Type section of the Pocket Formation

TABLE M6. TYPE SECTION OF THE POCKET FORMATION

Unit	Lithology	Thickness (m)
Blue Waterhole Formation	fine hard black chert	
	brown shale	75
	impure limestone	11
	brown shale	115
	impure grey limestone, highly fossiliferous in places, with thin shale interbeds	140
	brown cleaved shale with a few coarser sandstone beds	115
Pocket Formation	impure, highly cleaved grey limestone	32
	brown shale, highly cleaved, with rare coarser beds	140
	coarse tuff	15
	brown shale	24
	medium-grained, lithic, slightly tuffaceous sandstone	21
	coarse hard tuff	15
Gurrangorambla Granophyre	intrusive granophyre sill	18
	End of section	

it is commonly fossiliferous and bioturbated. The cleavage becomes more pronounced southward and increasingly distorts the fossils, which - with the formation of slate in the south - are completely destroyed.

Limestone lenses 1 to 3 m thick are common, and some are up to 140 m thick. The limestone is invariably impure, grey, often highly fossiliferous, and commonly has thin interbeds of shale. Its boundary with the mudstone may be sharp, but is generally gradational: either the mud content of the limestone increases through calcareous mudstone to mudstone, or the interbeds of shale or mudstone gradually become dominant. Stylolites are common in the limestone, and some beds have been completely recrystallised to medium-grained calcite in which the original textures are destroyed. Most of the unrecrystallised limestone has abundant fossil debris showing evidence of transportation, and has a fine micrite or sparite cement. Patches of pelletal limestone also occur. According to the terminology of Folk (1968), most of the limestone is biomicrite or biosparite; biopelsparite is uncommon and dark grey dismicrite is rare. Cleavage in the limestone is pronounced in the Pocket Creek area, where it has destroyed all evidence of original textures.

A few thin, medium to fine quartz sandstone beds occur near the base of the unit near Pocket Saddle, but are deeply weathered; no trace of a basal conglomerate similar to that in the Peppercorn Formation is evident.

Environment of deposition

The Pocket Formation, like the Peppercorn Formation, is a marine transgressive unit deposited in relatively shallow water. Evidence for this is the abundance of marine fossils and the presence of limestone lenses rich in corals and stromatoporoids. Sedimentary structures are rare, mainly as a result of intense bioturbation. In contrast to the Peppercorn Formation, the transgression of the sea over the area of the Pocket Formation may well have been rapid, since only thin coarser beds are present at the base, and offshore silt and mud sedimentation was soon established.

Fossils and age

Both the mudstone and limestone of the Pocket Formation are locally richly fossiliferous, though species diversity is commonly low. The fauna from the mudstone (from Legg, 1968) includes the brachiopods *Molongia elegans* Mitchell, *Atrypoidea angustans* Mitchell & Dun, *Howellella nucula* Barrande, *Atrypa* spp., and *Pholidostrophia* aff. *nitens* Williams, and the trilobite *Encrinurus* cf. *mitchelli* Foerste. The limestone beds contain a rich coral and stromatoporoid fauna including *Heliolites daintreei* Nicholson & Etheridge, *Favosites gothlandicus* Lamarck, *Plasmopora heliolitoides* Lindström, *Phaulactis shearsbyi* Süssmilch, *Tryplasma lonsdalei* Etheridge, and *Pycnostylus dendroides* Etheridge. The brachiopod *Conchidium* is present but rare. The few limestones sampled have so far yielded no diagnostic conodonts - only simple cones of little stratigraphic value.

The macrofauna, all of it from beds high in the Pocket Formation, is not sufficiently well known for an accurate age to be determined. It probably indicates a late Wenlockian age. Lithological correlation with the Peppercorn Formation suggests that the base of the Pocket Formation is of late Llandoverian age.

Relations

The Pocket Formation rests unconformably on the Tantangara Formation in the Pocket Saddle area, and passes conformably up into the Blue Waterhole Formation near Cave Creek. It is thought to pass laterally to the west into the Cooleman Limestone and Peppercorn Formation. The relations between the Pocket Formation and the remainder of the Cooleman Plains Group is discussed in detail later.

Thickness

The thickness of the Pocket Formation exposed in the type section is 750 m. This is a minimum thickness for the unit as its base is not exposed there. The total thickness is more than 1000 m.

Cooleman Limestone

Nomenclature

The name Cooleman Limestone was first published by Leigh & Etheridge (1894). Walpole (1952), Stevens (1957, 1958b), Legg (1968), and Palmer (1972) described the limestone, but none of them formally defined it.

Stevens (1958b) introduced the name Wilkinson Limestone for a limestone which overlies the Blue Waterhole Formation east of the Mount Black Fault, and suggested that it was younger than the Cooleman Limestone. Our mapping has demonstrated that Stevens's Wilkinson Limestone does not overlie the Blue Waterhole Formation, but is a tongue of Cooleman Limestone within the Blue Waterhole Formation. The name Wilkinson Limestone is thus a junior synonym of the Cooleman Limestone. Walpole (1964) and Best & others (1964) used the name Wilkinson Limestone instead of Cooleman Limestone for the main mass of limestone on Cooleman Plain, but the name Cooleman Limestone has priority.

Derivation of name

Leigh & Etheridge probably derived the name from Cooleman Plain.

Type section

Previous workers have failed to designate any type or reference sections in the Cooleman Limestone. We propose to designate the two measured sections described below as type and reference sections.

The nominated type section (Fig. M15, Table M7) exposes the upper 250 m of the limestone. It starts at the base of a steep bluff on the western side of Cave Creek, about 0.6 km upstream from the southern crossing of the Blue Waterholes Trail over Cave Creek (grid ref. 518560), and extends east (updip) along Cave Creek for about 150 m, before following a steep gully which enters Cave Creek at a point where the creek swings sharply to the north. At the top of the gully the section continues along a bearing of 110^{o} up to the contact between the limestone and the overlying Blue Waterhole Formation (grid ref. 522559). Exposures are virtually continuous from the start of the section to the top of the gully, but are sparse over the last 150 m of the section.

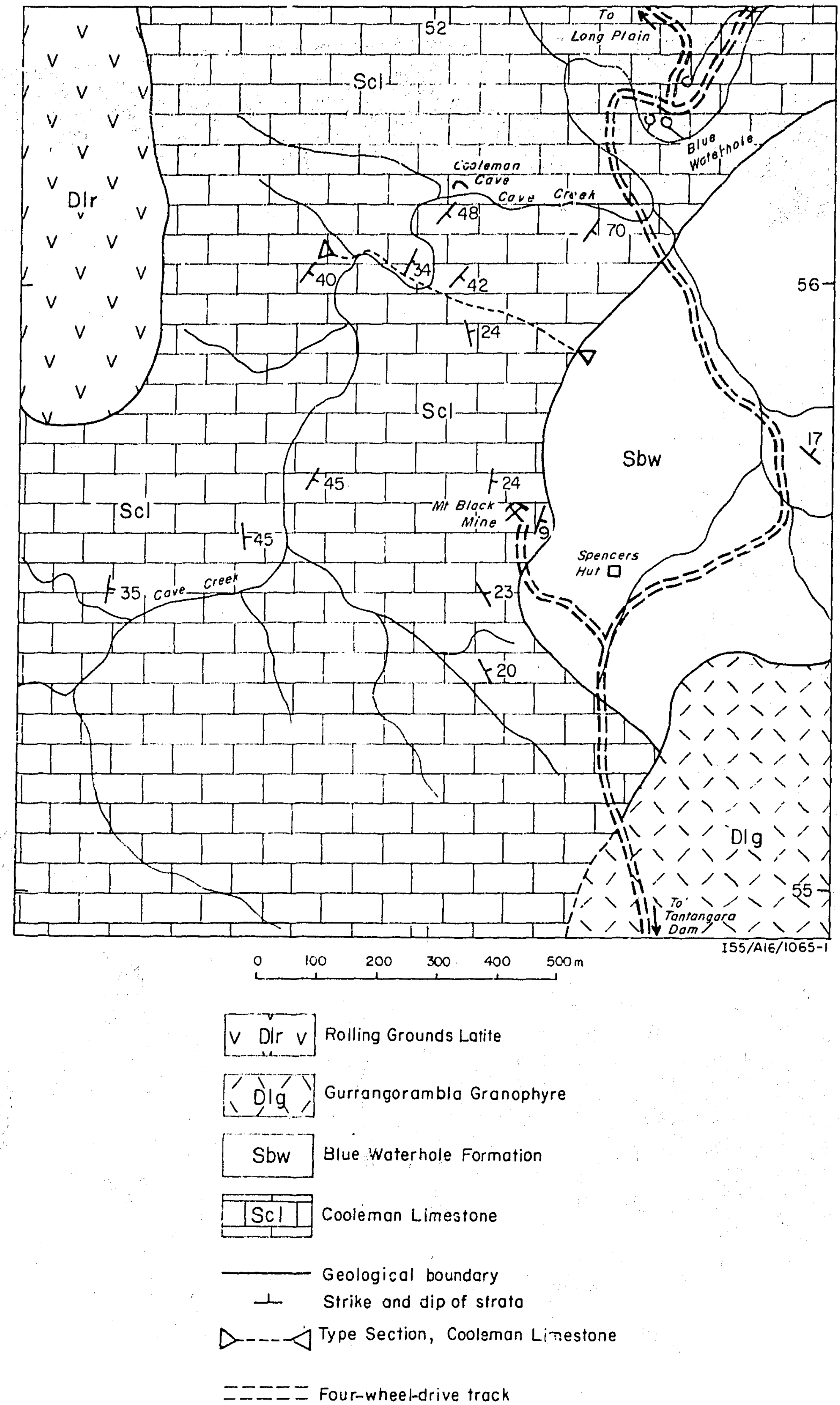

Fig. M15. Type section of Cooleman Limestone

TABLE M7. TYPE SECTION OF THE COOLEMAN LIMESTONE

Unit	Lithology	Thickness (m)
Blue Waterhole Formation	thinly bedded siltstone	
	?disconformity	
	poorly exposed massive limestone	75
	thinly bedded (5-15 cm) dark grey limestone with irregular bedding planes, passing up into thicker (10-20 cm) evenly bedded limestone with stylolites	41
	well-bedded light grey recrystallised sparite limestone	5
	massive to poorly bedded (2 m) biomicrite limestone. Crinoids, corals, bryozoans, gastropods, molluscs, and brachiopods. Slumped blocks of Blue Waterhole Formation (cherty siltstone) to 2 m diameter, 10 m above base	37
Cooleman Limestone	massive pale cream recrystallised limestone	11.5
	(not exposed) about	15
	poorly bedded (10-50 cm) cream, partly recrystallised limestone; rare brachiopods and bivalves	7
	massive coarsely recrystallised limestone	6
	medium to thin-bedded (5-25 cm), partly dolomitised limestone; poorly preserved fossils	10
	cream, highly fossiliferous (brachiopods) limestone bed	0.5
	white, partly recrystallised limestone, sparsely fossiliferous	3.5
	poorly bedded to massive recrystallised limestone with rare large bivalves	38.5

The proposed reference section (Fig. M16, Table M8) exposes about 207 m of limestone considered to be stratigraphically lower in the Cooleman Limestone than that in the type section, though the interval separating the two is unknown. It begins at the contact between the limestone and the intrusive Gurrangorambla Granophyre (grid ref. 514534) in a shallow (2-m deep) doline which receives the waters of a steam draining north from Gurrangorambla Range. The section trends at 020° from this doline over a fairly flat plain on which exposures are scattered at first but become more common about 150 m from the doline. After 260 m, the section follows the west bank of a wide (50 m) shallow north-trending gully along which exposures are common for about 170 m, until the gully joins Cave Creek south branch. The section continues northward beyond the alluvium of Cave Creek south branch for a short distance until the limestone is covered by solifluction deposits derived from the Rolling Grounds Latite, which crops out on the low hill to the north (end of section at grid ref. 517540).

Distribution

The Cooleman Limestone crops out over an area of 21 km^2 in the Cooleman Plain, lower Cave Creek, Goodradigbee River, and Peppercorn Creek areas; a further 1 km^2 is thinly covered by ?Tertiary ferruginous gravels. This is far less than the 80 to 100 km^2 of limestone that Clarke (1860) reported.

The main area of outcrop of the Cooleman Limestone is on the southern part of Cooleman Plain, in a lunate band from Harris Hut (grid ref. 483557) to north of Blue Waterholes, and has a maximum width in the centre of about 3 km. It is bounded to the south and east by the intrusives of the Gurrangorambla Range and Mount Black, and to the north by the Blue Waterhole Formation and the Mountain Creek Volcanics. Outliers of Rolling Grounds Latite overlie the limestone on the plain, where they seem to be present as breccias filling depressions formed by the solution of the underlying limestone.

The second main area of the Cooleman Limestone is in the northern part of Cooleman Plain north and west of Coolamine homestead, where it crops out in a roughly triangular area with a narrow extension to the southwest. It is separated from the main area to the south by the east-west ridge of the Blue Waterhole Formation immediately south of Coolamine homestead.

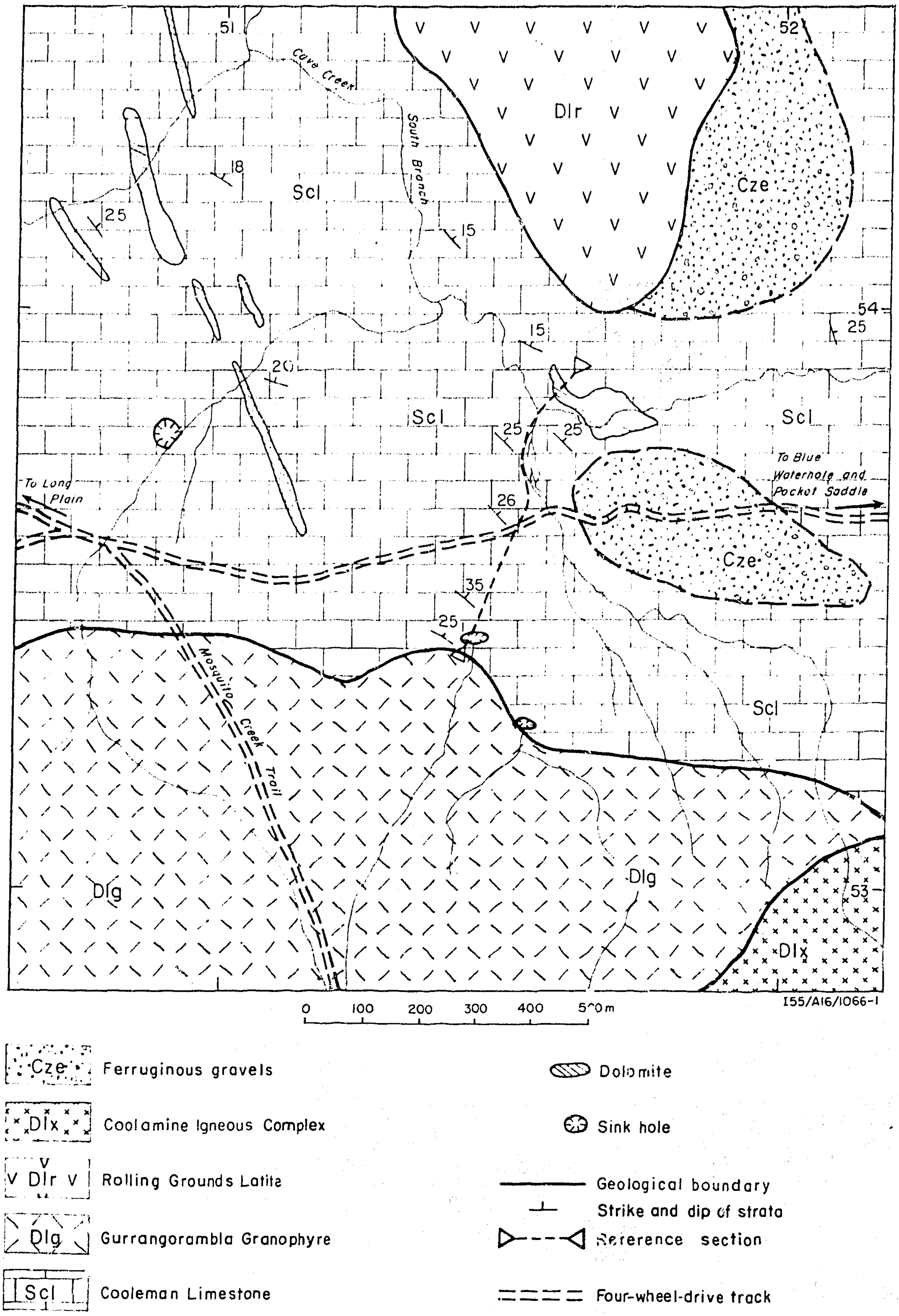

Fig. M16 Reference section in the Cooleman Limestone

TABLE M8. REFERENCE SECTION OF THE COOLEMAN LIMESTONE

Unit	Lithology	Thickness (m)
	Colluvium from unconformably overlying Rolling Grounds Latite	
	sparry biomicrite partly replaced by dolomite	2
	sparry dolomite with small areas of micrite limestone	5
	well-bedded (15-40 cm) moderately to very fossiliferous grey biomicrite (brachiopods, bivalves, stromatoporoids)	5
	(not exposed across alluvium, Cave Creek south branch)	5
Cooleman Limestone	well-bedded (15-40 cm) moderately to very fossiliferous grey biomicrite (brachiopods, bivalves, gastropods, nautiloids, stromatoporoids, rare corals). Some minor dolomitisation in upper part, minor pelletal sparite	70
	(gradual transition)	
	discontinuous outcrops of massive to thick-bedded dark grey limestone, partly recrystallised; rare fossils, mainly brachiopods	70
	(not exposed)	40
	massive grey fossiliferous limestone (brachiopods, bivalves, crinoids, corals)	10
	base of section (Gurrangorambla Granophyre)	

Further limestone is present in an elongate belt extending first east along the lower Cave Creek valley to its junction with the Goodradigbee River, and then (in a faulted zone) north along the west side of the Goodradigbee valley as far as Dunns Flat (grid ref. 565625).

The limestone also crops out at two places in the Peppercorn Creek valley: one (at grid ref. 540669) is a roof pendant in an intrusion of the Coolamine Igneous Complex ; the other (at grid ref. 517630) is in the Blue Waterhole Formation.

The Cooleman Limestone exhibits many features typical of karst landscapes. Dolines are widespread on the southern part of Cooleman Plain, and have been formed by both solution and collapse. Solution runnels (rillenkarren) are minor solution features. Many streams draining from the surrounding ranges flow underground as soon as they reach the limestone, and dry blind valleys and small caves are common. All the underground drainage of the area finally resurges at Blue Waterholes, a group of large risings which form the permanent source of Cave Creek (Jennings, 1974). Above Blue Waterholes the creek flows only after very heavy rain.

Lithology

Although the Cooleman Limestone comprises several different rock types, extensive recrystallisation has hindered attempts to map their distribution. In general, the unit consists of light grey massive to thickly bedded limestone, though in places it is moderately thinly bedded. Fossils are mostly sparse and may be completely lacking where recrystallisation has reached an advanced stage; however, some beds, generally of small lateral extent, are richly fossiliferous (Fig. M17).

The bulk of the unit is formed by a partly recrystallised massive to thickly bedded (2 m), light to medium grey limestone with few or no fossils. In thin section, calcite crystals are commonly of two sizes. The larger comprises sparry calcite crystals of 2 to 4 mm, commonly with concave boundaries; the smaller is a finer sparry calcite (0.4 mm) or micrite groundmass. Variation between samples is usually limited to the degree to which the larger sparry calcite has replaced the finer calcite, and to the rare occurrence of recrystallised fossil fragments.

This partly or completely recrystallised limestone in places grades both laterally and vertically into a medium grey, thickly bedded, moderately fossiliferous limestone showing relatively few signs of recrystallisation. Thin sections commonly show a very fine-grained (0.05 mm) calcite groundmass and a large proportion of biogenic fragments up to several millimetres. Fossils, which are seldom complete, include crinoid columnals, corals, bryozoans, gastropods, bivalves, brachiopods, and possible ostracods. Much of the lower half of the reference section is formed by this moderately fossiliferous limestone.

Highly fossiliferous limestone results from an increase in the proportion of fossil fragments rather than a decrease in the degree of recrystallisation. Although it comprises mainly biogenic fragments, it has a similar range of fossils and textures to that in the less fossiliferous limestone. Both the moderately and highly fossiliferous limestone beds show abundant evidence of bioturbation, and many fossils are worn and broken. Many fossiliferous limestone beds also contain pellets 0.3 mm to 4.0 mm in diameter, generally formed of micritic calcite. Stylolites are ubiquitous. This fossiliferous limestone is a biopelsparite or biopelmicrite, depending on the nature of the cementing matrix of the rock.

Crinoidal limestone is present in places in the upper part of the Cave Creek gorge. It is a light grey limestone containing crinoid ossicles and columnals in a coarse sparry calcite matrix. Unlike the previously described fossiliferous limestone, abrasion of the crinoid fragments is minimal.

The Cooleman Limestone in the upper part of the type section, in the gorge upstream of Blue Waterholes, is unusual in that it contains a sequence of dark grey well-bedded limestone about 40 m thick (Table M7). At the base of this sequence the bedding surfaces are uneven and 5 to 15 cm apart; higher, the bedding surfaces gradually become flat and are 10 to 20 cm apart. Stylolites are common, and fossils rare. In thin-section, the limestone is partly recrystallised, and commonly comprises about 60% sparite apparently derived from a micrite groundmass. Recrystallisation has almost destroyed the rare fossil fragments.

Much of the limestone near Harris Hut (grid ref. 483557) is formed by massive to thickly bedded, coarse-grained cream sparite which has resulted from complete recrystallisation of the limestone.

Dolomitisation of the limestone in various degrees of intensity is fairly widespread. It has mostly taken place along major joints, and is unusual for the sharp boundary between the dolomite and the surrounding unaltered limestone. The combination of joint-controlled dolomitisation and sharp contacts with the unaltered limestone creates the superficial field appearance of dykes of dolomite intruding the limestone. Several of these dolomite 'dykes' are shown in Figure M16. Dolomitisation away from joints is patchy, but appears to be controlled to some extent by original lithology; however, no detailed study was made of this factor.

Unlike the main mass of Cooleman Limestone, the limestone east of Mount Black Fault, formerly called the Wilkinson Limestone, contains near its base thin cherty beds which reflect a gradual transition from the underlying cherty Blue Waterhole Formation (Fig. M18). The chert beds highlight penecontemporaneous slump-structures near Cooleman Falls (grid ref. 541563). The intrusion of the Jackson Granite has highly recrystallised almost all the adjacent Cooleman Limestone, which as a result has a sugary texture, and in parts of the Goodradigbee valley a strong cleavage is developed. Fossils are consequently rare and poorly preserved.

Fossils and age

In spite of the widespread recrystallisation of the Cooleman Limestone, fossils are abundant and fairly well preserved in places. Brachiopods dominate the fauna, though corals, stromatoporoids, gastropods, bivalves, crinoids, bryozoans, and ostracods also occur; trilobites have not been recorded. Among the corals recorded by Legg (1968) are Favosites gothlandicus Lamarck, Heliolites daintreei Nicholson & Etheridge, Parastriatopora sp., Phaulactis shearsbyi Süssmilch, Tryplasma lonsdalei Etheridge, Pycnostylus sp., and Actinostroma sp. The brachiopods include Kirkidium sp. and ?Pentamerus. A large (100-mm wide) thick-walled unidentified bivalve is distinctive at some levels, and algal balls (oncolites) are also present. The age of this fauna is late Wenlockian to Ludlovian.

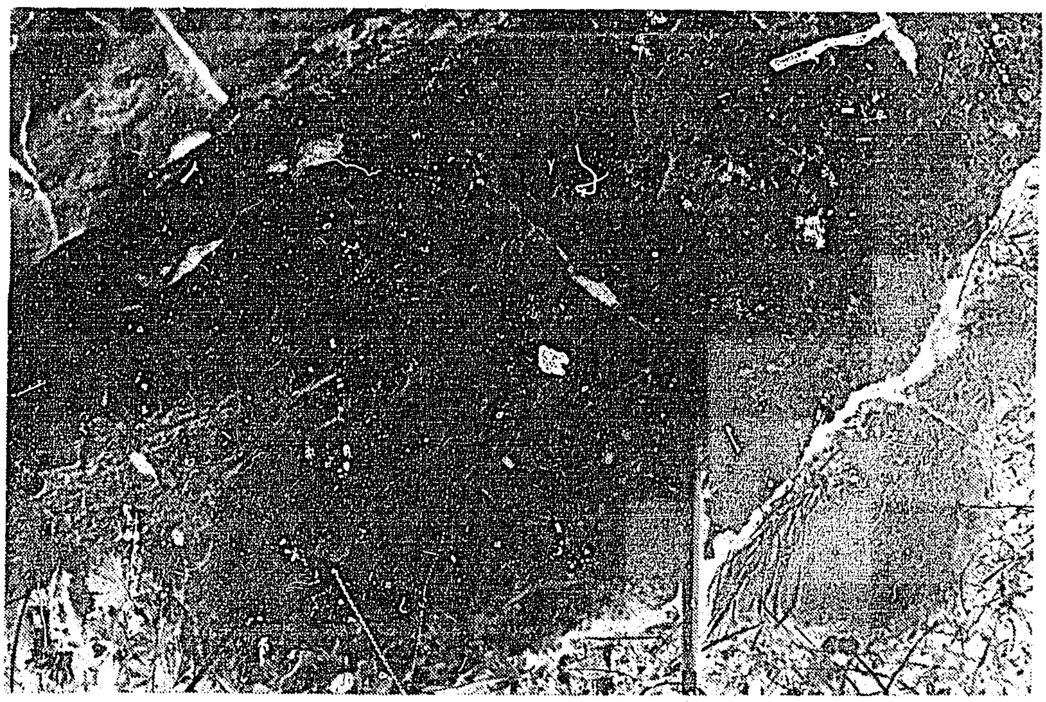

Fig. M17. Fossiliferous Cooleman Limestone in the reference section on Cooleman Plain.
(GB/1835)

Fig. M18. Transitional contact between cherty Blue Waterhole Formation (below) and the Cooleman Limestone (above) at Cave Creek Falls, grid reference 542564. About 20 m of the cliff face is shown in the photograph.
(GA/8039)

At grid reference 495569 (locality A in Fig. M19), allochthonous blocks of limestone that have slumped from the Cooleman Limestone into the Blue Waterhole Formation (see under Lithology, Blue Waterhole Formation) have yielded an abundant conodont fauna, which includes (in sample 3054A) *Spathognathodus remscheidensis*, *S. inclinatus*, *Ozarkodina media*, *O. typica*, and *Neoprioniodus multiformis*. This fauna indicates a Ludlovian to Pridolian age. A similar though less abundant fauna has been obtained from the top of the Cooleman Limestone at Mount Black mine.

Thickness

The total thickness of the Cooleman Limestone cannot be estimated with certainty because its detailed structure is not fully understood. The two measured sections together total 457 m, and may be separated by up to 200 m of limestone, which would give a thickness approaching 650 m. However, 2.5 km north of Harris Hut the width of outcrop of the limestone rapidly decreases to less than 100 m between the underlying Peppercorn Formation and the overlying Blue Waterhole Formation, and its thickness is only about 70 m.

Relations

The possible relations between units in the Cooleman Plains Group are discussed later and shown in Figure M21.

Environment of depositon

Because the Cooleman Limestone is extensively recrystallised, and little detailed petrographic work has been done on it, the depositional environment of the unit is difficult to interpret. In a unit as thick and extensive as the Cooleman Limestone some variation in environments is likely. The bulk of it appears to have been a micritic mud with relatively few fossils, but locally shell banks must have developed to produce the patches of richly fossiliferous limestone. Corals are relatively rare, so extensive coral reefs are unlikely to have been present. Similarly, stromatolitic structures are unknown, so the depositional environment was probably below the intertidal zone. Any suggested environment must also account for the absence of detrital terrigenous material while surrounding areas received an abundance of such sediment. We consider that the Cooleman Limestone was deposited in a subtidal environment on a shallow offshore platform rising above a region of somewhat deeper water in which fine terrigenous sediment accumulated (Blue Waterhole Formation).

Blue Waterhole Formation

Nomenclature

The name Blue Waterhole Beds was first published by Stevens (1958b), who had previously introduced it in an unpublished SMHA report (Stevens, 1957). In his unpublished report Stevens also introduced the name Harris Beds for a series of clastic sediments overlying the Cooleman Limestone south of Coolamine homestead, but in his later paper he included this unit in the Blue Waterhole Beds - a move with which we concur.

Best & others (1964) introduced the name Marys Hill Beds for essentially the same beds that Stevens had called Harris Beds. As we follow the prior terminology published by Stevens (1958b), the Marys Hill Beds are considered a junior synonym of the Blue Waterhole Beds. Sufficient information is now available to formalise the name to Blue Waterhole Formation.

Derivation of name

The Blue waterhole Formation is named from Blue Waterholes (grid ref. 524563), a series of springs forming the perennial rising of Cave Creek.

Type section

Stevens designated neither type nor reference section for his Blue Waterhole Beds. We therefore propose to designate a section on Cave Creek as the type section.

The section commences at the unexposed boundary between the Blue Waterhole Formation and the underlying Cooleman Limestone at grid reference 501557, and follows Cave Creek northward to a point on the hillside (grid ref. 500562) north of where Cave Creek swings sharply west (Fig. M19).

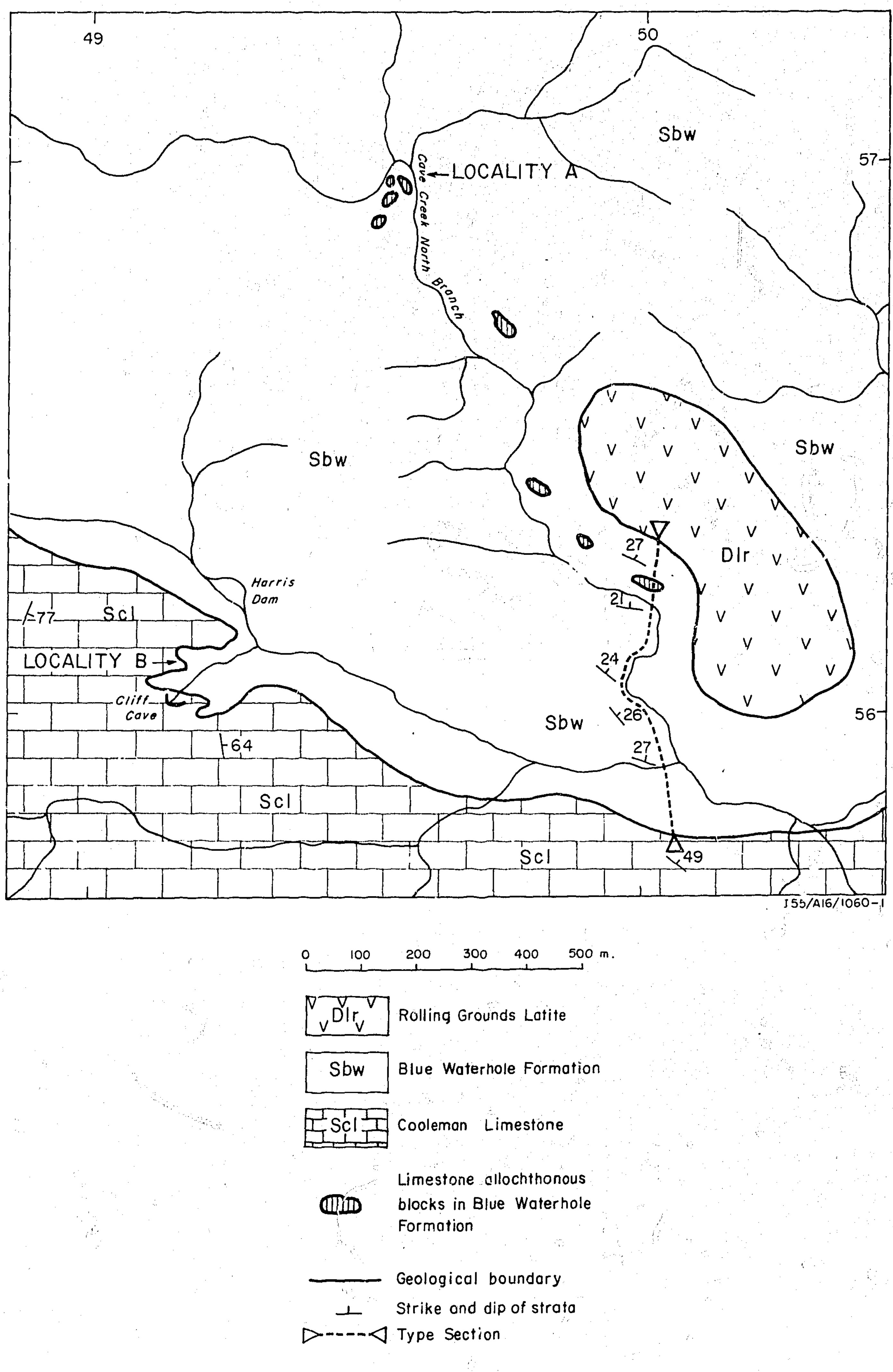

Fig M19 Type locality of the Blue Waterhole Formation

TABLE M9. TYPE SECTION OF THE BLUE WATERHOLE FORMATION

Unit	Lithology	Thickness (m)
	colluvium from unconformably overlying Rolling Grounds Latite	
Blue Waterhole Formation	grey mudstone, thinly bedded, with some siltstone and minor chert	40
	sandstone and sandy siltstone in beds 5-15 cm thick, minor mudstone; allochthonous limestone blocks to 25 cm diameter near base	10
	finely banded siltstone, in beds 5-10 cm thick, with interbeds of dark grey mudstone in beds 10-25 cm thick; shows conchoidal fracture	10
	(no exposure)	10
	as above	34
	(no exposure)	50
	weathered brown siltstone	3
	(no exposure)	30
	?unconformity	
Cooleman Limestone	massive limestone	

Much of the lower part of the section, including the contact with the Cooleman Limestone, is not exposed, but the upper part is almost continuously exposed (Table M9). Most of the section contains finely banded siltstone to fine sandstone beds, 5 to 10 cm thick, rhythmically interbedded with massive, conchoidally fracturing dark grey mudstone in beds 10 to 25 cm thick. Variation in the section is mainly in the proportions of siltstone or sandstone to mudstone. Thin chert beds start to appear near the top of the section, and allochthonous blocks of limestone, up to 25 cm diameter, occupy a sequence showing slump structures about 140 m above the base.

Distribution

The Blue Waterhole Formation crops out in four main areas: the Coolamine/north Cooleman Plain area; the Blue Waterholes area; the lower Cave Creek/Goodradigbee River valley/Koorabri area; and the Peppercorn Creek area. Altogether the Blue Waterhole Formation occupies an area of about 20 km^2.

Lithology

The lithology of the Blue Waterhole Formation shows considerable variation between the different areas of exposure; it is mainly fine sandstone and mudstone in the west, and chert in the east. We have described the lithologies in each of the main areas separately.

Coolamine/north Cooleman Plain area. The Blue Waterhole Formation in the area south of Coolamine homestead comprises mainly rhythmically bedded siltstone or fine sandstone, and mudstone. The siltstone, generally in beds 5-10 cm thick, is composed of subangular quartz-grains, minor chlorite, epidote, and opaque minerals in a clay matrix; sorting is moderate and most of the rock is best considered as a muddy siltstone. Slightly coarser-grained varieties are fine sandstone, which is similar in composition to the siltstone except that it contains rare rock fragments. The siltstone is finely laminated and small-scale cross-bedding is present.

The mudstone is generally unbedded, probably owing to bioturbation, though indistinct light and dark grey bands may be visible. The mudstone forms beds 10 to 50 cm thick and breaks with a conchoidal fracture. Mud-cracks are evident on the upper surface of some beds near the base of the succession (e.g., at grid ref. 490570).

The basal Blue Waterhole Formation near Cliff Cave (grid ref.491559, locality B in Fig. M19) is a dark brown micaceous siltstone weathering to light brown, which appears to have been deposited on an irregular surface developed on the Cooleman Limestone. It appears to be at least 40 m thick, and passes up into typical mudstone and siltstone.

Thin beds (5-15 cm) of dark blue-grey chert in the upper part of the sequence are interbedded with generally hard dark grey siltstone. Above this, hard fine-grained micaceous sandstone containing small amounts of rock fragments apparently forms the uppermost beds in the area south of Coolamine.

A distinct zone of slumping along Cave Creek extends from the type section north-northwest for 900 m as far as a sharp U-bend in the creek (locality A in Fig. M19). This zone is about 140 m above the base of the Blue Waterhole Formation in the type section. Bedding is extremely contorted. Numerous allochthonous blocks of limestone ranging from less than 5 cm to several metres highlight the zone. The limestone blocks become more common towards the north-northwest, and reach their greatest development at locality A in Figure M19 (grid ref. 496569). They appear to have been lithified before the slumping took place. We consider that they are derived from the Cooleman Limestone, which they resemble, and with which they share a similar conodont fauna. They indicate that the Cooleman Limestone was exposed in the Cave Creek area while the Blue Waterhole Formation was accumulating.

A poorly exposed sequence of the Blue Waterhole Formation on the northern edge of Cooleman Plain is similar to the main part of the succession described above, except that fine sandstone appears to predominate over mudstone.

Blue Waterholes area. The Blue Waterhole Formation in the Blue Waterholes area appears to be transitional in lithology between the mudstone and siltstone in the west, and the chert which predominates in the east. In the Mount Black mine area (grid ref. 522557), soft brown micaceous siltstone in beds averaging 15 to 20 cm thick forms the base of the Blue Waterhole Formation, and appears to lie unconformably on the Cooleman Limestone, though the evidence is ambiguous. The micaceous siltstone passes up into a dark grey to black fine siliceous siltstone in the area immediately east of Spencers Hut (grid ref. 523555). The siliceous siltstone, which contains abundant fossils preserved as moulds, rests directly on the Cooleman Limestone above Clarkes Gorge (grid ref. 529563, Fig. M20), where it appears to have been deposited on an irregular surface developed on and in fissures within the Cooleman Limestone. The micaceous siltstone apparently lenses out between Spencers Hut and Clarkes Gorge. Towards Mount Black from Spencers Hut the siliceous siltstone is overlain by a fine-grained quartzite which has been intruded by several sills of the Gurrangorambla Granophyre.

Lower Cave Creek/Goodradigbee River valley/Koorabri area. East of the Mount Black Fault, in the lower valley of Cave Creek and extending downstream along the Goodradigbee River as far as Dunns Flat (grid ref. 563634), the Blue Waterhole Formation is formed of bedded black chert containing disseminated pyrite, and a dark siliceous fossiliferous siltstone, in places calcareous, similar to that near Spencers Hut. Limestone lenses are also present. The Blue Waterhole Formation in this area rests directly on the Pocket Formation with apparent conformity, and passes upwards into a limestone unit that Stevens named the Wilkinson Limestone, which we consider to be part of the Cooleman Limestone. Farther downstream on the Goodradigbee River, rocks of the Blue Waterhole Formation are exposed both above and below the Cooleman Limestone, which lenses out into cherts near Dunns Flat.

Similar chert rocks with limestone lenses crop out farther downstream, around Koorabri homestead. XRD mineralogical studies show that the chert contains zeolites - principally laumontite - which may be locally abundant.

Peppercorn Creek area. In this area the Blue Waterhole Formation crops out in a north-northeast-trending elongate belt, about 1.5 km wide, from northwest of Mount Jackson in the Peppercorn Creek valley to the junction of Peppercorn Creek and the Goodradigbee River. At the southern end of this belt the Blue Waterhole Formation consists of well-bedded siliceous siltstone, fine sandstone, and mudstone, with a few interbedded lenses of limestone at grid reference 518632. Farther north these give way to poorly bedded brown micaceous siltstone and lithic sandstone, apparently above the rocks farther south. At the northern end of this belt the rocks are similar in appearance to the Blue Waterhole Formation in the Goodradigbee valley: black siliceous siltstone in beds 1 to 3 cm thick are interbedded with cream chert in beds 2 to 3 cm thick. This chert-siliceous siltstone sequence appears to be older

Fig. M20. Cherty facies of the Blue Waterhole Formation above Clarkes Gorge, grid reference 529563.
(GA/8028)

than the succession in the central part of the belt, and contains limestone lenses, and is presumably a reappearance of the succession at the southern end of the belt.

Slumping is a feature of the cherty facies of the Blue Waterhole Formation, and is well exposed at many places in the bed of the lower part of Peppercorn Creek, and in parts of the Goodradigbee River about 2 km above Dunns Flat.

Fossils and age

The fauna of the Blue Waterhole Formation is extensive, though mostly poorly preserved. Fossils are generally present in the siliceous siltstone, and are especially common in the lower Cave Creek valley. Among the macrofossils identified by Legg (1968) are _Heliolites daintreei_ Nicholson & Etheridge, _Favosites gothlandicus_ Lamarck, _Plasmopora heliolitoides_ Lindström, _Alveolites_ sp., _Mucophyllum_ sp., _Entelophyllum_ sp., _Tryplasma lonsdalei_ Etheridge, _Mazaphyllum_ sp., _Rhizophyllum_ sp., atrypoid brachiopods, _Encrinurus_ sp. cf. _mitchelli_ Foerste, _Calymene_ sp., and crinoid plates.

No conodonts have been obtained from the Blue Waterhole Formation, though an abundant fauna (listed above - see under Fossils and age, Cooleman Limestone) has been collected from the allochthonous blocks of Cooleman Limestone at locality A in Figure M19. That fauna indicates a Ludlovian to Pridolian age, so the Blue Waterhole Formation at this locality can be no older.

Thickness

The Blue Waterhole Formation is estimated to be 600 m thick in the area south of Coolamine. Farther east it is about 70 m thick where it overlies the Pocket Formation, but thickens northwards to at least 500 m near Dunns Flat. At least 500 m of the Blue Waterhole Formation is exposed in the lower Peppercorn Creek valley, though the true thickness in this area is unknown as the unit is overlain unconformably by the Mountain Creek Volcanics to the east.

Environment of deposition

The Blue Waterhole Formation is thought to have been deposited in rather deeper water than the Cooleman Limestone, in basins surrounding the shoals on which the limestone formed. Sedimentary structures are rare, probably owing to bioturbation, so little can be said in detail about the environment. Towards the east, in the lower Cave Creek valley, fossils - including large tabulate corals in their position of growth - are now largely preserved as moulds in a siliceous siltstone; the rock is thought to have been a calcareous siltstone deposited in rather shallower water than the remainder of the Blue Waterhole Formation, and later silicified, most probably during intrusion of the Jackson Granite.

Relations in the Cooleman Plains Group

Several factors obscure the relations between the Peppercorn Formation, Pocket Formation, Cooleman Limestone, and Blue Waterhole Formation. These include the complex structure of the area: the intrusion and extrusion of igneous rocks which conceal critical areas; the lack of good palaeontological control in all except the Peppercorn Formation; and the complex facies variations thought to be present.

Before attempting to discuss the possible relations between the various units (shown in Fig. M21), we have first summarised the reliable data from which any conclusions are to be drawn.

The Peppercorn Formation forms a transgressive unit, following a mid-Llandoverian orogenic episode. It has a basal conglomerate which grades up through sandstone into a thick sequence of siltstone and mudstone. Macrofossils are common immediately above the conglomerate, but provide little useful stratigraphic information. Limestone lenses in the upper part of the Peppercorn Formation near Cooinbil and Tantangara Reservoir have yielded an abundant late Llandoverian condont fauna. The contact between the Peppercorn Formation and the Cooleman Limestone appears to be gradational on the west side of Cooleman Plain, but in the lower Peppercorn Creek Valley the Peppercorn Formation passes directly up into the Blue Waterhole Formation.

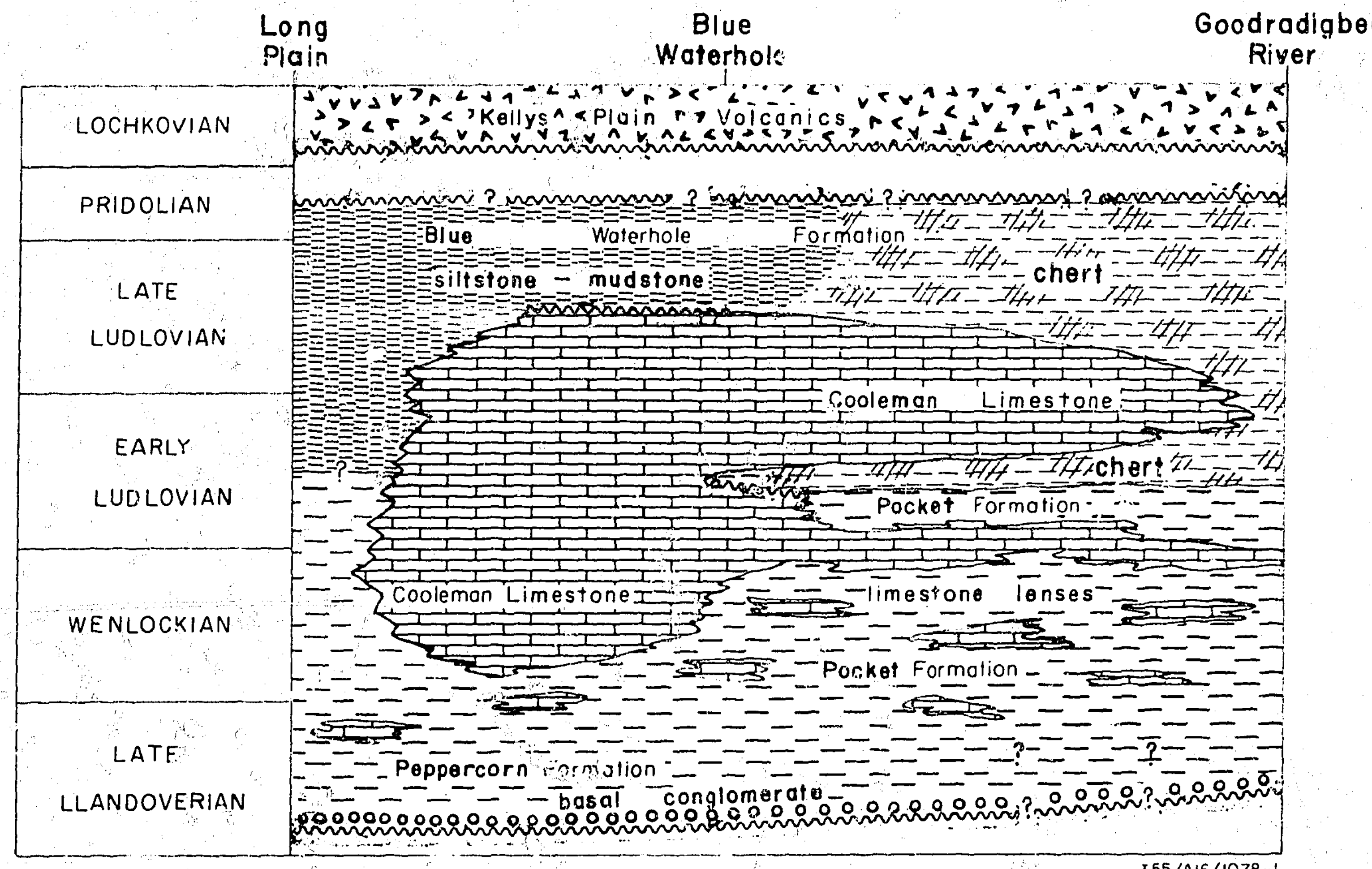

Fig M21 Possible relations between units in the Cooleman Plains Group

The Pocket Formation has yet to be dated accurately, though a broad similarity between the macrofaunas from the Pocket Formation and Cooleman Limestone indicates that the two may be close in age. The base of the Pocket Formation is an unconformity resting on the lower Llandoverian Tantangara Formation; the top of the unit passes conformably into the Blue Waterhole Formation. The siltstone and mudstone that form the bulk of the Pocket Formation are similar lithologically to those in the upper part of the Peppercorn Formation, and the limestone lenses in the Pocket Formation are similar to parts of the Cooleman Limestone.

Fossils, including conodonts, indicate that the Cooleman Limestone ranges from at least late Wenlockian to probably late Ludlovian or Pridolian, though much more work on the microfauna is needed before the limits are properly known as all the faunas so far found are from the upper part of the limestone. The base is conformable on the Peppercorn Formation west of Cooleman Plain, and the top appears to be marked by a disconformity. At several localities, including Cliff Cave (locality B in Fig. M19) and grid reference 508562, the basal micaceous siltstone of the Blue Waterhole Formation appears to have been deposited on an irregular surface of the Cooleman Limestone. At grid reference 530561, on the southern edge of Clarkes Gorge, a karst surface appears to have developed on the Cooleman Limestone before the basal Blue Waterhole Formation was deposited; siliceous siltstone of the Blue Waterhole Formation fills fissures up to 5 m deep and 25 cm wide in the limestone. However, the tongue of Cooleman Limestone east of the Mount Black Fault (formerly the Wilkinson Limestone) is both underlain and overlain conformably by the chert facies of the Blue Waterhole Formation.

The Blue Waterhole Formation has not been directly dated by conodonts. However, the unit both overlies and underlies the Cooleman Limestone east of the Mount Black Fault; overlies limestone dated as Ludlovian to Pridolian near Mount Black mine; and contains slumped blocks of limestone which have yielded a similar conodont fauna along Cave Creek north of Harris Dam (Fig. M19). It rests conformably on the Pocket Formation in the east, and disconformably on the Cooleman Limestone in the west, whereas the tongue of Cooleman Limestone to the east is conformable within the Blue Waterhole Formation. The top of the unit is either faulted or unconformably overlain by younger volcanics. Evidence from the lower Peppercorn Creek area suggests that the chert facies of the Blue Waterhole Formation may be older than the siltstone-mudstone facies.

The Cooleman Limestone and Pocket Formation are considered to be in part lateral equivalents, though the lower part of the Pocket Formation is probably older than the Cooleman Limestone. Evidence for this is that both are overlain by the Blue Waterhole Formation, the Pocket Formation conformably and the Cooleman Limestone disconformably (though probably with no great time interval), and the larger limestone lenses in the Pocket Formation resemble limestone in the Cooleman Limestone.

The Blue Waterhole Formation is in part laterally equivalent to the upper part of the Cooleman Limestone as it both overlies and underlies conformably the limestone tongue east of the Mount Black Fault. However, the siltstone-mudstone facies in the west overlies the Cooleman Limestone disconformably.

The history of the area from the late Llandoverian through to the Pridolian may now be summarised. After the mid-Llandoverian orogenic episode the sea transgressed the area (basal conglomerate of the Peppercorn Formation) and sedimentation rapidly changed to fine clastic and locally carbonate deposition. An increase in carbonate sedimentation in the west led to the deposition of the Cooleman Limestone, perhaps commencing early in the Wenlockian, while farther east and to the north fine clastic sedimentation continued with the formation of sparse limestone lenses which become more numerous upwards. In the early Ludlovian, calcareous muds (later altered to chert) were deposited conformably on the Pocket Formation in the east, while limestone was still accumulating in the west. Soon after, the mud sedimentation in the east was interrupted by the deposition of a limestone tongue extending northeast from the main mass of Cooleman Limestone. Shortly thereafter, carbonate deposition over the whole area ceased, probably in the early Pridolian. After temporary emergence of the limestone in the west, during continuous mud sedimentation in the east, a thick sequence of siltstone and mudstone, the final known marine deposits, covered the area. The age of these youngest sediments is unknown, but cannot be later than Pridolian as the whole sequence was folded during the Bowning orogeny, dated as earliest Devonian in the Yass Basin (Link, 1970).

Tidbinbilla Quartzite

Nomenclature

Noakes (1946) introduced the name Tidbinbilla Quartzite for a sequence of gently dipping quartzite with minor shale on the eastern side of the Cotter valley, around the subsequent site of Bendora Dam. He named the unit after Tidbinbilla Mountain, but designated no type section. He assumed the unit to be of Late Silurian or Devonian age.

Our mapping has shown that the extent of the Tidbinbilla Quartzite is much less than that shown by Noakes (1946) and Best & others (1964): it has a restricted area of outcrop between Bendora Dam and Tidbinbilla Mountain, with small outliers in the upper Cotter valley to the south and on the Two Sticks Road to the north. Previous workers have failed to recognise the presence in the area of gently dipping graptolite-bearing Ordovician rocks, upon which the unit rests with only slight unconformity.

Derivation of name

The unit is named after Tidbinbilla Mountain (grid ref. 693757, BRINDABELLA).

Type section

We have proposed as the type section (Table M10) about 130 m of the Tidbinbilla Quartzite exposed in a southerly draining gully about 300 m west-southwest from the summit of Tidbinbilla Mountain. The section commences at the boundary of the Tidbinbilla Quartzite with the underlying Ordovician Adaminaby beds (at grid ref. 690756): although the contact is not exposed, its position can be estimated to within a metre.

The type section is in rugged country with thick scrub; a more accessible locality to examine the Tidbinbilla Quartzite is at Bendora Dam (grid ref. 658757), where massive quartzite is exposed in the dam abutments, and immediately northwest of the dam, where interbedded quartzite and shale overlying the massive quartzite are exposed in a quarry.

TABLE M10. TYPE SECTION OF THE TIDBINBILLA QUARTZITE

Top of section (summit of Tidbinbilla Mountain)

well-bedded (10-30 cm) quartzite with minor thin siltstone interbeds towards the top	50 m
massive quartzite	40 m
well-bedded (20 cm) quartzite	5 m
quartzite with mudstone clasts	0.5 m
well-bedded quartzite	10 m
interbedded quartzite and shale with several conglomeratic and slumped beds	25 m
very coarse sandstone with scattered pebbles	2 m

Ordovician flysch sediments

Distribution

The Tidbinbilla Quartzite crops out over about 11 km^2 between Tidbinbilla Mountain and the Cotter River, from 2 km south of Bendora Dam to 7.5 km north-northeast of the dam. Its outcrop along the Cotter River is interrupted by the intrusive Cow Flat Porphyry, and by an extrusive dacite which may lie disconformably on the quartzite. We have tentatively included in the unit a small area of flat-lying quartzite on the Two Sticks Road (at grid ref. 685950), which Walpole (1952) also considered to be Tidbinbilla Quartzite. We have also placed in the Tidbinbilla Quartzite a small area of chert conglomerate lying on Ordovician flysch in the upper Cotter valley at grid reference 655552.

Lithology

The Tidbinbilla Quartzite is mostly composed of a well-sorted, medium-grained sublitharenite which has been converted to a quartzite by the overgrowth of quartz onto grains rather than by metamorphic recrystallisation. Coarser-grained sandstone, conglomerate, and shale crop out near the base of the unit, and shale becomes an important constituent near its top. Volcanic rocks are absent.

The base of the Tidbinbilla Quartzite in the type area is formed by a 2-m-thick bed of massive, poorly sorted, very coarse sandstone to fine conglomerate. The rock is formed of rounded to subangular grains of quartz, chert, mudstone, and altered basic volcanic rock fragments, and includes a moderately high clay content. The grainsize averages about 2 mm, but may reach 5 mm; the larger grains are usually better rounded. From a visual estimate, quartz forms about 50%, chert 10%, mudstone 10%, other rock fragments 5%, and clay 25% of the rock. Minor zircon and tourmaline are also present, but feldspar appears to be absent. All the rock fragments can be matched with the local Ordovician rocks. In the upper Cotter valley the base of the Tidbinbilla Quartzite is formed by a conglomerate in which clasts, up to 5 cm, are mostly chert. Farther north, on the Two Sticks Road, a medium-grained quartz sandstone appears to form the base of the unit.

In the type area, 25 m of interbedded conglomerate, quartzite, and shale overlie the basal bed; slumping is evident at some levels. The conglomerate consists of rounded chert and mudstone clasts up to 5 mm in diameter and tabular silty mudstone clasts up to 45 x 10 mm in a virtually clay-free matrix of rounded quartz grains up to 2 mm. The chert (which may contain radiolarians) and mudstone clasts were lithified before they were deposited; but the silty mudstone clasts, which are composed of varying amounts of subangular silt-grade quartz grains in a muddy matrix, appear to have been soft and unlithified when they were deposited, because their edges now partly enclose quartz and chert grains. The quartz grains forming the matrix of the conglomerate are well rounded, many with fairly high sphericity, and most show plane extinction (though some have undulose extinction and some are polycrystalline). Many quartz grains have optically continuous secondary overgrowths of silica in which the outline of the original grain is marked by impurities.

The quartzite in this lower part is typical of that throughout the Tidbinbilla Quartzite; the only variation is in grainsize, which tends to decrease higher in the sequence. The rock consists of well-rounded quartz grains and rock fragments, up to 2 mm in diameter in the lower part but rarely greater than 0.4 mm higher in the unit. Clay material is usually virtually absent, but may constitute up to 15% of the finer-grained quartzite. Rock fragments include chert and mudstone, and may form up to 10% in the coarser rocks, though only 1 or 2% in the fine-grained quartzite. Muscovite, tourmaline, and zircon may also be present.

Shale interbeds are rare and thin through most of the Tidbinbilla Quartzite; they are more common in the lower 25 m, where they may be up to 20 cm thick, and in the upper 50 m where they may be up to 2 m thick.

At least three levels of slumping are evident in the type section: about 5 m, 10 m, and 20 m above the base of the unit. The slumped beds, which are 1 to 3 m thick, are distinct, and can be followed in outcrop on the western side of Tidbinbilla Mountain from the type section almost down to Bendora Dam. They are composed of unorientated tabular masses of mudstone, some of which have been deformed, in a matrix mainly of quartz grains. The mudstone clasts are up to 30 by 10 cm, and the quartz matrix is well sorted, with grains up to 2 mm in diameter and relatively little clay matrix.

Environment of deposition

Sedimentary structures are rare in most of the Tidbinbilla Quartzite. Apart from the slumped beds near the base, they are restricted to rare large-scale cross-bedding in tabular sets up to 1 m thick, and even rarer ripple cross-lamination in 1 to 3 cm sets. All five directional measurements of cross-bedding indicate sediment supply from the west. Sedimentary structures indicative of turbidite deposits, and trace fossils, appear to be lacking. Owing to the dearth of significant sedimentary structures, the depositional environment of the unit is difficult to interpret. The base of the unit - with coarse sandstone, conglomerate, and slumped beds - appears to be the initial part of a transgressive cycle. The water apparently deepened rapidly to below the zone of wave action, since much of the unit has regular parallel bedding from 0.2 to 1 m thick, or is unbedded, and lacks the range of sedimentary structures to be expected in shallow inshore environments. The absence of turbidite deposits, the high degree of sorting, and the roundness of individual grains may indicate that the Tidbinbilla Quartzite was deposited as an offshore shoal in a shelf environment. Channels and discontinuous coarser beds in the uppermost part of the unit, which consists of interbedded shale and quartzite, probably mark a shallowing of the sea.

Thickness

The thickness of the Tidbinbilla Quartzite is estimated to be 300 m.

Relations

The Tidbinbilla Quartzite rests unconformably on the Ordovician Adaminaby beds: on the western side of Tidbinbilla Mountain, both the Adaminaby beds and Tidbinbilla Quartzite have gentle westerly dips with no more than a 10^{o} or 15^{o} difference in dip. The Tidbinbilla Quartzite is thought to be overlain unconformably or possibly disconformably by the Paddys River Volcanics south of Bullock Head Creek.

Age

Strusz (1971) reported the occurrence of a fragmentary graptolite from the Bendora water-main excavation at grid reference 676798; it was provisionally identified as *Monograptus flemingi* or *M. chimaera* var. *salweyi*, indicating an early Ludlovian age. However, more recently, this locality has yielded a specimen of *Climacograptus* sp., possibly *C. caudatus*; therefore, it must be of Ordovician age, and is thought to be part of the Adaminaby beds rather than the Tidbinbilla Quartzite. The specimen identified as *Monograptus* may be a broken part of a *Dicellograptus* sp. No fossiliferous localities are known in the Tidbinbilla Quartzite, and its age must be deduced from regional stratigraphic considerations.

We suggest that the age of the Tidbinbilla Quartzite is late Llandoverian to early Wenlockian, similar to that of the Peppercorn Formation to the west and the State Circle Shale and Black Mountain Sandstone in Canberra to the east. The Peppercorn Formation is a shallow marine transgressive unit, similar to the base of the Tidbinbilla Quartzite, whereas the Black Mountain Sandstone is a proximal turbidite deposit (Crook & others, 1973). We envisage that, after the mid-Llandoverian phase of folding in the

Tantangara area, a shelf was formed on which the Peppercorn Formation and Tidbinbilla Quartzite were deposited, while flysch sediments continued to pour into a trough that persisted farther east towards Canberra. This interpretation is compatible with the Tidbinbilla Quartzite being devoid of volcanic products, which - as discussed later (see under Age, Paddys River Volcanics) - first erupted in the Silurian locally - in the Uriarra area - probably no earlier than the late Wenlockian.

Glen Bower Formation

Nomenclature

Harper (1909) first used the name Glen Bower Series for Silurian sedimentary rocks in the Mount Boambolo area, where Shearsby (1905) had previously mapped Silurian rocks. Best & others (1964) named the sequence the Glen Bower Beds on the Canberra 1:250 000 Sheet. Moignard (1970) more recently mapped the area, and Strusz (1975) has summarised his work.

Moignard (1970) divided the sequence into two units - an upper, the 'Boambolo Formation', and a lower, the 'Glen Bower Formation' - separated by an unconformity. However, recent mapping by students of the Department of Geology, ANU, suggests that the whole sequence mapped by Harper is conformable, and that a separation of the succession into two units is not justified (K.S.W. Campbell, ANU, personal communication 1976).

The detail of our fieldwork on this sequence is insufficient to suggest which of these two hypotheses is correct, but we have followed the later ANU mapping, and consider that the succession is conformable.

Derivation of name

We assume that Harper (1909) derived the name from the now ruined Glen Bower homestead (grid ref. 708224).

Type section

No type section for the Glen Bower Formation has been designated in the literature, so we propose that the section exposed in the Glen Bower

Anticline at grid reference 721210, the earliest recognised locality for the unit, be nominated the type section. Moignard (1970) measured a detailed section in the Glen Bower Anticline, Strusz's (1975) summary of it is reproduced below.

Poorly exposed silty sandstone, and sporadic limestone lenses containing reworked shells and abundant crinoid ossicles; becoming sandier upwards, with cross-bedding developed towards the top	69 m
Massive bioclastic to algal limestone	7.5 m
Calcareous mudstone to fine-grained sandstone with thin silty and sometimes stromatolitic calcarenites	ca 18 m
Stromatolitic limestone with infilled channels	ca 11 m
Coarse-grained quartzose sandstone with prominent cross-ripple bedding and occasional clasts of red-stained limestone	12 m
Very thick-bedded rubbly to nodular silty limestone, of which the top 30 cm is stromatolitic and contains a good silicified shelly fauna	6 m
Calcareous siltstone with abundant Parastriatopora	1 m
Medium-grained argillaceous quartz sandstone with some cross-ripple bedding	13 m+

The base of the section is below water-level, and the top is apparently unconformably overlain by the Laidlaw Volcanics.

Distribution

The Glen Bower Formation crops out over about 15 km^2 in BRINDABELLA and YASS; two-thirds of its outcrop area is in BRINDABELLA. Almost all of this area is on the east bank of the Murrumbidgee River in the basin of Copplestone Creek; there are two small areas west of the river: from the Glen Bower Anticline north to the ruined Glen Bower homestead (grid ref. 708224), and east of Cavan homestead.

Lithology

The Glen Bower Formation consists of a laterally and vertically variable sequence of mainly siltstone and shale, and less common limestone and sandstone. Both the extensive faulting and the lateral variability obstruct the detailed correlation of marker beds.

The lower part of the succession is exposed in Sapling Point Creek (YASS), where dacitic garnet-bearing tuff correlated with the Hawkins Volcanic passes up first into a reworked lithic tuff and then into quartz-rich volcaniclastic sandstone and siltstone. Within this conformable gradational sequence the boundary is placed at the change from reworked lithic tuff to quartz-rich volcaniclastic sandstone, which marks a significant change in the textural maturity in the sediment.

The quartz-rich volcaniclastic sandstone and siltstone comprise mainly poorly to moderately rounded quartz grains in a variable amount of clay matrix; volcanic rock fragments are common, feldspar grains are subordinate, and garnet is a rare accessory. Sorting is poor. The quartzose volcaniclastic sandstone and siltstone, which are about 155 m thick, become more quartz-rich and better sorted upwards before the first calcareous bed; this is a silty calcirudite, 5 m thick, with oncolites, overturned colonies of Heliolites, and stromatoporoids. Higher in the sequence volcaniclastic sediments, becoming increasingly argillaceous upwards, are exposed for over 80 m, followed by a sequence of silty and quartzose sandstone with interbedded limestone for a further 80 m. Lack of exposure terminates the section in Sapling Point Creek.

A succession similar to that in the upper part of the Sapling Point Creek section appears to dominate the remainder of the sequence: dark olive, in places reddish, siltstone and shale, calcareous shale, and thin (<10 m thick) biostromal limestone. Apart from the limestone beds, exposure is poor.

Limestone is common in the upper part of the succession, as in the type section, but terrigenous sediments again predominate near the top. Various types of limestone are present, including rubbly or nodular silty limestone, algal limestone, stromatolitic limestone, and massive bioclastic limestone.

The uppermost part of the sequence, exposed on the western slopes of Mount Boambolo, is a sequence of finely laminated shale, siltstone, calcareous sandstone, and sandy conglomerate; the conglomerate contains clasts of red-stained limestone, presumably derived from lower in the sequence. As mentioned earlier, Moignard (1970) considered that this uppermost part of the sequence, which he named the Boambolo Formation, rests unconformably on the Glen Bower Formation, but more recent work by ANU students indicates that the sequence is conformable. The presence of limestone pebbles presumably derived by subaerial erosion of limestone lower in the formation is not unexpected in what must have been a very shallow-marine environment, where only small changes in sea level would expose rocks to erosion.

Environment of deposition

The Glen Bower Formation is considered to have been deposited mainly in a very shallow-marine environment; evidence for this comes from the limestones, which are commonly algal or stromatoporoidal. Moignard (1970) suggested that the part of the sequence below the frequent limestone interbeds is mainly fluviatile or deltaic, since fossils are rare, and that calcareous interbeds represent rare subtidal marine incursions. Higher in the sequence, normal marine sediments predominate until near the top; Moignard interpreted the return to poorly fossiliferous finely laminated shale and siltstone as a change to an estuarine environment, in which the sandy conglomerates represent beach deposits.

Relations

The Glen Bower Formation rests conformably on the Hawkins Volcanics in Sapling Point Creek, and is overlain apparently unconformably by the Laidlaw Volcanics on Mount Boambolo and near the Glen Bower Anticline.

Thickness

Moignard (1970) suggested that the Glen Bower Formation may be up to 1000 m thick; our own work indicates that this figure is probably substantially correct.

Age

Little work has been done on fossils from the Glen Bower Formation. Shearsby (1905) and Harper (1909) collected faunas which were identified - though not illustrated - by W.S. Dun. Later Hill (1940) listed fossils from the unit in her descriptions of the corals Phaulactis shearsbyi, Entelophyllum latum, and Tryplasma lonsdalei.

Moignard (1970) described more of the fauna, listed in Strusz (1975), and also obtained conodonts from the Glen Bower Anticline locality. The available faunal evidence appears to indicate that the Glen Bower Formation correlates with the Yass Formation - that is, earliest Ludlovian. This is further supported by the similar stratigraphic position of the two units between the Hawkins and Laidlaw Volcanics.

Yass Formation

The Yass Formation has at various times been called the 'Yass Series' (Brown 1941), the Yass Group (Link, 1970), and the Yass Subgroup (Pogson & Baker, 1974). Link divided the unit into two formations, the O'Briens Creek Sandstone and the Cliftonwood Limestone, which he mapped in the Yass area. Pogson & Baker recognised both but neither is evident as far south as BRINDABELLA, which suggests that they may not be laterally continuous. We propose that the Yass Group of Link and the Yass Subgroup of Pogson & Baker be more appropriately called the Yass Formation, which in the Yass area can be divided into two members - the Cliftonwood Limestone Member and O'Briens Creek Sandstone Member.

The Yass Formation crops out over only a narrow south-southeast-trending belt 5 km long by 1 km wide in the northeast corner of BRINDABELLA. Its continuity of outcrop northwards, and its identical stratigraphic position - between the Hawkins and Laidlaw Volcanics, enable it to be correlated with the more extensive development of the formation in YASS. Its outcrop continues into CANBERRA, almost to the ACT border near Hall.

In BRINDABELLA, the Yass Formation is poorly exposed, and consists of cleaved olive-brown siltstone and shale; sandstone, limestone, and fossils are lacking.

The thickness of the Yass Formation in BRINDDBELLA appears to be in the order of 300 to 400 m; lack of outcrop precludes a more accurate estimate. Link & Druce (1972) reported that the thickness varies considerably, but is about 190 m near Yass township.

The age of the Yass Formation is earliest Ludlovian (Link & Druce, 1972).

Micalong Creek beds

Nomenclature

Edgell (1949) gave the name Micalong Creek Limestone to a sequence of steeply dipping Silurian limestone and shale which crops out near the junction of Micalong Creek and the Goodradigbee River south of Wee Jasper. He also correlated an area of limestone farther south near the junction of the Goodradigbee River and Limestone Creek with the Micalong Creek Limestone. Edgell's work has remained unpublished, but Brown (1964) has since published the name Micalong Creek Limestone. Since the unit is composed of both limestone and shale, and since the unit has faulted boundaries with all other units of the area the informal name Micalong Creek beds is preferred.

Derivation of name

The unit is named after Micalong Creek, which flows across the outcrop of the Micalong Creek beds at grid reference 535046 - 9 km south of Wee Jasper.

Reference section

No type section has previously been nominated for the Micalong Creek beds. We have named as a reference section the road section immediately south of Micalong Creek from grid reference 537041 to 535045, where about 100 m of sparsely fossiliferous dark limestone underlies about 50 m of cleaved siltstone and shale; the sequence dips 70° to the east.

Distribution

The Micalong Creek beds crop out in three separate areas in the Goodradigbee River valley as fault slices along the Long Plain Fault. The northernmost area extends as a narrow (0.5 km) strip from 0.5 km south to 4 km north of Micalong Creek; exposure in this zone is poor, except south of Micalong Creek. Another strip of similar width, about 5 km south-southeast of Micalong Creek, exposes limestone for 3 km along the Goodradigbee River around its junction with Limestone Creek. The southernmost outcrop is a small area of limestone 0.2 by 1 km a further 3 km to the south at the junction of Dinnertime Creek and the Goodradigbee River.

Lithology

The Micalong Creek beds in their reference area consist of interbedded limestone, siltstone, and shale; farther south, only limestone is present. The limestone is variable in lithology. In the reference section it ranges from micrite to biomicrite and biosparite and may be completely recrystallised; it is invariably dark grey in hand specimen, and has thin interbeds of greenish shale. Farther south the limestone is completely recrystallised at Limestone Creek, and altered to a marble at Dinnertime Creek.

Siltstone and shale within the Micalong Creek beds are generally light brown, and are always strongly cleaved and weathered.

Age

Edgell (1949) listed an extensive macrofauna from the limestone immediately south of Micalong Creek; Strusz (1975) summarised the main elements of it, and suggested a general correlation with the latest Wenlockian to earliest Ludlovian of the Yass Basin sequence. Conodonts identified by R.S. Nicoll (BMR) suggest a rather younger, mid-Ludlovian age.

Depositional environment

Recrystallisation of the limestone and well-developed cleavage in the shale make a detailed environmental study of the Micalong Creek beds difficult. The presence of a diversified coral, brachiopod, and trilobite fauna in the limestone indicates a shallow-marine depositional environment.

Thickness

About 150 m of shale and limestone are exposed in the reference section, and the maximum thickness of the unit in the northern area of outcrop is probably no more than 200 m. About 150 m of limestone are exposed in the central area, and 50 m in the southern area. These thicknesses are minimum values as all contacts are faulted.

Relations

The Micalong Creek beds are in faulted contact with all other units, so a discussion of their relations is speculative. Their lithology and probable Late Silurian age suggest a correlation with the Blue Waterhole Formation, which crops out more than 20 km to the south. It appears likely that a marine connection along the present day Goodradigbee valley existed between the Yass and Cooleman areas during at least part of the Late Silurian. This strait would have been bordered to the west by land formed by the Goobarrangandra Volcanics and to the east by the subaerial volcanics of the Uriarra area. The Micalong Creek beds may in part be a time equivalent of the Goobarragandra Volcanics in which siltstone and shale are interbedded with dacitic volcanic rocks in the lower part of the Dinnertime Creek valley (grid ref. 567927); in this area, the fault separating the Micalong Creek beds from the Goobarragandra Volcanics is not considered to be the main Long Plain Fault, but a minor splinter fault.

SILURO-DEVONIAN VOLCANIC UNITS

Extensive felsic volcanism characterised the middle to Late Silurian in TANTANGARA and BRINDABELLA. Six volcanic units have been recognised. The most extensive is the Goobarragandra Volcanics, a thick sequence of subaerial ignimbrites occupying much of the area west of the Long Plain Fault. Farther east, volcanism commenced with the Paddys River Volcanics, soon followed by the Hawkins and Walker Volcanics of similar composition. A break in volcanic activity, during which the Yass Formation accumulated, was followed by the eruption of the Laidlaw and Uriarra Volcanics; these two units carry different phenocryst minerals from those of the earlier volcanics.

In the Early Devonian felsic volcanism recurred in the central and western parts of the Sheet areas; two types have been recognized. The earlier Kellys Plain Volcanics contain similar minerals to the Goobarragandra, Paddys River, and Walker Volcanics. But the minerals in the slightly younger Mountain Creek Volcanics and the related Rolling Grounds Latite are distinct from those in any of the other Siluro-Devonian felsic volcanics.

Goobarragandra Volcanics

Nomenclature

Joplin & others (1953) reported that the Fiery Range consists mainly of intrusive late Middle Devonian quartz-feldspar porphyry. They named this porphyry the Fiery Range Porphyry in TANTANGARA, and the Wyora Porphyry in BRINDABELLA. These two intrusives were supposedly separated in the south of BRINDABELLA by a belt of Ordovician sediments. Our mapping has shown that no such belt exists and that the two porphyries should be regarded as one unit.

Adamson (1960) renamed the porphyries of the area the Goobarrangandra Porphyry, which he mapped as underlying the Upper Silurian Yarrangobilly Limestone. He considered the porphyries to be volcanic because they contain interbedded altered andesite south of Clifford Creek (Batlow SMA 1-Mile Series Sheet, grid ref. 28801983).

Best & others (1964) used the name Peppercorn Beds for a sequence of shale, sandstone, tuffaceous sandstone, and conglomerate near Peppercorn Hill (grid ref. 458627), and also applied this name to the volcanic rocks of the Fiery Range. Strusz (1971) presumed that the Wyora Porphyry to the north was the final stage of intrusion of the Burrinjuck Granite.

In TUMUT - in the Goobarragandra district 21 km southeast of Tumut - Ashley, Chenhall, Cremer, & Irving (1971) described a sequence of low-grade metamorphosed porphyritic rhyodacite and dacite, mafic volcanics, and minor sedimentary rocks to which they gave the name Goobarragandra Beds. These are continuous with the quartz-feldspar porphyries of the Fiery Range west of the

Long Plain Fault. However, a reappraisal of the geology of the Goobarragandra district by P.M. Ashley (personal communication 1976) indicates that the mafic metavolcanics and metasediments are separate from (probably faulted against) the felsic metavolcanics, and are better equated with the Honeysuckle Beds (Ashley & others, 1971). This interpretation is consistent with the scarcity of sediments and absence of mafic volcanics in the area of felsic volcanics that we have mapped. We therefore propose to rename these felsic rocks the Goobarragandra Volcanics.

Type locality

The type locality is here defined as the hillside at grid reference 395588, alongside the Yarrangobilly River 400 m southwest of Bucket Flat. This is the best exposure of the unit and consists about 2000 m^2 of 60-70% outcrop of a massive strongly porphyritic dacite with phenocrysts of plagioclase up to 20 mm and quartz up to 10 mm in a dark blue groundmass. More accessible reference sections are present along the Snowy Mountains Highway between grid references 377466 and 363473, and on the Nottingham Road between 530036 and 528032.

Distribution

The Goobarragandra Volcanics crop out over large parts of BRINDABELLA, TANTANGARA, TUMUT, and YARRANGOBILLY, including over 480 km^2 of BRINDABELLA and almost 100 km^2 of TANTANGARA. The eastern limit of the volcanics is the Long Plain Fault; to the west the unit is intruded by the Young Batholith and Bogong Granite, or overlain by purple and green shale underlying the Yarrangobilly Limestone, and the Ravine beds. In YARRANGOBILLY, regional reconnaissance mapping to the west of the Ravine beds syncline has shown another belt of felsic volcanics continuous with the Blowering beds to the north, apparently beneath the Ravine beds, and so at a similar stratigraphic position to the Goobarragandra Volcanics; therefore the Blowering beds and Goobarragandra Volcanics, which are chemically similar (Ashley & others, 1971) are probably continuous beneath the Ravine beds syncline. In YASS, to the north, Pogson & Baker (1974) have mapped, as part of the Douro Group, volcanics which are continuous with the Goobarragandra Volcanics near Burrinjuck Dam and Old Jeremiah Creek. The age of these Douro Group volcanics is still uncertain, so we have refrained from including the Goobarragandra Volcanics in the Douro Group; we suspect that they are equivalent to the Hawkins Volcanics of Pogson & Baker (1974).

Large areas of good exposure are rare in the volcanics; the type locality is the best example. More commonly, exposures consist of rounded boulders and tors up to several metres in diameter. This style of outcrop is predominant for the more massive rock types with abundant phenocrysts. Less porphyritic examples crop out as smaller, more angular boulders and fractured rock bars. Semicontinuous exposure is common along major streams with steep gradients, and good exposures also occur in the gorge of the Goodradigbee River above its junction with Flea Creek (grid ref. 593881); here the river has followed east-northeast-trending joint planes in the volcanics, rather than the Long Plain Fault as elsewhere.

The Goobarragandra Volcanics are uniform over large areas, suggesting that most of the outcrops are thick welded zones of ignimbrite. According to Ross & Smith (1961) the uniformity of such ignimbrite sheets over large areas and distances is an important criterion for their recognition, since it is not found in either ash-fall tuffs (bedded tuffs) or flow rocks of silicic composition, and is rarely found in flow rocks of intermediate composition. These authors, who have examined ignimbrites at many localities, have found that single units are often 100 m thick, and believe that units up to 300 m thick are not unlikely. Although we have not been able to identify individual flow units in the Goobarragandra Volcanics (because of poor exposure), we suspect that in many places - such as the type locality and Goodradigbee gorge - single units are at least 100 m thick.

Lithology

By far the most abundant rock type is a strongly porphyritic dacite, commonly with phenocrysts (up to 40%) less than 10 mm of rounded clear quartz and subhedral yellowish white feldspar in roughly equal proportions in a dark blue-grey fine-grained groundmass. At many localities near later intrusions, the groundmass is medium-grained and pale grey. In most samples a few soft chloritic patches, rarely exceeding 3 mm and commonly bounded by crystal outlines, are evident, indicating pseudomorphism after primary mafic phenocrysts. A less common rock type is similar to the strongly porphyritic dacite except that it contains fewer phenocrysts (15% or less); in this type, feldspar phenocrysts are much more common than quartz, and phenocrysts are less than 5 mm.

Voclanic breccia is present at a number of localities (e.g., grid ref. 371463), and consists of very angular dark green fragments - poor in phenocrysts and up to 100 mm - in a paler more siliceous matrix. Only on lightly weathered surfaces are the fragments visible, so volcanic breccias may be much more common than our field mapping indicates.

Banding in the volcanic rocks appears to be rare. At grid reference 468638 a few parallel pale bands 20-50 mm thick in darker material may represent airfall tuff bands; definite flow banding is not evident.

Interbedded sediment is evident at only a few places. At grid reference 350499 (YARRANGOBILLY) a chert bed about 0.25 m thick lies within porphyritic volcanics; it dips south at 30°. At grid reference 588867 a weakly porphyritic dacite grades up into a pale grey shale about 0.4 m thick which dips east-southeast at 48°; the shale has been baked by an overlying ignimbrite. Volcaniclastics crop out at a few localities, notably on the Nottingham Road (at grid ref. 528035) and on the northern slopes of Sulky Alex Hill (grid ref. 572917), where a quarry has exposed dark grey mudstone with interbedded volcanogenic sandstone. These sediments have a limited extent and probably represent small fluviatile and lacustrine deposits within the volcanic pile.

At grid reference 406237 a pod of limestone, 150 m wide, completely surrounded by later intrusives - but presumably part of the Goobarragandra Volcanic sequence - has been metamorphosed to a coarse-grained (20 mm) pure white marble. Veins and patches of calc-silicates in the marble contain garnet, diopside, tremolite, epidote, and quartz. Other limestone lenses crop out about 14 km farther north, near Talmo (YASS).

Petrography

The phenocryst content of over 100 thin sections of the Goobarragandra Volcanics enabled the unit to be divided into two main groups: those containing 15 to 40% phenocrysts, of which plagioclase is usually slightly more abundant than quartz, and mafics are up to 10%; and those containing 0-15% phenocrysts, of which plagioclase is much more abundant than quartz, and mafics are virtually absent.

Differences in the groundmass enable the rocks to be further subdivided:

(i) incipiently welded ignimbrites still with evidence of original ignimbritic structures such as glass shards, perlitic cracking, and eutaxitic layering

(ii) strongly welded ignimbrites, and/or lavas in which the original texture has been obliterated by welding and devitrification of a glassy groundmass

(iii) lavas in which flow alignment of microlites is preserved

(iv) rocks with a coarse-grained (greater than 0.2 mm) groundmass of graphic, granitic, granoblastic, or spherulitic texture in small porphyry intrusives or hornfelsed zones around later intrusions.

The group (iii) groundmass type is restricted to the rocks containing 0-15% phenocrysts, but all other groundmass types have examples from both phenocryst groups.

<u>Phenocrysts</u>. Plagioclase, the most abundant phenocryst (up to 30%) in the Goobarragandra Volcanics, is usually albitised or saussuritised. Albitised phenocrysts have RI less than quartz and uniform extinction, but commonly contain concentric bands of sericite inclusions where the phenocrysts were once oscillatorily zoned. Fresh plagioclase phenocrysts are evident in a number of samples from several different areas, notably on Feints Range north of Peppercorn Trail, along the Nottingham Road north of Limestone Creek, near Webbs Hut (grid ref. 377895), and near Millers and Log Bridge Creeks. These fresh phenocrysts are commonly euhedral and average 1 to 3 mm; they have broad oscillatorily zoned cores generally around An_{40-45} - less commonly up to An_{50} (e.g., at grid ref. 450126) - and commonly narrow rims of An_{10-20}. The state of the plagioclase might be an indication of domains - perhaps burial metamorphic zones - in which plagioclase is fresh on the one hand and albitised on the other.

Quartz forms large, rounded, embayed, and commonly composite grains around 3-4 mm, and smaller (1-2 mm) euhedral grains with bipyramidal beta-quartz habit. All quartz grains are unaltered and free of inclusions and vacuoles.

Potash feldspar has not been observed as a phenocryst phase in the Goobarragandra Volcanics. It may not nucleate until late in the crystallisation sequence of magmas of such composition.

Biotite is the most common mafic phenocryst. It ranges from 0 to 10% of the rock, and forms subhedral flakes 0.5 to 1 mm completely altered to chlorite; sphene, epidote, quartz, and opaques are other less common alteration products. Heat and water trapped in the ignimbrite sheet when it was deposited probably altered the biotite. The original biotite is fresh at only a few localities (e.g., grid refs. 517966 and 410654); elsewhere fresh biotite is due to later contact metamorphism, where ?altered phenocrysts have recrystallised to a mosaic or smaller biotite flakes. Pleochroism of original biotite is from X = very pale yellow-brown to Y = Z = bright red-brown. Biotite is rare (1% or less) where quartz is rare.

Up to 3% hornblende, and chlorite pseudomorphing hornblende, is present in a few places (e.g., grid ref. 395208) and in the belt of volcanics east of Black Andrew Mountain, (grid ref. 441231). It forms subhedral prisms up to 0.5 x 1 mm and has X = pale yellow, Y = green, Z = blue-green.

Pseudomorphs after cordierite are relatively common in samples with abundant phenocrysts. They form rather rounded irregular patches up to 5 mm of ?talc and pale chlorite, commonly also with biotite and opaques. In one sample (from grid ref. 517966) the pseudomorphs are prismatic crystals (1 mm) of ?talc and chlorite. These cordierite crystals must have been in equilibrium with the magma at some stage, as they have sharp edges with virtually no evidence of resorption. Only one sample (from grid ref. 409655) contains fresh corderite - a single grain, about 3 mm, which is untwinned, has $2V_x = 70^o$, contains biotite and opaque inclusions, and is cut by a network of ?talc veins.

Hypersthene also occurs in the cordierite-bearing sample from grid reference 409655. It is pleochroic from pale pink to colourless, and partly altered, with rims of green biotite, chlorite, and quartz. A sample from grid reference 512994 contains about 5% actinolite prisms; these may be altered hypersthene crystals as they have pyroxene cleavage and some contain cores of chlorite. A sample from grid reference 524087 also contains a few actinolite phenocrysts.

In almost all samples, euhedral apatite and zircon and irregular grains of opaques form minor accessories.

Groundmass. As mentioned above there are four types of groundmass texture in the Goobarragandra Volcanics.

(i) Incipiently welded. The groundmass is fragmental, and consists of elongate and sickle-shaped devitrified shards and ash separated by chlorite and minor granular opaques. The shards average 0.5 mm but may be up to 1 mm long, and are virtually undeformed by welding. The coarser shards have devitrified into a granophyric and axiolitic intergrowth of quartz and feldspar, whereas the finer shards and ash have devitrified into microcrystalline material. Perlitic structures replaced by quartz and chlorite are common; the chlorite fills voids produced during the devitrification process. Where there has been stronger welding, eutaxitic layering has developed and bends around phenocrysts. Small elongate phenocrysts such as biotite flakes and plagioclase prisms are elongated parallel to the eutaxitic layering.

The presence of undeformed shards in this group of rocks indicates that welding was only of minor importance and that the rocks come from either the top or bottom of ignimbrite cooling units (Smith, 1960).

(ii) Strongly welded. Most thin sections belong to this group. The groundmass has no evidence of original shards, and rarely is eutaxitic layering preserved; thus the rocks are either densely welded ignimbrites from the centre of cooling units, or devitrified glassy lava flows. The groundmass exhibits different degrees of devitrification, as observed experimentally by Schloemer (1964) and Lofgren (1971).

The first product of devitrification is a microcrystalline mosaic of quartz, feldspar, microspherulites, chlorite, and opaques. Staining with sodium cobaltinitrite revealed that potash feldspar is the dominant feldspar, but plagioclase microlites 0.05 mm long are also present. Under plane-polarised light the devitrified groundmass is colourless to pale brown. The spherulites are of two types - radiating needles, and rounded growths with uniform extinction throughout (patch spherulites). The two types do not occur together.

As devitrification continues the microspherulites in the groundmass became larger and more abundant. In samples from grid references 377519 and 409660 the groundmass consists entirely of potash feldspar-rich spherulites up to 0.7 mm with interstitial granules and flakes of opaques and chlorite, giving a pale grey-brown colour under plane-polarised light.

The end product of devitrification is the granophyric or granitic stage (Lofgren, 1971, p. 122), where all traces of spherulitic fibres have been erased. This stage is evident in many samples where the groundmass consists of allotriomorphic equigranular quartz, albite, and orthoclase (0.1 mm) with interstitial chlorite. Low-grade burial metamorphism and/or slight heating of the whole of the volcanic pile from later intrusions probably aided devitrification.

(iii) Flow alignment of microlites. This texture is present only in rocks with few or no quartz phenocrysts - that is, rocks that could be classed as andesites. However, interstitial to the microlites are abundant quartz and orthoclase (confirmed by staining), as well as chlorite and opaques; so these 'andesites' are probably chemically similar to all the other rock types, except that they cooled from a higher-temperature magma from which the late-stage quartz phenocrysts did not have time to crystallise. The microlites are up to 0.2 mm and give the groundmass a pilotaxitic structure. The higher temperature of the magma reduced its viscosity, presumably enabling it to produce lava flows rather than ignimbrites.

(iv) Coarse-grained groundmass. Many samples of the Goobarragandra Volcanics, especially from BRINDABELLA, have a relatively coarse-grained groundmass (greater than 0.2 mm), and are either contact-metamorphosed volcanics or intrusive rocks (porphyry dyke, sill or feeder pipe) comagmatic with the volcanics. The intrusive rocks, which are rare, have allotriomorphic equigranular groundmasses of quartz, perthitic orthoclase, and albite, approximating a minimum melt composition; plagioclase and biotite phenocrysts are mostly unaltered.

Samples of contact-metamorphosed rocks display a great range of groundmass textures. In only slightly metamorphosed rocks granitic textures prevail, though some samples show radia, spherulites up to 1.2 mm. Several of the samples with spherulitic textures (e.g., from grid refs. 451719 and 378958) contain blue-green actinolite needles which cut through the spherulites in random directions; these samples are 'andesites' without quartz phenocrysts. Granophyric growths up to 1 mm are also common, and in some samples the texture has developed by overgrowth on quartz phenocrysts. Two samples (from grid refs. 410654 and 392933) with a groundmass grainsize of 1 mm have granitic textures with abundant graphic intergrowths of quartz and orthoclase perthite.

The groundmass of more highly metamorphosed volcanics has recrystallised to a granoblastic aggregate of quartz, orthoclase, andesine, and biotite with grainsize about 0.3 mm. One sample (from grid ref. 517069) has poikiloblastic perthitic orthoclase up to 1.5 mm enclosing polygonal quartz grains, and another (from grid ref. 450126) contains 1-mm rosettes of actinolite needles.

The most recrystallised samples of Goobarragandra Volcanics come from the contact aureole on the western side of the Burrinjuck Adamellite. Samples from within a few tens of metres of the contact consist of the assemblage: quartz-andesine-orthoclase-biotite-hornblende-sphene, with minor epidote, opaques, apatite, and zircon. The hornblende has X = pale yellow-green, Y = green with a yellowish tinge, Z = green. Phenocrysts of quartz have completely recrystallised, but plagioclase phenocrysts (oscillatorily zoned cores around An_{35}, and An_{25} margins) are still present. One sample (from grid ref. 416265, YASS has metamorphic plagioclase of An_{40} composition, and poikiloblastic grains of diopside (0.5 mm), in addition to the above assemblage.

Alteration products. The usual alteration products are chlorite, epidote, calcite, and prehnite, and rare actinolite and possible talc. Of these, chlorite and epidote are the most common, composing up to 3% of some rocks. Chlorite occurs in irregular patches up to 1 mm, possibly filling cavities which may have been produced by a volume decrease upon devitrification. It is also associated with glomeroporphyritic groups of plagioclase (An_{20-30}) and quartz up to 10 mm across, some of which are obviously cognate xenolithic volcanic rock fragments. Chlorite also pseudomorphs biotite, cordierite, and possibly hornblende crystals up to 1 mm.

Epidote also forms patches up to 1 mm, commonly as radiating euhedral crystals probably filling cavities. It is also a common groundmass constituent, but is not necessarily more abundant where plagioclase phenocrysts have been albitised.

Calcite also forms irregular patches up to 1 mm, in amounts ranging up to 3%. It is an alteration product of both plagioclase phenocrysts and groundmass material.

Prehnite is rarer than the previous products, and has been identified only in samples from the Kennedy Ridge and Bucket Flat areas south of Peppercorn Trail. It occurs as fracture and cavity fillings, and veins up to 2 mm. In the cavities the prehnite occurs as anhedral grains up to 0.3 mm with a few euhedral epidote crystals up to 0.2 mm; euhedral quartz crystals up to 0.1 mm long penetrate the cavities from the cavity wall.

?Talc and actinolite replace cordierite and hypersthene phenocrysts.

Age

The Goobarragandra Volcanics have yielded no fossils, and their age is uncertain. They are intruded by the Micalong Swamp Basic Igneous Complex, dated as 430 ± 9 m.y. by the K/Ar method on hornblende (see GEOCHRONOLOGY). They are also intruded by the comagmatic Young Batholith, thought to be of latest Silurian age. Ashley & others (1971) have equated the Goobarragandra Volcanics with the Blowering beds (in YARRANGOBILLY), from which they have reported the middle to late Silurian conodonts *Triconodella inconstans* and *Ozarkodina* cf. *jaegeri*.

The Australian Mineral Development Laboratories (AMDEL) has isotopically dated samples of the Goobarragandra Volcanics that we collected (see GEOCHRONOLOGY): they determined a whole-rock Rb/Sr isochron age of 429 ± 16 m.y., a biotite/whole-rock Rb/Sr age of 417 ± 8 m.y., and a K/Ar age of 429 ± 9 m.y. for the same biotite.

At grid reference 336518 (YARRANGOBILLY), in a road-cut on the northeastern side of the Snowy Mountains Highway, weathered subaqueous tuffs of the Goobarragandra Volcanics are interbedded with volcaniclastic siltstone and green mudstone over a thickness of about 10 m. These pass conformably up into purple and green mudstones equatable with the Kings Cross shales (Moye & others, 1963), and about 70 m west of the road-cut (at grid ref. 336518) the shale almost certainly passes conformably up into the Yarrangobilly Limestone, of Ludlovian age (Talent, Berry, & Boucot, 1975; Vandyke & Byrnes, 1976).

These data suggest that the Goobarragandra Volcanics are of Wenlockian age, at least in the area east of Yarrangobilly. Farther north they form such a thick volcanic pile that they may range up into the Ludlovian.

Environment of deposition

The Goobarragandra Volcanics consist of an unknown thickness of felsic ignimbrites and lavas with minor airfall tuffs and widely scattered volcanogenic sediments and mudstones. The presence of welded glass shards is generally considered to indicate a subaerial environment (Ross & Smith, 1961; Rast, 1962), but their presence in tuffs interbedded with marine sediments in other volcanic formations (Mutti, 1965; Howells, Leveridge, & Evans, 1973) indicates that they can also develop in a submarine environment.

The Goobarragandra Volcanics, in which marine sediments are rare, were almost entirely produced by subaerial ignimbritic eruptions, but also commonly as fissure eruptions of lava. Basal and near-source accumulations commonly contain angular breccia fragments. The apparent scarcity of airfall (banded) tuffs may be due to poor exposure. Towards the west (e.g., at Yarrangobilly) a marine environment prevailed, at least late in the volcanic episode; this is consistent with the Goobarragandra Volcanics passing laterally westward into the mainly submarine Blowering beds in the Tumut Trough. To the east of the Goobarragandra Volcanics belt, near Cooleman Plain, a shallow-marine environment prevailed (Cooleman Plains Group), and only minor tuff beds are present - in the Pocket Formation. Farther north near Canberra, shallow-marine felsic volcanism (Paddys River Volcanics, Walker Volcanics and, in CANBERRA, Mount Painter Volcanics) predominated in the Wenlockian. The main belt of Goobarragandra Volcanics was thus deposited on a structural high bounded to the west by the Tumut Trough and to the east by the Canberra-Yass Shelf

Paddys River Volcanics

Nomenclature

Malcolm (1954) introduced the name Paddys River Volcanics for a volcanic sequence (with minor interbedded sediment) exposed in two separate areas: in the Paddys River valley and west of Uriarra homestead. Best & others (1964) first published the name, and Struss (1975) has briefly described the unit.

Derivation of name

The unit is named after Paddys River, a tributary of the Cotter River entering below Cotter Dam.

Type section

Malcolm (1954) designated the lower reaches of Paddys River as the type locality. We here describe a type section around Paddys River caves (grid ref. 763882). It starts due west of the caves at the contact with the Shannons Flat Adamellite, and extends east, through the limestone lens containing the caves, to the western slopes of the Bullen Range. The sequence is summarised as:

Adaminaby beds

__________ Bullen Range Fault __________

Dacite - grey-green, coarse; contains xenoliths and includes ignimbrite and airfall tuff; well exposed in Paddys River

Tuff - 50 m; fine to medium; water-laid

Limestone - 60 m; sharp contact with overlying tuff

Poorly exposed fine-grained sediments

Hedenbergite - thin; almost pure; probably formed by metasomatic alteration of a thin limestone bed

Dacite - green, coarse

Shannons Flat Adamellite

Dips in the type section are steep towards the east, and the exposed thickness is about 300 m, of which slightly less than half is sedimentary rock. Elsewhere sedimentary rocks are less common.

Distribution

The Paddys River Volcanics crop out in five widely separated areas. Two of these are in the Paddys River valley : one in the lower reaches near the

Cotter River, and the other farther upstream around Riverlea. Both areas, which total about 4 km^2, lie between the Bullen Range Fault and the Shannons Flat Adamellite; in the southern area, the volcanics rest unconformably on Ordovician sediments present as a sedimentary screen within the adamellite. Another small area of the volcanics, about 2 km^2, crops out in the Cotter valley, between a point 1.5 km north of Bendora Dam and Bullock Head Creek, where they form a narrow belt about 5 km long between the Cotter Fault to the west and a splinter fault to the east; they rest with an uncertain relation on the Tidbinbilla Quartzite. The largest area of exposure, 29 km^2, extends for a distance of 14 km in a meridional belt up to 3 km wide between the Pig Hill Fault and Two Sticks Fault; in the north of the belt the volcanics rest unconformably on Ordovician sediments, but all other contacts are faulted. The northernmost area covers 16 km^2, and is centred on The Mullion, again in a meridional fault-bounded belt between the Pig Hill and Dingo Dell Faults; the unit rests unconformably on Ordovician sediments in the south and is overlain unconformably by the Lower Devonian Mountain Creek Volcanics in the north.

In all five areas the igneous component of the Paddys River Volcanics crops out as low rounded boulders rarely more than a metre high, and is usually deeply weathered. With the exception of the Paddys River limestones, the sedimentary rocks in the unit are rarely exposed; most of the information about them has come from road-cuts.

Petrography

The typical rock type in the Paddys River Volcanics is quartz-albite-biotite ± cordierite ± garnet dacite that may have originated as ignimbrite. In hand specimen the rock is medium to dark grey, rarely light grey, and commonly has a distinct secondary foliation. It contains quartz and plagioclase phenocrysts up to 10 mm in diameter and smaller ferromagnesian phenocrysts. Flow banding is very rare.

Phenocrysts in the quartz-albite-biotite ± cordierite ± garnet dacite. Thin sections show that the phenocrysts of quartz, albitised plagioclase, and altered ferromagnesian minerals are set in a fine-grained groundmass. The phenocrysts commonly form 25 to 40% of the rock. Quartz forms commonly embayed euhedral to anhedral crystals or splintered angular fragments ranging from 0.5

to 10 mm, but rarely greater than 6 mm; many grains, particularly in the more strongly foliated rocks, show undulose extinction. Plagioclase forms subhedral to euhedral phenocrysts up to 8 mm, though usually less than 4 mm, and is invariably smaller and less common than quartz in the same rock. Albitisation is ubiquitous, and many plagioclase grains are untwinned. Narrow concentric bands of sericite in some crystals provide evidence that the plagioclase was often oscillatorily zoned before albitisation. In the rare samples containing unaltered plagioclase the composition is oligoclase-andesine, with zoning from An_{45} cores to An_{30} (or less) rims; oscillatory zoning is common. Potash feldspar phenocrysts are unknown in any of the Paddys River Volcanics.

All the ferromagnesian minerals except garnet have been partly or completely altered, generally to chloritic minerals. However, the types of alteration of little-altered ferromagnesian minerals in samples of the Kellys Plain Volcanics (from grid ref. 499430) can be confidently assigned to particular original minerals. From our observations of similar types of alteration - though to higher degrees - in other samples, we have extrapolated from the Kellys Plain Volcanics samples the identity of the ferromagnesian minerals in other Silurian acid volcanics, including the Paddys River Volcanics.

Biotite occurs as anhedral to euhedral flakes usually between 1 mm and 2 mm long, but rarely up to 4 mm, and is almost always completely altered to chlorite and opaques. Many grains have kinked cleavage traces. Biotite is much less common than quartz or albite, and rarely forms more than 15% of the phenocrysts.

Cordierite, the next most common mafic phenocryst phase, rarely forms more than 5%. It is present in only about two-thirds of the sampled volcanic rocks of the Paddys River Volcanics, in contrast to biotite which occurs in almost all. The cordierite is always completely altered to a pale green to almost colourless chlorite, commonly showing anomalous 'Berlin blue' interference colours and lacking any inclusions of opaque minerals. The crystals are euhedral to subhedral, and up to 5 mm long but commonly less than 3 mm. We consider that most of the euhedral cordierite grains grew in equilibrium with a melt, but that rare anhedral grains containing rounded biotite inclusions up to 0.3 mm in diameter are xenocryst cordierite of metamorphic origin. These xenocrysts are commonly surrounded by clear rims of cordierite that may have crystallised from the melt. Although all the cordierite is now completely altered to chlorite, small differences in the chlorite formed from each of the two phases of cordierite reflect their contrasting original compositions.

Apatite and zircon are common accessory minerals. Apatite forms subhedral to euhedral crystals up to 0.8 mm, whereas zircon is much smaller, less than 0.05 mm, and ranges from anhedral to euhedral in outline. Garnet is an occasional accessory occurring as large phenocrysts up to 6 mm, apparently of xenocrystic origin; it is commonly surrounded by a reaction rim of plagioclase, biotite, and chlorite. Epidote is a common alteration product in the Paddys River Volcanics; it may occur as veins or randomly distributed through the rock, but often is preferentially developed in biotites.

Groundmass in the quartz-albite-biotite ± cordierite ± garnet dacite. The groundmass is commonly microcrystalline, but may be cryptocrystalline, and often shows evidence of the secondary foliation common to much of the Paddys River Volcanics. This foliation has destroyed virtually all evidence of eutaxitic layering, but dacite from the bed of Paddys River in the type section still contains traces of it. Staining has shown that the groundmass is composed mainly of quartz and potash feldspar, and only minor plagioclase.

Other volcanic rocks. Volcanic rocks containing a different suite of minerals from that described above are of minor importance in the Paddys River Volcanics. Tuffs in the western outcrop area (at grid refs. 717925 and 692874) contain phenocrysts of only quartz and albite to 3 mm diameter, and ignimbrite rock fragments to 6 mm diameter, and may represent material slightly reworked by water. In the Paddys River area, a pale cream banded sodic rhyolite at grid reference 778859 is composed of quartz and albite (demonstrated by staining), lacks phenocrysts, and shows extensive development of spherulites. Close by, at grid reference 778858, a breccia is formed of dacite fragments up to 20 mm in a matrix of identical composition but finer grainsize. The dacite fragments have phenocrysts of quartz and albite in a groundmass containing flow-aligned microlites and plagioclase laths; the matrix to the fragments also has flow-aligned laths and microlites. The rock is apparently an autobrecciated lava. It appears to be related to the nearby sodic rhyolite, since both lack potash feldspar - an unusual feature in the Paddys River Volcanics.

A dacite at grid reference 688871 contains phenocrysts of quartz, labradorite (zoned An_{55-45}), and altered biotite, pyroxene, and cordierite in a microcrystalline groundmass of quartz and potash feldspar. It is the only rock in the Paddys River Volcanics known to contain altered pyroxene phenocrysts, and shows some similarities with part of the Walker Volcanics.

Sedimentary rocks. Lenses of sedimentary rock are fairly common in the Paddys River Volcanics; in the west they are small and comprise only strongly cleaved mudstone, but in the Paddys River area they are larger, more common, and include several lenses of limestone. The mudstone lenses are thin and of limited lateral extent; the one at The Mullion (grid ref. 705109), the largest, is about 20 m thick with a strike length of over 200 m. The mudstone is grey, weathering olive-brown, and all traces of its bedding have been destroyed by cleavage. A lens on the Brindabella Road at grid reference 709903 has yielded unidentifiable trilobite remains.

In the Paddys River area the two southernmost limestone lenses (at grid refs. 773863 and 777851) have been altered to marble and skarn deposits against the Shannons Flat Adamellite, but the northern lens (in the type section) is a large mass of recrystallised sparite which is only partly altered to skarn and contains crinoid ossicles. Discontinuous outcrop of black shale and mudstone between the three limestone lenses suggests that they may be at the same stratigraphic level.

Environment of deposition

Much of the Paddys River Volcanics appears to have formed as ignimbrite flows in a terrestrial environment invaded from time to time by the sea. The marine influence was greater in the east, where limestone was deposited, indicating that the Paddys River Volcanics probably accumulated on the eastern edge of a land area with the open sea farther east; thus the unit may be correlated with the upper part of the mainly shallow-marine Canberra Group in the Canberra area (see Age).

Relations

The Paddys River Volcanics rest unconformably on Ordovician flysch sediments in the Paddys River, Swamp Creek, and Tinkers Creek areas, and with an uncertain relation on the Tidbinbilla Quartzite. The volcanics may be interbedded with the upper part of the Tidbinbilla Quartzite in the Cotter valley, but the area is one of poor, deeply weathered exposures, and alternative interpretations are that the Paddys River Volcanics there are either high-level intrusives or rest on an irregular surface on the Tidbinbilla Quartzite. We prefer the latter interpretation for two reasons: the texture of the rock is that of an extrusive, and regional considerations suggest that the Tidbinbilla Quartzite antedates and the Paddys River Volcanics postdate early Wenlockian folding in the Canberra region.

The Paddys River Volcanics are overlain unconformably by the Lower Devonian Mountain Creek Volcanics at the northern limit of their outcrop, near Bonnieville homestead, and are intruded by the Upper Silurian Shannons Flat Adamellite in the Paddys River area.

Thickness

The Paddys River Volcanics are about 300 m thick in the type section, between an intrusive contact and a fault. Their greatest thickness is in the western area, particularly west of Uriarra homestead, where they crop out for 3 km across strike. As so little bedding is exposed in this section, which again is fault-bounded, the structure cannot be defined, but the few measured dips are all steep; allowing for some folding, we estimate that the thickness is at least 1000 m.

Age

Internal evidence for the age of the Paddys River Volcanics is lacking; the Paddys River limestones have so far proved unfossiliferous apart from crinoid ossicles, and the few marine fossils in the shale lenses are unidentifiable. All that can be said is that they are the oldest acid volcanics in the two Sheet areas; they rest unconformably on the Ordovician, and probably unconformably on the Tidbinbilla Quartzite; and they are intruded by the Upper Silurian Shannons Flat Adamellite, dated at 414 ± 2 m.y. (Roddick & Compston, 1976).

Such a major volcanic episode as the one that produced the Paddys River Volcanics is likely to be reflected in contemporaneous sediments around Canberra, only 15 km to the east. There, the mainly sedimentary formations in the upper part of the Canberra Group contain interbedded acid volcanics, which pass up into the Ainslie Volcanics. According to Öpik (1958) the earliest accumulation of these - tuff and rhyolite - is in the Riverside Formation, although the underlying Turner Mudstone contains some tuffaceous sandstone. We therefore consider that the Paddys River Volcanics can be correlated with these early volcanics in Canberra, whose age according to Strusz (1975) is most likely late Wenlockian.

Walker Volcanics

Nomenclature

Malcolm (1954), in an unpublished report, gave the name Uriarra Volcanics to the sequence of acid volcanics cropping out in the Cotter Dam/ Uriarra Forest area, northwest of the Winslade Fault. He called the lowest member of this sequence the Walker Member. Our studies have shown that the Walker Member is distinct petrographically and chemically from the remainder of the Uriarra Volcanics and we suggest that an erosional break may be present at the top of the Walker Member. We therefore rename the unit the Walker Volcanics - a separate formation from the Uriarra Volcanics, whose basal subdivision thus becomes the Tarpaulin Creek Ashstone Member.

The only published reference to the unit is by Green (1961), who did not describe it but collected samples of it at Uriarra Crossing and north of Cotter Dam for palaeomagnetic studies.

Derivation of name

Malcolm (1954) named the unit after Walker trig station (grid ref. 779950), 3 km south of Uriarra Crossing.

Type section

Malcolm (1954) designated the Uriarra Crossing area as the type area of the Walker Volcanics. We propose that the type section be on the Murrumbidgee River from 50 m downstream of the causeway at Uriarra Crossing (grid ref. 775981), to about 200 m upstream of the causeway (grid ref. 776978). Much of the river section is in massive reddish purple garnet-bearing dacite, which is characteristic of much of the Walker Volcanics, but tuff beds are also present - for example, on the west bank of the river about 100 m above the crossing.

Distribution

The Walker Volcanics form a wedge-shaped outcrop pattern over about 60 km^2 of BRINDABELLA, from the Cotter Dam in the south to Cusacks Crossing in the north. They are bounded to the west by the overlying Uriarra Volcanics, to the southeast by the Winslade Fault, and to the northeast by an older unnamed sediment and tuff sequence (Sv_1). They extend into CANBERRA along the Molonglo River downstream of Coppins Crossing (grid ref. 835943), but their full extent in that Sheet area is still uncertain.

Petrography

The Walker Volcanics characteristically comprise an interbedded sequence of grey-green massive welded dacitic tuff, purple massive welded dacitic tuff, and purple bedded unwelded tuff, all of which may contain garnet. They also contain local agglomerates, volcaniclastic sediments, and small limestone lenses.

The grey-green and purple massive dacitic tuffs both have a similar suite of minerals, typically quartz-plagioclase-biotite-garnet ± cordierite ± orthopyroxene. All ferromagnesian minerals except garnet are invariably altered to chlorite. The colour of these dacites is merely a reflection of the degree to which they are oxidised; this was well demonstrated during construction of the Pine Ridge sewerage tunnel (grid ref. 813981), where irregular areas of purple dacite were in sharp contact with grey-green dacite; thin sections across the contact illustrate that only one rock type was present.

<u>Phenocrysts in the massive dacitic tuffs</u>. In thin section the dacite contains phenocrysts of quartz, plagioclase, and ferromagnesian minerals, which form up to 50% of the rock, in a fine microcrystalline or cryptocrystalline groundmass. Quartz, usually the most common phenocryst, forms euhedral to anhedral crystals - often strongly embayed - and angular fragments, and may be up to 6 mm in diameter. Undulose extinction is rare. Plagioclase, always less abundant than quartz, forms subhedral to euhedral crystals generally less than 2 mm but rarely up to 4 mm. Albitisation of plagioclase is widespread, and many grains are untwinned. When unalbitised the plagioclase is moderately zoned, often oscillatorily, from cores of An_{55} to rims of An_{35}, and is usually strongly sericitised. Potash feldspar apparently does not form phenocrysts in the Walker Volcanics.

All the mafic minerals except garnet are totally altered to chloritic and opaque minerals, but their identity (as explained above) has been extrapolated from samples of the Kellys Plain Volcanics containing little-altered ferromagnesian minerals. Biotite forms anhedral to euhedral flakes, usually less than 1 mm long, altered to chlorite with opaque minerals developed along the cleavage traces; in the purple dacites the altered biotite consists almost entirely of opaque minerals. Like biotite, anhedral to euhedral cordierite forms up to 10% of the phenocrysts, but it is always altered to a pale green to colourless chlorite lacking any opaque inclusions. Larger crystals of cordierite, which may be up to 4 mm long, may have inclusions of anhedral altered biotite.

Orthopyroxene, present in about half of the dacite samples, generally forms about 5% of the phenocrysts. It forms subhedral crystals up to 1 mm long, and is altered to green chlorite with inclusions of opaque minerals.

Garnet is present at almost every locality in the Walker Volcanics, though never in sufficient quantity to ensure its presence in thin section.

It forms large anhedral phenocrysts up to 6 mm, often with a distinct reaction rim formed of plagioclase, biotite, and chlorite up to 2 mm thick. Apatite and zircon are ubiquitous accessory minerals; apatite forms euhedral crystals up to 0.6 mm, and zircon forms anhedral to euhedral crystals less than 0.05 mm.

In the more oxidised, purple dacites, an abundance of opaque minerals rimming all the phenocrysts, including quartz and plagioclase, give a distinctive appearance to the rock. The opaque mineral is presumed to be hematite.

Groundmass in the massive dacitic tuffs. The groundmass is commonly cryptocrystalline to microcrystalline, and rarely may show signs of vague eutaxitic layering, but is generally structureless. Thin sections from the base of an ignimbrite unit in contact with volcaniclastic sediments exposed in the Pine Ridge tunnel (grid ref. 813981) show an unwelded groundmass with undeformed glass shards; a few metres above the base, all the original groundmass texture is destroyed. Staining has shown that the groundmass comprises quartz and potash feldspar, but no plagioclase.

Other rock types. Purple bedded unwelded tuff crops out at many localities in the Walker Volcanics. It is generally deeply weathered, so little can be said of its mineralogy, but in hand specimens it appears to be similar to the massive dacite in composition as it contains quartz, plagioclase, garnet and mafic minerals. Its grains are angular and generally poorly sorted, and since cross-stratification is absent it is thought to be an airfall rather than a water-laid tuff.

Agglomerate crops out at several localities, particularly west of Cusacks Crossing and at the eastern end of the Pine Ridge tunnel. West of Cusacks Crossing it forms the uppermost beds of the Walker Volcanics, immediately underlying the Tarpaulin Creek Ashstone Member, where it is unsorted and contains angular clasts of welded dacite up to 10 cm in a crystal matrix. At the eastern portal of Pine Ridge tunnel, dacite blocks up to 50 cm are enclosed in a crystal tuff.

Definite water-laid sediments are known from only three areas - two of them with limestone. The area without limestone is in the Pine Ridge tunnel, where 30-40 m of fissile black shale were exposed between agglomerate and overlying dacite ash-flow tuffs. The shale was finely laminated as a result of variations in the amount of fine silt-sized quartz and albite present, and at several levels was rich in pyrite.

Limestone with associated clastic sediments crops out at two localities in the Walker Volcanics: one in BRINDABELLA north of Uriarra Crossing (grid ref. 790992); the other in CANBERRA northwest of Coppins Crossing (grid ref. 835943). In BRINDABELLA, the limestone is up to 15 m thick, and occurs as several lenses (separated partly by minor faulting) over a strike distance of about 250 m. At the southern end of the outcrop the sequence is:

purple dacite	thickness unknown
volcaniclastic arenite	?5.00 m
massive coarse dark grey crinoidal biosparite	2.00 m
poorly bedded to massive dark grey micrite	1.50 m
poorly bedded rubbly dark micrite	0.50 m
thickly bedded light to dark grey micrite, laminated or conglomeratic in places	0.90 m
laminated pinkish algal micrite	0.35 m
nodular dark grey biomicrite in shale matrix, with several dark grey micrite beds to 30 cm thick	5.00 m
light brown poorly bedded mudstone, bedding sometimes highly contorted (?slumped)	5.00 m+

base of section

Environment of deposition

The Walker Volcanics are thought to have accumulated in a terrestrial environment because they include ignimbrite flows, which predominate in the sequence, and poorly sorted bedded tuff with angular euhedral phenocrysts, which indicate a lack of water transport and sorting. Brief marine incursions deposited limestone as lenses in the Coppins Crossing area (CANBERRA) and northwest of Uriarra Crossing.

Relations

In BRINDABELLA the base of the Walker Volcanics is exposed in the Murrumbidgee River valley between Cusacks Crossing and the Molonglo River, where it passes conformably down into an unnamed sequence of volcaniclastic sediment with ignimbrite and airfall tuff.

We consider that the Walker Volcanics are similar in age to the Mount Painter Volcanics, because garnet is common in both but rare in other volcanics of similar age in the Canberra region. We also consider that the Paddys River Volcanics are slightly older than the Walker Volcanics since they rest unconformably on Ordovician rocks, but the two units may in part be lateral equivalents.

The Walker Volcanics are overlain with probable disconformity by the Uriarra Volcanics in the west, and by the Laidlaw Volcanics and Deakin Volcanics in the east, around Mount Stromlo (CANBERRA).

Thickness

The total exposed thickness of the Walker Volcanics is considered to be about 2000 m in the area between the Molonglo and Cotter Rivers; this, however, is a minimum thickness, since the base is not exposed in this area. Farther north, in the Cusacks Crossing area, the Walker Volcanics thin to about 300 m, probably because they were eroded before the Uriarra Volcanics accumulated on top of them.

Fossils and age

An extensive shelly marine fauna has been collected from the sedimentary lenses in the Walker Volcanics along the Molonglo River below Coppins Crossing (grid ref. 835943, CANBERRA), and a poorer fauna, mainly corals, is present in the limestone at Uriarra Crossing (grid ref 790992). As only a few of the species have so far been described, the faunas at present are of rather limited value for correlation. We have suggested above that, on lithological grounds, the Walker Volcanics correlate with the Mount Painter Volcanics. This suggests a late Wenlockian age.

Dr D.L. Strusz (BMR) has identified the following genera in the fauna from Coppins Crossing.

Trilobites: *Encrinurus*, *Coronocephalus*, *Gravicalymene*, *Otarion*, *Sphaerexochus*, *Ceratocephala*, *Staurocephalus*, harpid cf. *Aristoharpes*, illaenid? cf. *Thomastus*

Brachiopods: *Salopina*, *Skenidioides*, *Aegiria*, *Pentlandina*, *Strophochonetes*, *Coelospira*, *Nanospira*, *Atrypoidea*, '*Eoreticularia*', cyrtiid new genus, *Craniops*, *Trimerella*.

Hawkins Volcanics

Brown (1940) used the name 'Hawkins Series' for volcanic rocks underlying the Bango Limestone east of Yass, and the name 'Douro Series' for volcanic rocks between the Bango Limestone and the 'Yass Series'. Later authors had difficulty applying this nomenclature when the Bango Limestone was absent, since the two volcanic units have essentially identical field appearance, and Pogson & Baker (1974) suggested that the name Douro Group be used for the whole volcanic sequence, including interbedded sediments, from the base of the 'Hawkins Series' to the base of the sedimentary Hattons Corner Group (see Table M11). Pogson & Baker (1974) applied the name Hawkins Volcanics to the whole volcanic sequence below the Yass Formation; we follow this nomenclature.

The Hawkins Volcanics crop out over about 5 km^2 of BRINDABELLA, in three small areas: the largest is in the far northeast corner, and the other two are around Mount Boambolo, on the northern edge of the Sheet area just east of the Murrumbidgee River. The unit is much more extensive in YASS and CANBERRA, where it probably covers several hundred square kilometres.

In BRINDABELLA, the Hawkins Volcanics comprise greenish grey dacite tuff - probably ignimbrite - which has a phenocryst mineral suite of quartz-plagioclase-biotite-cordierite±garnet. Quartz, the most abundant, forms about 50% of the phenocrysts, and is commonly embayed. Euhedral to subhedral plagioclase (andesine), which forms about 35% of the phenocrysts, is not albitised in BRINDABELLA, but is in the Hawkins Volcanics in CANBERRA (Henderson, 1975). Both biotite and cordierite are altered to chlorite and opaque minerals, whereas any garnet present is fresh. The groundmass is a microcrystalline mixture of quartz and potash feldspar, and shows evidence of eutaxitic layering in some samples.

The local thickness of the Hawkins Volcanics cannot be estimated; elsewhere in YASS and CANBERRA it must be of the order of several thousand metres. The age of the Hawkins Volcanics must be late Wenlockian, since Crook & others (1973) have shown that they rest with slight unconformity on early Wenlockian beds, while Link & Druce (1972) have dated the overlying Yass Formation as earliest Ludlovian.

Laidlaw Volcanics

Nomenclature

Mann (1921) first applied the name Laidlaw stratigraphically to acid porphyritic rocks cropping out around Laidlaw trig station, 1 km west of Yass. Both Jenkins (1878) and Shearsby (1912) had previously described these rocks and noted that they occur between two sedimentary sequences. Sherrard (1936) mapped in some detail the igneous rocks of the area, and used the term 'Laidlaw porphyry' for a porphyry lying between two sedimentary sequences near Laidlaw trig.

Brown (1941), who mapped the whole of the Yass Basin, named the tuffaceous sequence between the Yass Series and Hume Series the 'Laidlow Series', and also used the name 'Laidlaw Tuff' for the same rocks. This terminology was used by later authors describing the area (such as Brown, Campbell, & Crook, 1968). Link (1970), as a result of detailed mapping of the sedimentary rocks of the Yass Basin, completely revised the stratigraphic nomenclature, renamed the 'Laidlaw Series' the Laidlaw Formation, and included it as the basal formation of the Hattons Corner Group. He named a thin limestone near the top of the Laidlaw Formation the Euralie Limestone Member, which he showed to be separated from the overlying Silverdale Formation by a thin tuff bed - the top of the Laidlaw Formation. Exact correlation of Brown's (1941) boundary between the Laidlaw and Hume Series with Link's work is uncertain, since Brown did not map the thin limestones (Euralie Limestone and Gums Road Limestone) which Link placed respectively near the top of the Laidlaw Formation and at the base of the Silverdale Formation. In a later publication, Link & Druce (1972) introduced two new names, which they included on the map accompanying their text but not in their text: the Willow Bridge Tuff Member for the thick volcanic sequence, which forms the bulk of the Laidlaw Formation, below the Euralie Limestone Member; and the Excursion Creek Sandstone Member for the tuffaceous beds at the top of the Laidlaw Formation - that is, above the Euralie Limestone Member.

The nomenclature of the area was again revised by Pogson & Baker (1974), who elevated the Willow Bridge Tuff to formational status, and restricted the Laidlaw Formation to the Euralie Limestone and Excursion Creek Sandstone. Thus, between 1941 and 1974 the term Laidlaw had changed from one implying a mainly volcanic sequence to one composed of sedimentary rocks, a change we consider does not follow the spirit of the Australian Code of Stratigraphic Nomenclature.

Our examination of the type area of the 'Laidlaw Series' (in the sense of Brown, 1941) has revealed a complex sequence not described by Link (1970), Link & Druce (1972), or Pogson & Baker (1974). Immediately overlying the Cliftonwood Limestone, at the top of the Yass Formation, is a sequence of some tens of metres of volcaniclastic sediments derived by the erosion of volcanic rocks of the Hawkins Volcanics (below the Yass Formation). Above this, a laterally and vertically variable sequence of ignimbritic quartz-feldspar-biotite porphyries passes up into the Euralie Limestone. The Excursion Creek Sandstone is also a volcaniclastic arenite, however, apparently derived by the erosion of the Laidlaw volcanic sequence.

We therefore propose that the name Laidlaw be restricted to that part of the sequence between the Yass Formation and Euralie Limestone, most of which is of volcanic origin, and therefore use the name Laidlaw Volcanics. This is in accordance with the original nomenclature of the area first detailed by Brown (1941). The Euralie Limestone and Excursion Creek Sandstone are best regarded as basal members of the overlying Silverdale Formation, with which they have much closer sedimentological affinities. Detailed work on the stratigraphy of the volcanic units of the Yass area is needed to complement Link's (1970) work on the sedimentary units, and until this is done the Laidlaw Volcanics must be regarded as an informally defined unit.

Our suggested nomenclature of the sequence in the Yass area, and comparisons with previous work, are given in Table M11.

Derivation of name

The Laidlaw Volcanics derive their name from Laidlaw trig station, 1 km west of Yass.

Type locality

No type locality can be designated until the geology of the unit in YASS is better understood. Our reconnaissance of the Laidlaw trig area suggests that this locality is not typical of much of the area of outcrop of the Laidlaw Volcanics both north and south of Yass, so it may not be suitable as the type locality.

Distribution

The Laidlaw Volcanics occupy over 200 km^2 in the east and northeast of BRINDABELLA in two areas of outcrop. The larger, about 185 km^2 in area, forms a belt up to 10 km wide from the northeastern corner of the map southwards to the Ginnindera Creek area, where it is faulted against older volcanics. Westwards this belt is terminated by the younger extrusive Mountain Creek Volcanics and intrusive Ginninderra Porphyry. Eastwards, the Laidlaw Volcanics extend for a short distance into CANBERRA (Henderson, 1975). Northwards the Laidlaw Volcanics extend into YASS.

The smaller outcrop area (about 20 km^2 in BRINDABELLA) is a triangle lying east of the Cotter Reserve, southeast of the Winslade Fault and northeast of the Murrumbidgee Fault. The Laidlaw Volcanics extend from this area into CANBERRA, where they occupy a considerable area in the southern part of Weston Creek and Tuggeranong and extend almost to Tharwa.

Brown (1941)		Link(1970), Link & Druce (1972)			Pogson & Baker (1974)			This Paper		
Hume Series		Booroo Ponds Group			Booroo Ponds Group			Booroo Ponds Group		
Hume Series	HUME LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	HUME LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	HUME LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	HUME LIMESTONE
Hume Series	BARRENDELLA SHALE	Hattons Corner Group	SILVERDALE FORMATION	BARRENDELLA SHALE	Hattons Corner Group	SILVERDALE FORMATION	BARRENDELLA SHALE	Hattons Corner Group	SILVERDALE FORMATION	BARRENDELLA SHALE
Hume Series	BOWSPRING LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	BOWSPRING LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	BOWSPRING LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	BOWSPRING LIMESTONE
Hume Series	BOWSPRING LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	TULLERAH SANDSTONE	Hattons Corner Group	SILVERDALE FORMATION	TULLERAH SANDSTONE	Hattons Corner Group	SILVERDALE FORMATION	TULLERAH SANDSTONE
Hume Series	BOWSPRING LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	GUMS ROAD LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	GUMS ROAD LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	GUMS ROAD LIMESTONE
?—?—?	?—?—?									
Laidlaw Series		Hattons Corner Group	LAIDLAW FORMATION	EXCURSION CR SANDSTONE	Hattons Corner Group	LAIDLAW FM	EXCURSION CR SANDSTONE	Hattons Corner Group	SILVERDALE FORMATION	EXCURSION CR SANDSTONE
Laidlaw Series		Hattons Corner Group	LAIDLAW FORMATION	EURALIE LIMESTONE	Hattons Corner Group	LAIDLAW FM	EURALIE LIMESTONE	Hattons Corner Group	SILVERDALE FORMATION	EURALIE LIMESTONE
Laidlaw Series		Hattons Corner Group	LAIDLAW FORMATION	WILLOW BRIDGE TUFF	Douro Group	WILLOW BRIDGE TUFF		Douro Group	LAIDLAW VOLCANICS	
Yass Series		Yass Group	CLIFTONWOOD LIMESTONE		Douro Group	YASS SUBGROUP	CLIFTONWOOD LIMESTONE	Douro Group	YASS FORMATION	CLIFTONWOOD LIMESTONE
Yass Series		Yass Group	O'BRIENS CR SANDSTONE		Douro Group	YASS SUBGROUP	O'BRIENS CR SANDSTONE	Douro Group	YASS FORMATION	O'BRIENS CR SANDSTONE
Douro Series		Douro Volcanics			Douro Group	HAWKINS VOLCANICS		Douro Group	HAWKINS VOLCANICS	

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Table M11 Nomenclature of part of the Silurian sequence near Yass

Petrography

The Laidlaw Volcanics in BRINDABELLA are remarkably uniform in appearance and composition. They are formed almost exclusively of a medium grey rhyodacite, of which exposures are common - generally as rounded boulders up to 1 m high which weather to a thin light grey skin; fresh rock is generally easy to obtain. Towards the base, in the east, they locally become darker grey and finer-grained, and the groundmass forms a greater proportion of the rock. Other rock types are limited to an ashstone 0.5 km south of Vimy Ridge homestead (grid ref. 715138), and a rhyolite, most of which crops out in CANBERRA, on the eastern border of the Sheet area northeast of Hillcrest (grid ref. 822120).

In YASS, to the north, bedded tuff and volcaniclastic arenites form a significant proportion of the unit. Volcaniclastic sediments are also more common to the southeast, in the Tuggeranong area (CANBERRA).

The rhyodacite contains quartz, labradorite, sanidine, biotite, and hypersthene phenocrysts in a cryptocrystalline groundmass which may show eutaxitic layering. The phenocrysts generally form between 30 and 50% of the rock; on average, quartz forms about 40%, plagioclase usually slightly less (about 35%), biotite about 10-15%, hypersthene about 5-10%, and sanidine up to 5%.

Quartz occurs as anhedral to euhedral grains, commonly embayed and showing no sign of undulose extinction. These are commonly less than 3 mm in diameter, but may reach 5 mm. Plagioclase forms subhedral to euhedral grains, up to 3 mm, which are usually strongly oscillatorily zoned. Composition is in the labradorite range; the cores have an anorthite content of up to 70%. Generally zoning is from An_{65} in the core to An_{40} on the rims of crystals. Many grains are angular in shape and were obviously derived by the disruption of large euhedral crystals. The larger grains of sanidine, which may be up to 2 mm across, are generally angular fragments, whereas the smaller grains are often subhedral or euhedral. Alteration of sanidine is generally slight; where present, it is faint, patchy, brownish, and turgid.

Biotite and hypersthene are the only two ferromagnesian minerals present. Biotite is often unaltered or only partly altered, and forms subhedral to euhedral flakes, up to 2 mm long, which are pleochroic from X = very pale yellow-brown to Y = Z = bright red-brown. Hypersthene is normally altered to chlorite plus iron oxides and quartz, but in places, particularly in the south near Ginninderra Creek and Surveyors Hill, cores of fresh hypersthene remain. These occurrences have provided valuable information on the style of alteration of hypersthene in acid volcanic rocks, and have assisted in the identification of completely altered hypersthene. The crystals are usually subhedral with rather rounded appearance, but euhedral basal sections or elongate sections occur in places. When fresh the hypersthene is faintly pleochroic (X = very pale pink, Z = very pale green), has $2V_x \simeq 55^{\circ}$, and appears to be unzoned.

Accessory minerals include zircon, allanite, and magnetite. Allanite, a rare-earth-bearing iron epidote, occurs in over half of the thin sections as either angular fragments or euhedral crystals generally less than 0.25 mm though rare elongate crystals may be up to 0.5 mm long. Some of the allanite in the Laidlaw Volcanics appears to be in the metamict state owing to the destruction of its crystalline structure by alpha-particle bombardment from radioactive elements in the mineral. Many crystals are surrounded by a dark halo due to the same process. The allanite varies from olive-green to yellow-brown or dark brown in plane light, and often shows oscillatory zoning. A qualitative electron-microprobe study of a sample from the Tuggeranong sewerage tunnel (CANBERRA) showed that appreciable amounts of cerium and thorium are present, together with yttrium, lanthanum, neodymium, and samarium. This occurrence of allanite in the Laidlaw Volcanics is of particular interest since it has only rarely been reported from acid volcanics, principally from the western USA, and never from the Lachlan Fold Belt. The only other units in BRINDABELLA in which allanite has been identified are the Uriarra Volcanics and Ginninderra Porphyry, within which it is much rarer.

Rock fragments are in general rare in the Laidlaw Volcanics, but at some localities, such as the falls on Mullion Creek (grid ref. 727118), xenoliths up to 5 cm of a dark reddish porphyry consisting of quartz, albite, and biotite in a red fine-grained groundmass and resembling the Ginninderra Porphyry are common. Similar xenoliths at Red Rocks Gorge on the Murrumbidgee River (CANBERRA, grid ref. 860788) are up to 30 cm; a xenolith of leucogranite was also found at this locality. Other rock fragments in the Laidlaw Volcanics are limited to occasional grains of dacite, usually less than 4 mm, similar in general appearance to the enclosing rock. They never form more than 1% of the total rock, and usually form much less.

The groundmass of the Laidlaw Volcanics is usually microcrystalline, structureless, and composed mainly of quartz and potash feldspar (demonstrated by staining). Rocks with well-developed eutaxitic layering and perlitic cracking are common, and all stages of devitrification, with resultant destruction of the layering, are evident.

Thickness

The lack of structural information in the Laidlaw Volcanics in BRINDABELLA precludes an accurate estimation of their thickness. If the unit is assumed to be horizontal a thickness of at least 340 m is suggested by the difference in altitude between the top of the Surveyors Hill and the Murrumbidgee River. If only gentle dips are assumed, then the thickness must be at least 500 m, but since the observed dips are all over 15° a thickness approaching 1000 m is possible.

The thickness in YASS appears to be variable: Link's map in Link & Druce (1972) indicates that 2 km south of Yass the unit thins to about 200 m, whereas north of Yass it appears to be around 1000 m thick.

Depositional environment

The presence of eutaxitic layering in the groundmass, partly destroyed at most localities but well preserved at some, indicates that the Laidlaw Volcanics were deposited as a result of ignimbrite activity. The remarkably uniform lithology and the absence of water-laid sediments and ashstones throughout BRINDABELLA suggest that the volcanics erupted over a short time span, and that they acted essentially as one cooling unit.

Age and relations

In the Yass area the Laidlaw Volcanics crop out between the Yass and Silverdale Formations, both fossiliferous sedimentary units. The volcanics have traditionally been considered to be part of a conformable sequence, but our reconnaissance of the area suggests that this may not be so, and that erosional breaks may be present. However, the sequence does provide good age control for the volcanics. Link & Druce (1972) put forward evidence that both the Yass Formation and the lower part of the Silverdale Formation are of early Ludlovian age. Therefore, even if erosional breaks are present, the Laidlaw Volcanics must also be of early Ludlovian age.

In BRINDABELLA the Laidlaw Volcanics occupy a similar stratigraphic position, resting on the Yass Formation in the northeast corner and on the Glen Bower Formation near Mount Boambolo. However, the Silverdale Formation does not crop out in BRINDABELLA, either because it was not deposited or because it was subsequently eroded, and the volcanics are overlain unconformably by the Lower Devonian Mountain Creek Volcanics. The Laidlaw Volcanics are also intruded by the Ginninderra Porphyry towards the southwest.

The relation between the Uriarra Volcanics and the Laidlaw Volcanics is uncertain. One possibility is that the Uriarra Volcanics are slightly younger than the Laidlaw Volcanics; in the southern part of YASS, north of Mount Boambolo, an area of reddish agglomerate and airfall tuff, bearing a close resemblance both in the field and in thin section to the Uriarra Volcanics, rests on top of the Laidlaw Volcanics, possibly conformably; as the Uriarra Volcanics rest on the Walker Volcanics (which are older than the Laidlaw Volcanics) in the Uriarra Forest area, this interpretation presupposes that the Laidlaw Volcanics were either not deposited in this area or were eroded before the Uriarra Volcanics erupted. A possible alternative interpretation is that the Laidlaw Volcanics are younger than the Uriarra Volcanics, but no volcanics of Uriarra type are known to crop out underneath the Laidlaw Volcanics. A third possibility is that the two units are contemporaneous, and represent different styles of eruption, the Uriarra Volcanics being airfall tuffs and the Laidlaw Volcanics ignimbrites. The similar chemistry and mineralogy of the two units, in particular the occurrence of allanite, supports this interpretation, which eliminates the need for periods of erosion before one or the other unit was deposited. Further work in YASS may indicate which is the most likely interpretation.

Uriarra Volcanics

Nomenclature

Malcolm (1954) introduced the name Uriarra Volcanics to include four members, the Walker, Tarpaulin Creek Ashstone, Swamp Creek, and Vanity Members. We have recognised significant petrographic and geochemical differences between the Walker Member and the remaining units, and have therefore made the Walker Member a separate formation, the Walker Volcanics. Further, we have found no lithological difference between Malcolm's Vanity and Swamp Creek Members, and so have dropped both these names. Instead we propose that rocks previously placed in these two units be known simply as the Uriarra Volcanics, and that the Tarpaulin Creek Ashstone be retained as a member of the Uriarra Volcanics - at the base of the sequence.

Derivation of name

We assume that Malcolm (1954) named the unit after Uriarra homestead.

Type locality

Malcolm named the Uriarra homestead/Uriarra Forestry Settlement area as the type area of the Uriarra Volcanics. Unfortunately this is an area of poor exposure. We therefore propose a type section for the Uriarra Volcanics on Uriarra Creek, from grid reference 754962 to 750957, where the creek has cut a small gorge. At the lower end of this gorge (grid ref. 54962) the Tarpaulin Creek Ashstone Member, about 6 m thick, rests on purple garnet-bearing dacite of the Walker Volcanics, and is overlain by rhyodacitic tuff of the Uriarra Volcanics, which forms the main part of the gorge. About 150 m of the Uriarra Volcanics is exposed in this section.

Distribution

The Uriarra Volcanics crop out over about 45 km^2 of BRINDABELLA, where they occupy a north-south belt about 17 km long and 2 to 4 km wide between the Vanity Crossing area on the Cotter River and Tinkers Creek.

Petrography

The Uriarra Volcanics generally form good fresh exposures of rounded boulders up to 1 m or more in diameter, but locally, where jointing is strongly developed as around Uriarra homestead, exposures may be poor and rubbly. The rock is generally pink when fresh, and has a thin grey skin when weathered. A rather indistinct bedding is often visible in good exposures, especially low in the sequence (such as in the type locality).

The Uriarra Volcanics are mainly rhyodacitic tuffs with the composition quartz-albite-sanidine ± biotite ± hypersthene, and usually with numerous xenoliths of volcanic rock. Much of the tuff is thought to be airfall tuff, with some ignimbrite higher in the sequence.

The airfall tuffs are notable for their high phenocryst content, typically between 60 and 80% of the rock, in contrast to the ignimbrites, in which phenocrysts commonly form only 30 to 40% of the rock. Quartz and feldspar, which form the bulk of the phenocrysts, are fairly well sorted in individual samples with a surprisingly even grainsize. Quartz is generally anhedral to subhedral, rarely embayed, and under polarised light often shows some evidence of strain. Grainsize in different samples commonly ranges from 1 to 6 mm. Albite, which is often more common than quartz as a phenocryst, is generally subhedral, and is thought to have resulted from the postdepositional albitisation of more calcic plagioclase. Sanidine is always present, and is often common in the airfall tuffs, in which it forms up to 20% of the phenocrysts; its rather angular anhedral crystals, of similar size to other phenocrysts in the rock, may be virtually unaltered, but often show a brownish turgid alteration, and have the characteristic low 2V. The alkali feldspar in some rocks has unmixed to form perthite, in which the albite end-member generally forms less than half but constitutes 50% in a rock from grid reference 719897.

Biotite is present in most samples, though never forms more than 5% of the phenocrysts; it is always partly or completely altered to chlorite, and is much smaller than other phenocrysts, usually less than 1 mm long. Hypersthene, which is present in places, is always altered to chlorite, opaques, and quartz, and never forms more than 2% of the phenocrysts. Other accessory minerals are ubiquitous apatite and zircon, and allanite, which is present in about 20% of the thin sections.

The occurrence of allanite is of particular interest since it has rarely been reported from acid volcanics, and never before from the Lachlan Fold Belt. Allanite, which is a member of the epidote group rich in rare-earth elements, occurs as small euhedral phenocrysts up to 0.25 mm. It is light to dark brown or grey in colour, sometimes slightly pleochroic, has high relief, and is commonly surrounded by a halo in the groundmass resulting from the disintegration of radioactive elements in the mineral. An additional point of interest is that we have also found allanite in many samples from the Laidlaw Volcanics, suggesting that the two units may be related.

A feature of the Uriarra Volcanics, and the Laidlaw Volcanics too, is that cordierite and garnet are completely absent, in contrast to their constant presence in the Walker Volcanics.

Rock fragments are a common component of the airfall tuffs in the Uriarra Volcanics. They are almost invariably of volcanic origin; volcaniclastic sediments are rare. Rock types include andesitic, dacitic, and rhyodacitic lava and tuff, and ashstone. Fragments are usually of similar size to the crystals in the rock, or sometimes slightly bigger, reaching a maximum size of about 10 mm.

Ignimbrites are thought to be present at some levels high in the Uriarra Volcanics. Their mineralogy is similar to that in the airfall tuffs, but they have fewer phenocrysts (commonly less than 40%), and quartz is often embayed. Rock fragments are also less common in the ignimbrites than in the airfall tuffs. One sample (from grid ref. 721900) has unaltered zoned plagioclase with the composition An_{55} to An_{40}, but all other samples have albitised plagioclase. Few of the ignimbrites have any indication of eutaxitic layering in the groundmass; when present it is always highly altered and indistinct.

Ashstone crops out in places in the Uriarra Volcanics, but is surprisingly rare for a sequence in which airfall tuff predominates. Poor preservation of the ashstone may partly account for its apparent scarcity. Only one ashstone is persistent enough to map: the Tarpaulin Creek Ashstone Member at the base of the Uriarra Volcanics.

Tarpaulin Creek Ashstone Member

The Tarpaulin Creek Ashstone Member is a thin persistent ashstone which forms the base of the Uriarra Volcanics along its entire eastern boundary, a strike distance of about 17 km. Malcolm (1954) named it after Tarpaulin Creek, which flows from the Uriarra Forestry Settlement northwards to the Murrumbidgee River. It has its type section in Uriarra Creek, at the type section for the Uriarra Volcanics (grid ref. 754962).

It crops out poorly in the field, except in creeks and road-cuttings, but rubbly float is common and facilitates the mapping of its distribution. In hand specimen it is dark grey to maroon, weathering easily to light brown or cream, and generally aphyric, though plagioclase phenocrysts are scattered through it in places. It varies from massive to well bedded in outcrop, but is generally only moderately bedded.

In thin section it comprises up to 25% of small (0.1 mm) angular fragments of quartz and albite, and minor apatite, zircon, and a mafic mineral altered to chlorite, in a microcrystalline groundmass. Some samples have larger scattered phenocrysts of angular quartz and albite up to 1.5 mm. Many of the more elongate microphenocrysts are aligned parallel to the bedding, reflecting their original depositional atitude rather than a subsequent foliation. Staining has shown the groundmass to be composed of quartz, albite, and potash feldspar.

The Tarpaulin Creek Ashstone Member ranges in thickness from 2 m at grid reference 758980 to over 10 m at several localities (e.g., at grid ref. 753946). At grid reference 758980 it ranges in thickness from 6 m to 2 m over a distance of about 100 m, possibly reflecting some postdepositional erosion before the overlying coarser tuffs accumulated.

Other ashstones higher in the Uriarra Volcanics, though similar petrographically to the Tarpaulin Creek Ashstone Member, cannot be traced laterally for any significant distance.

Environment of deposition

The Uriarra Volcanics are thought to have been deposited entirely in a subaerial environment, since evidence of water-laid deposits is lacking. Further, airfall tuff rather than ignimbrite is thought to dominate the sequence. The two types of tuff are distinguished by the greater abundance of phenocrysts, better sorting, and lack of embayed quartz crystals in the airfall tuffs; in addition, the airfall tuffs often show rather indistirct bedding in good outcrops, whereas the ignimbrites are always massive. The presence of indistinct rather than well-defined bedding structures in airfall tuff characterises deposits formed either close to a vent or by repeated closely spaced blasts from a vent (Fuchtbauer, 1974). Since agglomerates are not apparent in the Uriarra Volcanics, the lack of well-defined bedding in the airfall tuff is considered to be due to the latter.

Thickness

The exposed thickness of the Uriarra Volcanics is probably 2000 m - a minimum value because their western (upper) boundary is either faulted or overlain unconformably by the Mountain Creek Volcanics.

Relations

The Uriarra Volcanics rest on an eroded land surface, probably of low relief, developed on the Walker Volcanics. The unconformity between them can at the most be of a very low-angle, since the two units have a similar structural attitude. The Uriarra Volcanics are overlain with angular unconformity by the Lower Devonian Mountain Creek Volcanics along almost half of their western boundary.

The relation between the Uriarra Volcanics and the Laidlaw Volcanics, is uncertain (see under Age and relations, Laidlaw Volcanics).

Age

The stratigraphic evidence for the age of the Uriarra Volcanics places them between the Walker Volcanics (late Wenlockian) and the Mountain Creek Volcanics (Early Devonian). Until their relation with the lower Ludlovian Laidlaw Volcanics is clarified, their exact age must remain in doubt, but would appear most likely to be ?early Ludlovian.

Unnamed Silurian volcanics

Two units of Silurian acid volcanics which crop out in BRINDABELLA have been left unnamed. For one a proper understanding of its age and relations must await further work in CANBERRA. A tunnel driven through the other during 1978 will provide much more information to supplement what little we know about it at present.

The smaller of the two areas (Sv_2) covers about 1 km^2 on the northern slopes of Mount Stromlo (CANBERRA); it is bounded to the north by the Winslade Fault, and is overlain in the south by the Laidlaw Volcanics. The unit appears to comprise mainly volcaniclastic water-laid sediment, possibly with some minor ashstone. These sediments appear to form part of a thick sequence of volcanic rocks which crop out in the Weston Creek/Woden area (CANBERRA), above the Yarralumla Formation. Strusz & Henderson (1971) included these volcanics in the Deakin Volcanics, but Henderson (1975) has since suggested that the name Deakin Volcanics be restricted to volcanics underlying the Yarralumla Formation, and that volcanics overlying the Yarralumla Formation remain unnamed until their stratigraphy is better understood.

The other unit (Sv_1) covers about 7 km^2 around Belconnen homestead, and appears to be conformable beneath the Walker Volcanics. It extends into CANBERRA, but its relations with units to the east are uncertain at present. A major sewerage tunnel, the Ginninderra sewerage tunnel, was driven through the unit during 1978; as this will add much new information about the unit, we have left it unnamed in our study.

Lang & Purcell (1976) have recently described the lithology of part of Sv_1. Volcaniclastic sediments predominate in the upper and lower parts of the unit, and dacitic tuff predominates in the middle. Sediments range from mudstone to coarse sandstone. The coarser rocks, which have been examined petrographically, consist of a variable proportion of rounded quartz grains up to 2 mm, volcanic rock fragments, minor plagioclase, and, in places, garnet as detrital grains. Sorting is variable, and appears to be generally better in the quartz-rich sediments.

The dacitic tuff contains quartz, plagioclase (generally albite, in places andesine), biotite, cordierite, garnet, and volcanic rock fragments. Biotite in some samples is fresh, but cordierite is always altered to chlorite. Phenocrysts form up to 60% of the rock.

Drill core described by Lang & Purcell (1976) from along the proposed line of the sewerage tunnel includes welded tuff, similar to that described above, grading into reworked volcaniclastic sandstone and shale. Scour-and-fill structures may be present near the top of a bed, and the succeeding dacite flow may contain contorted shale clasts up to 1 m.

Kellys Plain Volcanics

Nomenclature

Newberry (1956) proposed the name Kellys Plain Dacite for a quartz-feldspar porphyry that crops out on Kellys Plain, 3 km southwest of Tantangara Dam, and on Smiths Range (grid ref. 480380) to the north. He recognised the extrusive nature of the unit, which had previously been mapped by Ivanac & Glover (1949) and Walpole (1952) as an unnamed intrusive. Stevens (1958b) first published the name, and described its occurrence in the Cooleman and Currango Plains areas. In the second edition of the Canberra 1:250 000 geological map, Best & others (1964) referred to the unit as the Kellys Plain Porphyry, which Packham (1969) retained. Bein (1968) described the unit in detail between Kellys Plain and the southern edge of Currango Plain, and called it the Kellys Plain Beds.

As the unit is entirely volcanic - mainly dacite and rhyodacite - we have proposed the name Kellys Plain Volcanics.

Derivation of name

The unit is named after Kellys Plain, about 3 km southwest of Tantangara Dam.

Type locality

As no type locality has been named, we propose that the large disused quarry at Traces Knob (grid ref. 489366, 1500 m southwest of Tantangara Dam) be considered the type locality (Fig. M11). About 25 m of fresh massive dark bluish quartz-feldspar porphyry, typical of much of the Kellys Plain Volcanics in the southern part of the outcrop, is exposed in this quarry. It is the only artificial exposure of the Kellys Plain Volcanics, and, as such, is also one of the few localities where unweathered rock is exposed.

Distribution

The Kellys Plain Volcanics have a continuous outcrop from the Nungar Creek valley to the lower Peppercorn Creek valley - a distance of 35 km. From the Nungar Creek valley the volcanics crop out in a belt widening gradually to the north. Extensive boulder outcrops are present on Smiths Range (grid ref. 480380) and Kellys Plain. North of the Murrumbidgee River the volcanics crop out over much of the floor of Tantangara Reservoir, and most of Currango Plain, where the outcrop is 10 km wide. From Currango Plain the main area of outcrop trends northwest to Skains Hill, and extends as far as the eastern edge of Long Plain. From Skains Hill the main outcrop narrows considerably and trends northeast along the Cooleman Mountains into the lower Peppercorn Creek and Tinpot Creek valleys. In addition, the Kellys Plain Volcanics crop out in a faulted belt extending from the northeastern edge of Currango Plain along Pocket Creek as far as Rolling Ground Ridge.

Lithology

The unit comprises several different lithologies, whose boundaries, however, are not mappable. The most common variety, a dacite, and the one present at Traces Knob quarry, is a quartz-plagioclase-biotite-cordierite porphyry with a dark blue-grey groundmass. The rock crops out as abundant large tors and boulders up to 4 m - the typical outcrop of all rock types of the Kellys Plain Volcanics. The pale brown weathered surface is generally encrusted with rounded or bipyramidal quartz phenocrysts up to 6 mm in diameter, and less common pale green feldspar crystals to 10 mm; the cordierite is evident in hand specimens as rounded to euhedral dark green (chloritised) prisms mostly around 2

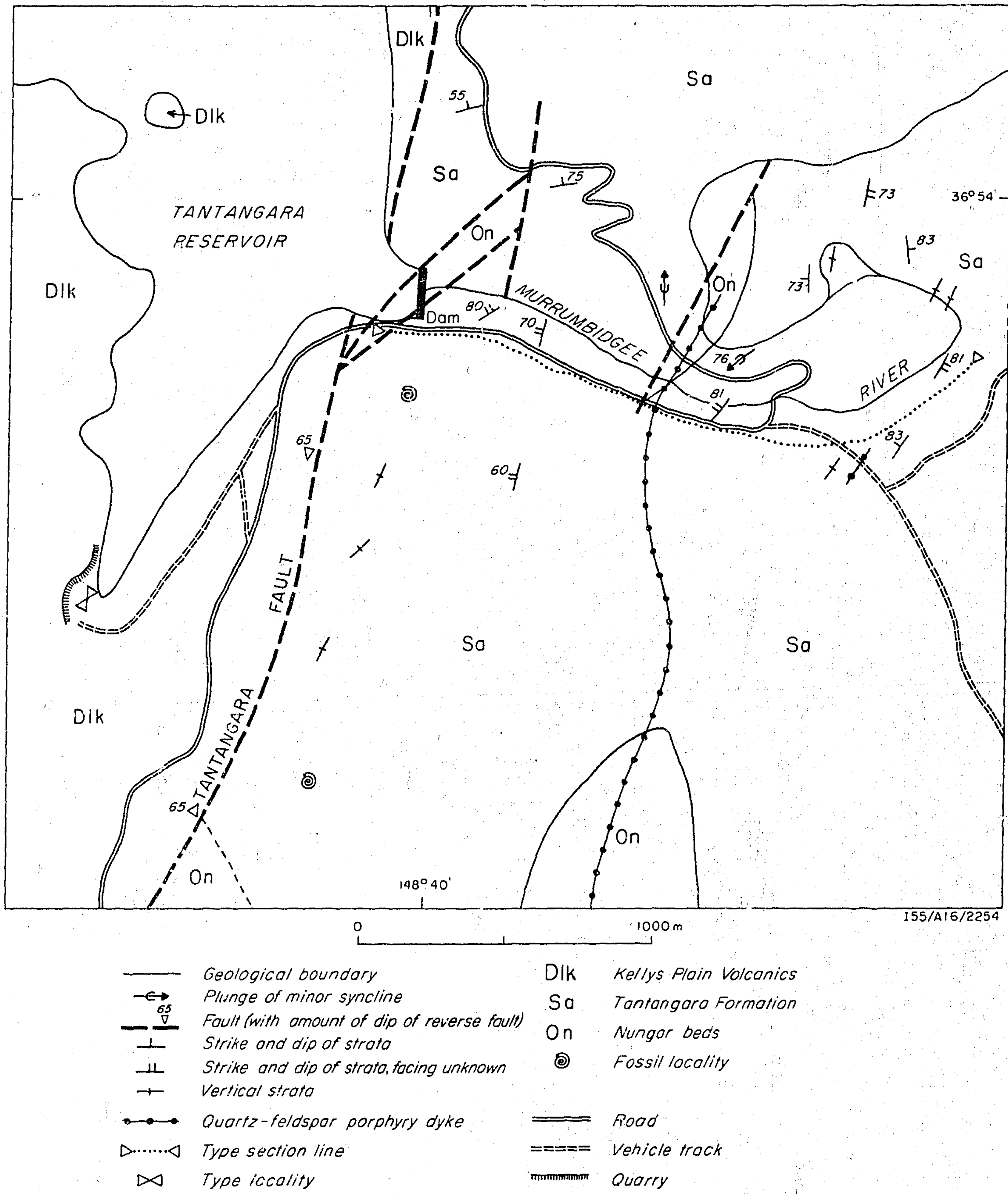

Fig MI1. Location of type section of Tantangara Formation and type locality of Kellys Plain Volcanics to 4 mm. This dark blue-grey porphyritic dacite crops out along the eastern side of Smiths Range (grid ref. 480380) and extends northward to form most of the outcrops on Currango Plain and in the Skains Hill and Cooleman Mountains areas. West of Smiths Range and in the lower Nungar Creek valley, the lithology is similar except that the groundmass is a distinct purple to purple-blue, and phenocrysts are less common, especially cordierite, which is rare. Lighter porphyritic quartz-plagioclase-biotite dacite is scattered through the areas of outcrop of the dark blue-grey variety, especially 1 to 2 km east-northeast of Port Phillip Gap (grid ref. 453482) and on the ridge between Tinpot Creek and Peppercorn Creek.

Lighter purple and cream porphyries crop out along the crest of Smiths Range, east of the Tantangara Fault near Currango, in outliers on Long Plain west and northwest of Cooinbil, and in the faulted block north of Pocket Saddle. Unlike the porphyries described above, these contain alkali feldspar phenocrysts in addition to or instead of plagioclase phenocrysts, and are thus rhyodacites and rhyolites. The alkali feldspar phenocrysts are mostly white and similar to plagioclase phenocrysts in hand specimen, but in some samples are pale pink.

Depositional structures are widespread south of but rare north of Currango Plain. Columnar jointing is common, especially in the lower Nungar Creek valley and on Currango Plain - for example, on the east bank of Nungar Creek at grid reference 477406 (Fig. M22) and on Currango Plain at grid reference 504498, 600 m north of Old Currango. The columns are up to 2.5 m long and 150 mm in cross-section, and have four to seven sides. The dip of the cooling surface indicated by the columnar jointing is generally less than 15° and almost always to the east.

Bedding, generally dipping east at 15° to 30°, is also common, especially south of the Murrumbidgee River, and generally consists of alternating quartz-rich and feldspar-rich layers, about 10 mm thick, which are emphasised by weathering. The bedding attitude of alternating light and dark grey bands 5 to 50 mm thick at grid reference 480366 varies considerably, apparently due to slumping; some of the dips are as much as 80°. These bedded tuffs are almost certainly airfall tuffs (Fuchtbauer, 1974).

Agglomeratic porphyry is widespread along the western side of the Kellys Plain Volcanics from Currango Plain southwards. An excellent example is on the west shore of Tantangara Reservoir at grid reference 490398, where rounded to angular fragments of quartz-feldspar-biotite porphyry 10 to 500 mm in diameter are enclosed in a porphyry with similar phenocrysts but darker matrix (Fig. M23). Elsewhere, a porphyry matrix encloses xenoliths of the underlying Ordovician and Silurian sediments, and at grid reference 503469 a tuffaceous matrix encloses angular fragments of chert, basaltic volcanics, quartzite, shale, and limestone.

Petrography

We have examined over 80 thin sections of the Kellys Plain Volcanics. Their groundmasses are similar to those in samples of the Goobarragandra Volcanics. Unwelded ignimbritic textures such as undeformed glass shards and perlitic structures are common, but in most samples an even-textured groundmass with no eutaxitic layering comprises patch spherulites or micrognanitic quartz and feldspar; these features probably result from the devitrification of welded glass. Eutaxitic layering is uncommon, and so too is the subtrachytic flow-alignment of microlites, which is evident in only one thin section (from grid ref. 481377) where the microlites are albite laths up to 0.2 x 0.03 mm. In a few samples, graphic intergrowths of quartz and feldspar surround quartz phenocrysts; the later quartz is in optical continuity with the phenocryst it surrounds.

Most of the Kellys Plain Volcanics can be divided into two groups according to the alkali feldspar phenocryst content: those containing quartz and plagioclase phenocrysts, and the lighter porphyries containing quartz and alkali feldspar phenocrysts with or without plagioclase. The lighter porphyries appear to be restricted in extent, and, at least on Smiths Range, overlie the darker volcanics.

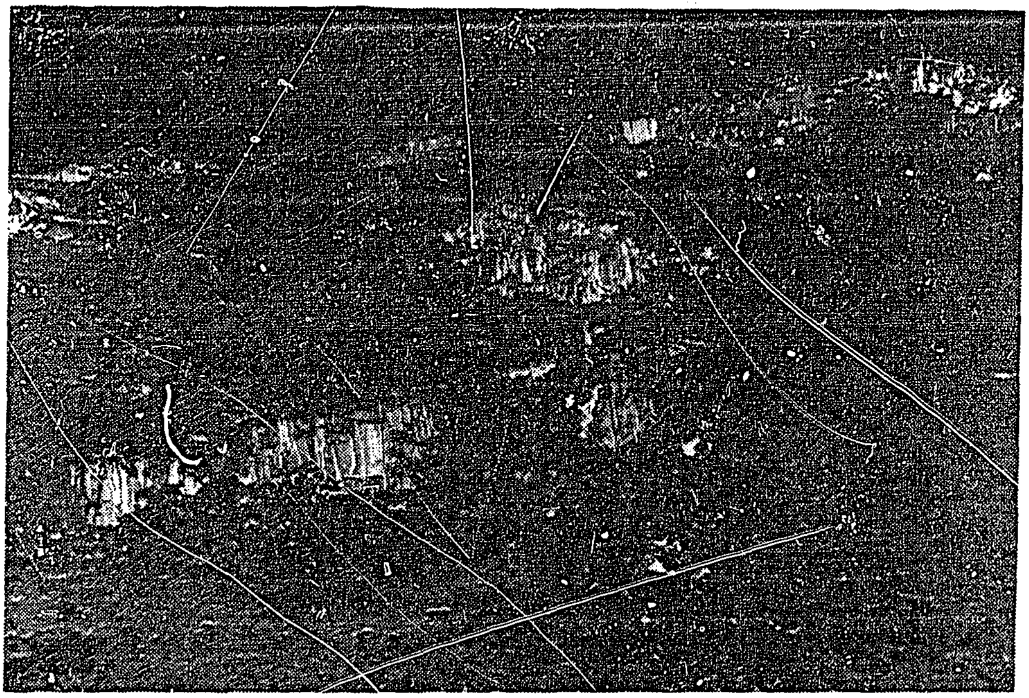

Fig. M22. Columnar-jointed dacite in the Kellys Plain Volcanics near Nungar Creek at grid reference 477406.
(GA/8093)

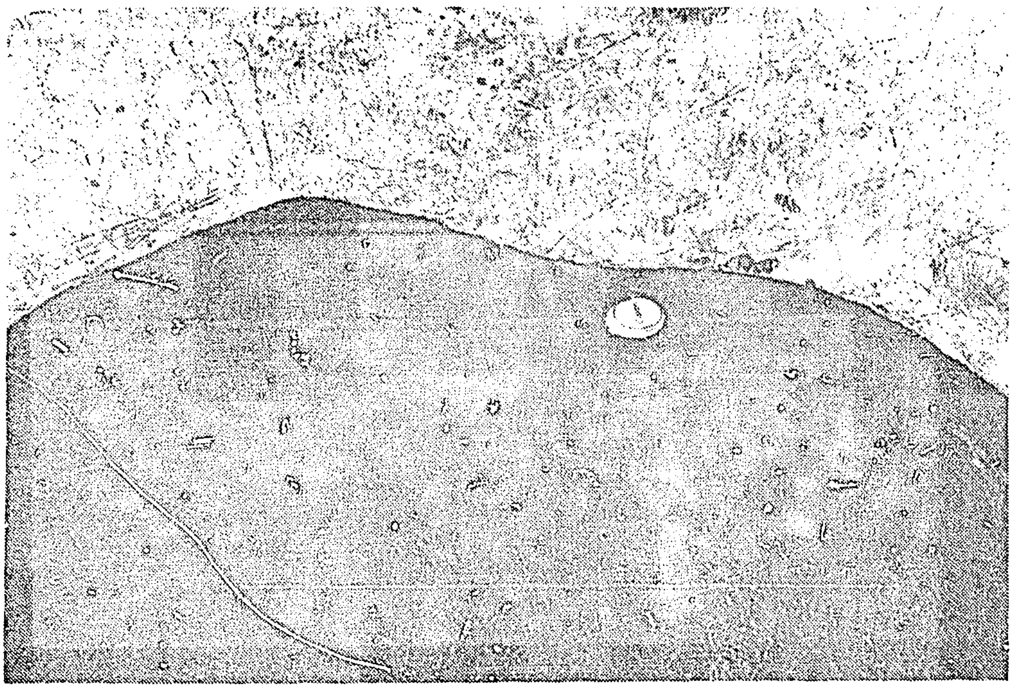

Fig. M23. Agglomerate in the Kellys Plain Volcanics on the west shore of Tantangara Reservoir at grid reference 490398.
(GA/8062)

<u>Group 1. Quartz and plagioclase but no alkali feldspar phenocrysts.</u> Quartz is the most abundant phenocryst (up to 20%), commonly occurring as partly rounded or resorbed grains (mostly 3 to 4 mm) of beta-habit.

Plagioclase is often as common as quartz, but rarely more so. This is in contrast to the Goobarragandra Volcanics, in which plagioclase is more common than quartz. The plagioclase is present as euhedral laths averaging 2 mm; some crystals are broken, and part of the grain is missing. In most samples the plagioclase has been albitised, but a few samples contain fresh plagioclase, commonly highly sericitised. This is invariably oscillatorily zoned, mostly around An_{30} to An_{40}, but in some samples An_{20} to An_{30} and rarely as calcic as An_{55} to An_{65}. Narrow albitic rims are uncommon, and absent from the more calcic examples.

Mafic phenocrysts range from 0 to 15% of a rock and are mostly altered, but some samples show red-brown biotite (up to 8% but mostly around 3 to 5%) only partly altered to talc, chlorite, opaques, and sphene.

Cordierite, garnet, and hypersthene are also present in the Kellys Plain Volcanics. The garnet is rare; it is present only in outcrops around grid reference 500430 and in a sample from grid reference 509515. Hypersthene is more widespread and cordierite is abundant, but both minerals are completely altered - the hypersthene to opaques and a mat of green ?serpentine and chlorite with a distinct first-order yellow birefringence, and the cordierite to very fine-grained chlorite with lower birefringence than the hypersthene alteration products, and no opaques. Both minerals are commonly euhedral and 1 to 2 mm, but cordierite in a sample from grid reference 489461 forms both euhedral equant prisms up to 4 mm and anhderal irregular ovoids of similar size.

A petrographically interesting locality in the Kellys Plain Volcanics is at grid reference 499430. Here, garnet-bearing dacite from near the base of the volcanic sequence is hardly altered, and the types of alteration of the ferromagnesian minerals can be confidently assigned to particular original minerals. The rock contains about 15% partly resorbed subhedral beta-quartz phenocrysts up to 4 mm, and about 10% of euhedral laths of plagioclase up to 2 mm and oscillatorily zoned from An_{65} to An_{55}. It also contains about

7% cordierite phenocrysts, some unaltered and others almost completely replaced by green chlorite and no other minerals. The cordierite phenocrysts, which are rarely simply twinned and have $2V_x = 80^o$, are of two types: euhedral squat prisms averaging 1 mm and mostly free of inclusions; and anhedral grains up to 3 mm and commonly containing large numbers of included minerals, such as rounded blebs of quartz about 0.02 mm, elliptical plates of biotite with their long axes aligned, and minute rounded zircons with pale yellow pleochroic haloes. Some cordierites contain sillimanite needles and associated green spinel octahedra. The sillimanite needles are up to 0.1 mm long and are aligned in a wavy or schistose pattern. The spinel is up to 0.03 mm and always accompanies sillimanite, never quartz. Hypersthene ($2V_x = 55$ to 60^o) is also present (5%) as euhedral to somewhat rounded crystals, about 2 mm, which range from fresh to completely altered to green chlorite and ?serpentine having a higher birefringence than the cordierite alteration product. The hypersthene is pleochroic from pale pink to pale green and commonly has inclusions of opaques and rounded biotite; some grains have been partly pseudomorphed by biotite. Biotite phenocrysts (5%) occur as euhedral plates up to 1.5 mm long and 0.5 mm thick; they are pleochroic from very pale yellow-brown to bright red-brown, and have rims with abundant inclusions of opaques, suggesting that they were at some stage out of equilibrium with the groundmass. Minor ilmenite, zircon, and apatite are scattered through the rock. Garnet occurs as rare xenocrysts up to 10 mm; these contain inclusions of plagioclase and apatite and are surrounded by reaction rims 1 mm thick of a vermicular intergrowth of cordierite (dominant) and chlorite (probably after hypersthene) indicating the reaction:

$$\text{garnet + quartz} \rightleftharpoons \text{cordierite + hypersthene.}$$

This reaction rim is surrounded by an ?accreted rim of stumpy euhedral labradorite and scattered biotite. Also present in the rock are cognate microxenoliths (5 to 10 mm) of oscillatorily zoned subhedral plagioclase, subhedral hypersthene (mostly altered), and uncommonly a little quartz, cordierite, and biotite. These microxenoliths have a hypidiomorphic texture produced by interlocking plagioclase laths, and appear to be phenocrysts accreted into glomeroporphyritic groups rather than residual source material with a metamorphic texture.

The mineral assemblage at this locality - quartz-labradorite-cordierite-biotite-hypersthene-garnet-sillimanite-spinel - is obviously not an equilibrium assemblage and indicates that the dacite or its source material, or both, has had a complex history in an environment which at some stage must have been at very high temperatures and very low water pressures (granulite facies environment). Hensen & Green (1972) indicate that the reaction:

$$\text{spinel} + \text{quartz} \rightleftharpoons \text{cordierite} + \text{garnet} + \text{sillimanite}$$

occurs under anhydrous conditions at around 1000^{o}C, and Green (1976) produced orthopyroxene in equilibrium with a melt derived from a pelite composition plus 5% H_2O at temperatures only above 900^{o}C and pressures below about 7 kb.

<u>Group 2. Quartz and alkali feldspar phenocrysts.</u> As with the group 1 rocks, beta-quartz is the most abundant phenocryst. Plagioclase (mostly albitised) when present is about as common as the alkali feldspar phenocrysts (3 to 5% each). The alkali feldspar is either subhedral orthoclase ($2V_x$ = 40-45^{o}) up to 2 mm, commonly containing perthite veins, or an unmixed sanidine-orthoclase (now a patch mesoperthite) of similar size composed of about Or_{60-70} or Or_{30-40}. Cordierite and biotite are both commonly present, but hypersthene and garnet are apparently absent.

<u>Other rock types</u>. At some localities (e.g., grid refs. 490418, 480366, and 484372) well-bedded volcanics interpreted as airfall tuffs comprise abundant (30%) angular and broken phenocrysts of quartz and less common albitised plagioclase in a groundmass of devitrified glass shards, spherulites, and chlorite. Rarely (e.g., at grid ref. 468349) the airfall tuffs contain no phenocrysts and consist entirely of poorly welded glass shards.

At grid reference 430571 an outlier of Kellys Plain Volcanics exposes rock composed of about 10% euhedral beta-quartz phenocrysts up to 4 mm, 10% altered euhedral cordierite phenocrysts up to 6 x 4 mm, and about 5% of euhedral white mica phenocrysts about 1 mm thick in a microgranitic groundmass with grainsize of about 0.03 mm. Plagioclase phenocrysts are completely absent. The white mica phenocrysts have common sphene inclusions and may be bleached biotite, but they appear more like primary muscovite flakes.

Alteration. Much of the Kellys Plain Volcanics has suffered post-depositional alteration in the form of welding, devitrification, chloritisation, introduction of carbonate, and albitisation of plagioclase phenocrysts. Much of this proceeded immediately after deposition owing to water and heat trapped in the cooling units, but some of it is probably due to low-grade burial metamorphism. Albitisation of plagioclase phenocrysts is probably related to burial metamorphism, as fresh plagioclase appears to be concentrated into areas (e.g., Currango Plain, outliers on Long Plain, and the Nungar Creek valley west of Mount Nungar). The presence in some samples of patches of zeolites (probably mostly stilbite, as $2V_x$ is small) and veins of albite plus zeolites is also probably due to burial metamorphism.

A significant feature of the Kellys Plain Volcanics is the rarity of epidote. This contrasts with the Goobarragandra Volcanics, in which epidote is widespread as an alteration product. Apart from that the two volcanic units have similar chemistry and mineralogy, so the epidote must signify that the Goobarragandra Volcanics were subjected to a higher degree of burial metamorphism than the Kellys Plain Volcanics.

Field relations and age

The Kellys Plain Volcanics unconformably overlie Upper Ordovician to Upper Silurian rocks of the Temperance Formation, Nine Mile Volcanics, Tantangara Formation, Peppercorn Formation, Cooleman Limestone, Blue Waterhole Formation, and Pocket Formation.

The contact of the volcanics with underlying rocks is exposed at two localities in the Nungar Creek valley. In the south, at grid reference 466341, a tuff layer about 2 m thick rests unconformably on cleaved siliceous mudstone of the Tantangara Formation, and is overlain by about 10 m of pale brown tuff; the contact dips east at 10^{o} with a strike of 015^{o}. Farther north, on the west side of Smiths Range at grid reference 476395, dacite tuff rests unconformably on cleaved dark grey mudstone of the Peppercorn Formation, the contact dipping 35^{o} due east; small (up to 10 mm) angular fragments of the underlying mudstone have been caught up in the basal 30 mm of the dacite.

The land surface upon which the Kellys Plain Volcanics were deposited appears to have been irregular. Inliers of cleaved Tantangara Formation and Peppercorn Formation are common, especially from Currango Plain south to the northern end of Smiths Range. In most places, the sedimentary rocks forming these inliers appear to be extensively silicified. A relief of at least 50 m is suggested by inliers of Peppercorn Formation in the upper Mosquito Creek valley.

The relation between the Kellys Plain Volcanics and the Rolling Grounds Latite in the Cooleman Plain area is unclear from direct field evidence as the two units are not in contact. However, geochemical and petrographic data suggest that the Kelly Plain Volcanics are the older. The Rolling Grounds Latite is closely related to the Coolamine Igneous Complex, which is probably its intrusive equivalent and intrudes the Kellys Plain Volcanics. The Kellys Plain Volcanics, then, are almost certainly older than the Rolling Grounds Latite. As the Rolling Grounds Latite is almost certainly of Lochkovian (Early Devonian) age, the Kellys Plain Volcanics must be of early Lochkovian or possibly late Pridolian (Late Silurian) age.

The unconformity beneath the Kellys Plain Volcanics can be correlated with that beneath the Snowy River Volcanics in JACOBS RIVER, to the south (Talent, 1965), and the disconformity beneath the Sharpeningstone Conglomerate in YASS, to the north (Link, 1970). Link has precisely dated the disconformity in the north as early Lochkovian; if this disconformity (representing the 'Bowning Orogeny' of earlier writers) is the same age as the unconformity beneath the Kellys Plain Volcanics, the Kellys Plain Volcanics can be no older than Lochkovian.

Thickness

As the Kellys Plain Volcanics accumulated on an irregular land surface, the thickness of the unit is probably quite variable. In the area of Skains Hill the thickness is about 300 m, and on Smiths Range, in the south, if a gentle dip to the east is assumed the thickness is about 150 m; both are minimum thicknesses as unknown amounts have been removed by subsequent erosion.

Rolling Grounds Latite

Nomenclature

Stevens (1958b, p. 254) gave the name Rolling Grounds Andesite to a series of augite-bearing 'andesites' on Rolling Ground Ridge and Cooleman Plain. He had previously used the name in a SMHA report (Stevens, 1957). Earlier, Walpole (1952) had mapped the unit as an unnamed intrusive porphyry. On the second-edition Canberra 1:250 000 geological map, Best & others (1964) included 'andesite' in the Kellys Plain Volcanics (the Rolling Ground Ridge outcrops) or Mountain Creek Volcanics (the Cooleman Plain outcrops). We have changed the name to Rolling Grounds Latite because the rock has roughly equal amounts of plagioclase and potash feldspars.

Derivation of name

The unit derives its name from Rolling Ground Ridge, which rises eastward from the junction of Cave Creek and the Goodradigbee River.

Type locality

As Stevens (1958b) designated no type locality, we have designated the area on Rolling Ground Ridge (at grid ref. 574560) as the type locality of the Rolling Grounds Latite. At this locality, lavas with poorly developed columnar jointing form low rubbly exposures.

Distribution

The main outcrop of the Rolling Grounds Latite is on Rolling Ground Ridge. Other outcrops include disconnected small areas on Cooleman Plain south of Coolamine, a large area trending northeast from Coolamine as far as the Mount Black Fault, and a narrow elongate belt about 7 km long by 0.5 to 0.75 km wide extending from the northwest side of Mount Jackson north-northeast along McLeods Ridge.

Lithology

The Rolling Grounds Latite mostly consists of dark green to grey lava of andesitic composition. Several tuffaceous rocks of more acid composition are associated with the latite.

The latite comprises dark green pyroxene phenocrysts up to 3 mm long, and rarer pale green feldspar phenocrysts up to 4 mm long, in a very dark green or grey groundmass. Exposed surfaces have a thin (2 to 4 mm) brown weathered crust with a rough surface texture.

The feldspar phenocrysts are commonly embayed and strongly altered, generally making identification impossible, but specimens from north of Mount Jackson contain plagioclase of labradorite composition. Augite ($2V_z$ = 40-45^o) occurs as common (10-15%) euhedral phenocrysts up to 2 mm and embayed grains up to 3 mm; the grains are colourless to very pale green and are unaltered, though in specimens from north of Mount Jackson the augite is completely uralitised. Minor exsolution lamellae parallel to (100) are common in the augite. Phenocrysts of a completely altered mineral of pyroxene habit are slightly less common; its alteration - to chlorite and talc - resembles that of orthopyroxene in the Coolamine Igneous Complex, so it is almost certain that the altered phenocrysts were originally orthopyroxene. Stevens (1958b) and Legg (1968) reported quartz as rare phenocrysts, but the only quartz that we observed was a few grains up to 0.3 mm - possibly alteration products rather than phenocrysts - in the groundmass of a sample from north of Mount Jackson (grid ref. 547658). Pyrite, which is common in the latite north of Mount Jackson, consititutes about 5% of a sample from grid reference 545654, in which it forms irregular grains less than 0.1 mm, and euhedral grains up to 0.3 mm in clusters of six or more.

The groundmass of the latite is extremely fine-grained and only small feldspar laths, commonly roughly aligned and with flow tendency around phenocrysts, are visible. Staining with sodium cobaltinitrite and sodium thiocyanate indicates roughly equal amounts of both alkali feldspar and plagioclase in the groundmass. X-ray diffractometry indicates that the alkali feldspar is sanidine and must be of high-temperature magmatic origin.

Relations and age

The Rolling Grounds Latite unconformably overlies the Upper Silurian Cooleman Limestone and Blue Waterhole Formation, and is therefore no older than latest Silurian. It conformably underlies the Mountain Creek Volcanics north of Mount Jackson and on Rolling Ground Ridge. As the Mountain Creek Volcanics are conformably overlain by Lower Devonian limestone, and are unconformably underlain by Upper Silurian rocks near Wee Jasper (Pedder, Jackson, & Philip, 1970, p. 207) and probably by lowest Devonian strata at Bowning in YASS (Link, 1970), an Early Devonian age for the Rolling Grounds Latite is almost certain.

The relation between the Rolling Grounds Latite and the overlying Mountain Creek Volcanics is complex. North of Mount Jackson they appear to be conformable, but in the Goodradigbee valley the Mountain Creek Volcanics directly overlie the Blue Waterhole Formation, and the Rolling Grounds Latite is absent. The latite probably forms a conformable wedge which thins towards the east.

The relation between the Rolling Grounds Latite and the Kellys Plain Volcanics is uncertain from field evidence, though a two-pyroxene andesite dyke similar to the Rolling Grounds Latite intrudes the Kellys Plain Volcanics at grid reference 472353. We consider that the Rolling Grounds Latite is younger than the Kellys Plain Volcanics as it is chemically similar to the Coolamine Igneous Complex, which intrudes the Kellys Plain Volcanics.

The Rolling Grounds Latite occupies a similar stratigraphic position to the Pilleuil Andesite in YASS (Pogson & Baker, 1974). Our sampling and chemical analyses of both units show that the two have similar mineralogy and chemistry. The mineralogy is identical except that the Pilleuil Andesite contains sparse resorbed quartz phenocrysts (?xenocrysts), and a little less sanidine in the groundmass.

Thickness

The latite in a few places shows columnar jointing or flow structure which indicate that the lavas are in general almost horizontal. Its minimum thickness is 140 m east of Coolamine, and probably slightly more on Rolling Ground Ridge. On McLeods Ridge, flow structure in the Mountain Creek Volcanics conformably overlying the Rolling Grounds Latite indicates dips of up to 80° to the east; here, the Rolling Grounds Latite is probably about 250 m thick, but thins to nothing only 1.5 km to the east at Basin Creek.

Mountain Creek Volcanics

Nomenclature

Walpole (1949, unpublished manuscript) first studied the Mountain Creek Volcanics in the northern Brindabella Range. Joplin & others (1953) first published the name Mountain Creek Volcanics, using it in the same sense as Walpole for the basal unit of the Black Range 'Series'. Browne (1959) used the term Mountain Creek Tuff in a different sense, referring to the upper part of the Black Range 'Series', and introduced the term Narrangullen Rhyolite for the basal unit of the Black Range 'Series'. Packham (1969) and Pedder & others (1970) followed the nomenclature of Browne, but Best & others (1964) and Strusz (1971) used the nomenclature of Walpole and Joplin & others. We here retain the name Mountain Creek Volcanics in the sense of Joplin & others (1953), as their nomenclature has priority over that of Browne (1959).

We do not use the name Black Range 'Series', or Group, as has been used in the past to combine the Mountain Creek Volcanics, Kirawin Formation, and Sugarloaf Creek Formation, as we do not think these three units are sufficiently similar to be grouped together: the Mountain Creek Volcanics are mainly subaerial rhyolite flows, ignimbrites, and pyroclastics; the Kirawin Formation is a mudstone from a restricted marine environment; and the Sugarloaf Creek Formation is a sandstone derived mainly by the erosion of the Mountain Creek Volcanics.

Derivation of name

The name was presumably derived from Mountain Creek, a stream which drains much of the northern Brindabella Range and flows into the Murrumbidgee River west of Taemas Bridge.

Type section

As no type section has previously been proposed, we nominate the power transmission line road between grid references 643939 and 604928 as the type section (Table M12). Although this section does not include the base or top of the succession it conveniently displays the most abundant rock types. The bottom of the succession is best exposed along Pabral Road between grid references 666907 and 650926, and the top of the succession is best exposed along Mountain Creek between grid references 633146 and 645152. The part of the succession below that exposed in the type section contains two mappable rock types: quartz-feldspar porphyry (Dlm_2) and pink massive granophyric rhyolite (Dlm_3). The porphyry is well exposed on Pabral Road and on the track to the top of Mount Coree, and the best exposure of the granophyric rhyolite is at the top of Mount Coree.

The type section can be summarised as consisting of three units: 1000 m or more of mainly massive ignimbrite, followed by over 1000 m of tuffs and reworked tuffs, which are overlain by flow-banded rhyolite lavas whose thickness probably exceeds 300 m.

Field occurrence

The Mountain Creek Volcanics form a meridional belt which occupies much of the Brindabella Range and Goodradigbee valley between Cooleman Plain in the south and Mount Narrangullen in the north, a strike length of 60 km. The maximum width of the belt, 15 km, is east of Wee Jasper.

In the Cooleman Plain area, outliers of the Mountain Creek Volcanics crop out over areas of 1 km^2 east of Coolamine homestead and more than 2 km^2 on Rolling Ground Ridge. A distinct belt of Mountain Creek Volcanics 1 to 2 km wide continues northward from north of Uriarra to meet the main belt near Vimy Ridge. A small outlier about 200 m wide crops out at grid reference 735123, 2.3 km southeast of Vimy Ridge.

TABLE M12. TYPE SECTION OF THE MOUNTAIN CREEK VOLCANICS

Approximate distance along road from start (m)	Geographical description	Geological description
0	Start of section at road junction (grid ref. 643939); section runs SW along road	Scattered float of green ignimbrite
520	Good outcrop on north side of road	Green massive ignimbrite with 10% of 1 mm pink albitised plagioclase phenocrysts; weak banding dips steeply west ($\geqslant 80^{o}$)
1800	Road bends north 50 m above creek; section follows road down to creek crossing	Green ignimbrite faulted against interbedded tuff, silt-stone, agglomerate, and rhyolite flows; one rhyolite flow has a brecciated base indicating younging to the west; dip vertical
2000	Ford over creek	Interbedded pale tuff and agglomerate
2500		Fine-grained cleaved dark green tuff
2700		Interbedded tuff and feldspathic siltstone
2900	Ford over Flea Creek; road continues south	
3400	Road bends gradually west	Interbedded cleaved tuff and feldspathic siltstone; bedding strikes 160^{o} and dips 86^{o}W
4200	Half way to top of ridge	Tuffs give way to cleaved banded blue-grey to black rhyolite flows
4500		Flow banding in dark blue rhyolite strikes 260^{o} and dips 70^{o}S; cleavage strikes 180^{o} and dips vertically
4700		Flow banding in dark blue-grey rhyolite strikes 160^{o} and dips 65^{o}W
5300	Top of ridge; end of section (grid ref. 604928)	Cleaved blue-grey rhyolite lava

We have divided the Mountain Creek Volcanics into nine lithological units (Dlm_1 to Dlm_9 in BRINDABELLA); only one of these units (Dlm_7) is evident in TANTANGARA. Lithological differences distinguish the units in the field, but textural and mineralogical differences are evident too. The units do not correspond to a layered stratigraphic sequence; rather, some of the units form lenses, and facies changes are common.

<u>Dlm_1</u> is the most extensive unit in the lower part of the sequence around Mount Coree, Mount Blundell, and Devils Peak. It also crops out higher in the sequence in the Mountain Creek valley west of Baldy Range. It has been mapped south of Brindabella, where the Koorabri Fault cuts it out in the west. Here, also, it may be near the base of the sequence, if the Mountain Creek Volcanics are in the form of a syncline between the Koorabri and Goodradigbee Faults, but the evidence for a syncline is weak as it involves the extrapolation of dips from well to the north and south. The small outlier southeast of Vimy Ridge has also been mapped as Dlm_1.

In the main area of outcrop, Dlm_1 intertongues with Dlm_2 and Dlm_3, which thus divide Dlm_1 into three parts. The lowest part unconformably overlies the Nungar beds and the Condor Granodiorite near Condor Creek; the middle part overlies a unit of tuff and sediment and intertongues with Dlm_2 west of Mount Blundell; and the highest part overlies Dlm_2 and Dlm_3 in a northeast-trending belt that is 1.5 km wide west of Mount Coree and extends to Dingo Dell Flats. This highest part unconformably overlies the Nungar beds northwest of Piccadilly Circus, so all the underlying Dlm_1, Dlm_2, and Dlm_3 have lensed out: that is, a section 2000 m thick near Mount Blundell has disappeared only 7 km to the southwest.

Dlm_1 is mainly flow-banded and massive dark blue to black rhyolite. It is exposed mainly as angular blocks of talus less than 1 m across, but also as irregular outcrops several metres across, especially on some of the steeper slopes and in creek sections. Exposures are semicontinuous on the eastern side of Devils Peak, and in Mountain Creek between grid references 652039 and 656039. The rhyolite is fresh and glassy, breaks with a splintery or conchoidal fracture, and has a grey to pale brown weathered surface only a few millimetres thick. The flow banding is a very penetrative feature, and, where exposures are good, individual bands less than 1 cm thick persist for several metres. Most bands are less than 5 mm thick and pale pink, and are separated from adjacent bands by several centimetres of massive dark blue to black rhyolite. The banding is mostly planar and is best exposed at grid reference 655039. In some exposures banding is only poorly represented, if at all. At a few localities (e.g., grid ref. 652039) the banding is chaotic or strongly folded. As the banding is so penetrative - differing from that produced by the flattening of pumice fragments and shards in ignimbrites - the rocks must have been lavas. Columnar jointing is rare. In a few places, fine tuff and reworked volcanic arenites are interbedded with the lavas.

In hand specimen the only phenocrysts commonly visible in the lavas are about 5% of euhedral white feldspar crystals about 1 mm across. Mafic phenocrysts less than 1 mm are evident on some weathered surfaces. Quartz phenocrysts are absent. A fine tuff bed at grid reference 664953 contains about 5% pyrite phenocrysts.

$\underline{Dlm_2}$ differs markedly from Dlm_1. It is a highly porphyritic ignimbrite with 10-15% quartz and 10% feldspar phenocrysts, and commonly also contains biotite visible in hand specimen. Flow banding is not evident.

Dlm_2 crops out in two separate belts: east of Mount Coree and, meridionally, across the Brindabella Road west of Piccadilly Circus. Both belts are in about the same stratigraphic position but are apparently discontinuous as the unit does not crop out northwest of Piccadilly Circus. The contact with Dlm_1 is apparently not exposed, but at grid reference 638898 Dlm_2 grades up over 20 m into Dlm_3 by a gradual decrease in phenocryst content.

In the field Dlm_2 is quite similar to the highly porphyritic Silurian volcanics to the east, as it is exposed as rounded tors and boulders and is commonly strongly weathered. Despite this resemblance it must be part of the Mountain Creek Volcanic sequence as it overlies the lowest part of Dlm_1.

$\underline{Dlm}$ occurs sporadically throughout the lower part of the Mountain Creek Volcanics in association with Dlm_1 and Dlm_2. Its main outcrop, at Mount Coree, is 3.5 km long and about 400 m thick. Smaller outcrops are 1.5 km east of Mount Coree, on the Brindabella Road west of Piccadilly Circus, in Baldy Range, and at grid references 632871, 655035, and 686056.

Dlm_3 is a massive unbanded or weakly banded pink rhyolite. West of Mount Coree it grades up into Dlm_1 by a gradual change from pink through purple to dark blue. Less than 5% pale pink feldspar phenocrysts are present but are difficult to see in hand specimen. Despite the good exposure at Mount Coree, no banding is evident. However, the rhyolite at grid reference 638899 is weakly banded. Quartz-feldspar porphyry and fine tuff xenoliths up to 15 cm across are common in Dlm_3 at Mount Coree; they may be from underlying parts of the Mountain Creek Volcanics. At the same locality, joint planes and cavities are commonly encrusted with purple fluorite and green epidote. At grid reference 625875 the overlying Dlm_1 unit contains xenoliths of a pink massive rhyolite similar to the Dlm_3 unit.

Dlm_4 is an extensive unit in the large northern area of the Mountain Creek Volcanics outcrop, where it tends to occupy the higher ground - e.g., the Brindabella Range near Mount Hartwood, Baldy Range, Dingi Dingi Range, Wombat Ridge, Mullion Gap Hill, and Mount Narrangullen. It overlies Dlm_1 west of Devils Peak, and forms the lower part of the type section. East of California Flats, California Creek and (to the south) Mountain Creek have cut through the unit to form rugged valleys; here the unit must be several thousand metres thick, yet it thins to nothing near Two Ewe Gap (grid ref. 580155) and southwest of Mount Coree.

Dlm_4 is a heterogeneous unit comprising flow-banded rhyolite lava, pyroclastic deposits, and minor reworked volcanic material, but by far the most abundant rock type is a hard massive green ignimbrite containing up to 10% (but mostly less than 5%) pale pink to reddish pink feldspar phenocrysts of about 1 mm. Eutaxitic layering and compacted pumice fragments are rare, so the massive rock resembles a massive lava in the field. The ignimbrite crops out as massive blocks and tors, in places up to 5 m high (e.g., grid ref. 585127). A widely spaced meridional cleavage or jointing is well developed, especially towards the west, where deformation has been more intense. At some localities (e.g., grid ref. 650950) amygdales of quartz up to 5 cm are common; elsewhere (e.g., grid ref. 632958) epidote veins and patches are present. At the foot of a power transmission line tower at grid reference 656951, the base of Dlm_4 consists of a well-exposed coarse agglomerate, in which fragments of ignimbrite up to 30 cm have apparently been tectonically stretched parallel to the regional cleavage.

Dlm_5 overlies Dlm_4 to the west, but like Dlm_4 it lenses out near Two Ewe Gap. Movement along a fault west of California Flats has thrust up and repeated part of the sequence of Dlm_4 and Dlm_5 to the west, in the Brindabella Range part way down the Goodradigbee River escarpment. Here Dlm_5 is overlain by a younger part of Dlm_4, which crops out on the eastern bank of the Goodradigbee River west of Webbs Range.

Dlm_5 consists of massive and flow-banded grey to dark blue rhyolite lava and minor ignimbrite, and is quite similar to Dlm_1 except that it is more strongly cleaved and weathered. Feldspar phenocrysts less than 1 mm are widely scattered (less than 3%), and indistinct in hand specimen. Planar flow banding is common and well exposed in the upper part of the type section. Elsewhere (e.g., grid ref. 603014) the banding is chaotic.

$\underline{Dlm_6}$, the most widespread unit in the Mountain Creek Volcanics, occupies about one-third of the total area of outcrop. It is composed almost entirely of pyroclastic deposits which crop out poorly and tend to erode more easily than the lavas and ignimbrites of the other units. This is well shown in the Flea Creek valley, where pyroclastics of Dlm_6 are flanked by lavas of Dlm_5 in Webbs Range to the west and by ignimbrites of Dlm_4 and lavas of Dlm_1 in the Brindabella Range to the east. Similarly Dlm_6 occupies the low country around Kangaroo Flat and Range View, and ignimbrite and lava occupy the higher elevations to the east and west.

The pyroclastic rocks have a great range of grainsizes, from fine ash to 30-cm bombs. Tuff with an average grainsize of less than 2 mm is the most common, but lapilli tuff is also abundant; both lack or contain only rare quartz. Good outcrops of lapilli tuff are at grid references 635098, 675132, 654112, and 666114. At grid reference 633126 an agglomerate bed 20 cm thick with bombs up to 10 cm is well exposed between beds of fine-grained tuff. Near the top of the Mountain Creek Volcanics at grid references 563131, 671137, and 642148 fine black mudstone identical to that of the Kirawin Formation is interbedded with Dlm_6. The Mountain Creek Volcanics must thus pass conformably into the Kirawin Formation.

Cleavage is well developed in the tuff - especially near the Long Plain and Koorabri Faults - more so than in adjacent lavas and ignimbrites. A number of folds can be traced from the overlying Kirawin Formation into the Mountain Creek Volcanics, and are concentrated in the northeast where Dlm_6 dominates the sequence. The thick massive units of Dlm_4 and Dlm_5 west of Mountain Creek have apparently acted together as a somewhat rigid block, deflecting the folding into the more easily deformed Dlm_6.

$\underline{Dlm_7}$ crops out only to the south of Brindabella. In BRINDABELLA it is composed of extremely cleaved interbedded blue-green and purple rhyolite, ignimbrite, and tuff, but farther south, in TANTANGARA, tuff is less common and cleavage much weaker. Dlm_7 conformably overlies the Rolling Grounds Latite on McLeods Ridge, and in the Rolling Ground Creek valley (where it forms a syncline), but east of Coolamine the latite was partly eroded before Dlm_7 was deposited, and in Basin Creek (grid ref. 550640) the latite is absent.

The ignimbrites and rhyolites in Dlm_7 are quite similar to those farther north, and contain sparse phenocrysts up to 1 mm of feldspar but not quartz. Columnar jointing roughly perpendicular to flow banding is common on McLeods Ridge. Near the Jackson Granite the Mountain Creek Volcanics have been strongly recrystallised and are much coarser-grained. At grid reference 536622, xenocrysts of pyroxene habit up to 10 mm, and xenoliths of amphibolite up to 2 m, occur in recrystallised rhyolite near the Jackson Granite. The xenocrysts are now amphibole because of contact metamorphism, and the amphibolite xenoliths were probably pyroxenite before metamorphism.

$\underline{Dlm}_8$ comprises small areas of strongly weathered, poorly exposed reworked tuff and feldspathic siltstone that crop out sporadically throughout the Mountain Creek Volcanics, mostly interbedded with pyroclastics. On of the most extensive siltstone units, along the western side of Blue Range, contains lead, zinc, silver, and copper mineralisation, and a little gold in quartz reefs in cross-cutting fractures (Carter, 1970). This siltstone unit crops out at grid reference 680945 on Blue Range Road as fine grey-green tuff with minor pyrite. A nearby tuff band (at grid ref. 664953) contains about 5% pyrite, but it is at a stratigraphically higher level than the main mineralisation.

$\underline{Dlm}_9$ crops out as an extensive meridional belt of the Mountain Creek Volcanics east of the Dingo Dell Fault near Kirawin and the Pig Hill Fault farther south. It comprises interbedded pink, green, and purple tuff, ignimbrite, siltstone, and sandstone. It unconformably overlies Silurian felsic volcanics and dips to the west at 30-50^o; as the Silurian volcanics also dip to the west the unconformity is not well marked.

The tuff and sediments are like those to the west of the Dingo Dell Fault, as quartz is rare to absent and clasts consist almost exclusively of feldspar and volcanic rock fragments, though a 15-mm rock fragment of pink granite in green tuff was collected from grid reference 733983.

Petrography

Although the units in the Mountain Creek Volcanics have overall mineralogical similarities, each is distinct enough to warrant a separate petrographic description.

$\underline{Dlm}_1$ contains between 1% and 5% of subhedral phenocrysts up to 1 mm of labradorite (An_{50-60}, some with oscillatory zoning) commonly aligned parallel to banding in the groundmass. Augite is a rare (less than 2%) but constant phenocryst phase, forming subhedral equant grains of about 1 mm; some are partly altered to pale green actinolite. Samples from grid references 736122 and 690007 contain fresh augite, and other grains of pyroxene habit altered to chlorite, talc, actinolite, and epidote; these altered grains were probably orthopyroxene. Rounded opaque phenocrysts about 0.5 mm across are also present in most samples. A brecciated, albitised rock at grid reference 657951 contains no augite, but some of the abundant epidote grains may be pseudomorphing pyroxene.

The groundmass of samples of Dlm_1 consists of structureless devitrified glass and fine-grained opaques. Mesoscopic banding is evident owing to the differences in grainsize of the devitrification products. In some bands granophyric devitrification patches are up to 0.5 mm. The bands may be as narrow as 0.01 mm, but extend completely across a thin section and have sharp edges. The banding is too long for it to have been produced by the flattening of pumice fragments in ignimbrites, so it must have been caused by flowage of viscous lava.

$\underline{Dlm}_2$ is a distinctive unit because of the presence of 10-15% of quartz phenocrysts up to 4 mm across. Altered biotite (5%) and feldspar (10%) are also phenocryst phases. In some rocks the feldspar is orthoclase and in others saussuritised plagioclase. Some samples contain both feldspars, and in one such rock (at grid ref. 677950) the plagioclase is fresh and oscillatorily zoned about An_{50}. One quartz-plagioclase-biotite porphyry (at grid ref. 649918) contains a 0.7-mm euhedral pink garnet.

The groundmass is fragmental and has the well-developed eutaxitic layering typical of welded ignimbrites.

$\underline{Dlm}_3$ contains albitised plagioclase phenocrysts (less than 5%) up to 1 mm in a granophyric groundmass of quartz and feldspar. Some granophyric growths are up to 1 mm. Epidote is a common alteration product, apparently derived from the calcium released by the albitisation of the plagioclase phenocrysts. Mafic phenocrysts are not evident, though some epidote and chlorite patches may be their relics.

The massive granophyric texture and lack of flow banding in Dlm_3 rocks suggests that they cooled more slowly than the lavas of Dlm_1. They may represent rhyolite domes that did not quite reach the surface. If so, their gradational contact with Dlm_1 west of Mount Cor-e may indicate that one such rhyolite dome (Dlm_3) flowed out onto the surface as lava (Dlm_1).

Most samples of $\underline{Dlm}_4$ are ignimbrites with a fragmental groundmass and eutaxitic layering. Albitised plagioclase is the only common phenocryst, but rarely exceeds 5-10% of the rock. Either calcite or epidote alteration accompanies the albitised plagioclase. Mafic phenocrysts are virtually absent, but a few samples contain patches of opaques, chlorite, and a dark green biotite. One sample from grid reference 632958 contains epidote, probably after pyroxene. Some samples contain fairly structureless groundmasses and may be glassy lavas, and in one sample (from grid ref. 650950) the groundmass contains microlites of feldspar with a trachytic alignment. Glass shards and collapsed pumice fragments are evident in some ignimbrites, and a sample from grid reference 602103 contains well-preserved undeformed glass shards. Another from grid reference 640050 contains extremely flattened glass shards which have amalgamated and devitrified together into optically continuous patches of about 0.6 mm.

One petrographic feature of Dlm_1 and Dlm_4 evide[illegible] in hand specimens is the colour of the plagioclase phenocrysts: unalbitised labradorite in Dlm_1 is white, but albitised feldspar in Dlm_4 is reddish pink.

$\underline{Dlm}_5$, unlike Dlm_4, consists mostly of flow-banded lavas; ignimbrites are uncommon. Albitised plagioclase, accompanied by epidote or calcite, is the only common phenocryst, but opaques and patches of green biotite, chlorite, and epidote up to 0.5 mm are present in some samples. The lavas resemble those of Dlm_1, and commonly have a banded groundmass, but, in contrast to the Dlm_1 lavas, their plagioclase is albitised and pyroxene (if present) is altered to calcite, epidote, and chlorite.

Most samples collected of $\underline{Dlm}_6$ are fine to medium-grained tuffs. Some of the samples contain lava or ignimbrite rock fragments up to 10 mm across and are lapilli tuffs. Albitised plagioclase crystals are more common in the tuffs than in the ignimbrites and lavas, and one sample (from grid ref. 628081) is a crystal tuff with about 40% albite crystals of 1 mm. Apart from albite crystals the remainder of the pyroclastic fragments in all the tuffs are of lava and ignimbrite like those comprising the rest of the Mountain Creek Volcanics. Some samples contain opaque crystals, and samples from grid references 609811 and 589827 also contain about 5% augite crystals of 1 mm [illegible] Pyroxene is altered to chlorite and calcite in a sample from grid ref[illegible]045.

The matrix of the tuffs from Dlm_6 contains abundant epidote, calcite, chlorite, and unidentifiable ash. Fine-grained tuffs from some localities (such as grid ref. 622932 in the type section) are almost entirely epidote, calcite, and chlorite.

One thin lava band interbedded with Dlm_6 from near the top of the Mountain Creek Volcanics at grid reference 670140 contains about 15% albitised plagioclase phenocrysts, 3% opaques, 1% fresh augite, and 1% altered pyroxene, possibly orthopyroxene.

Ignimbrite, lava, and tuff in $\underline{Dlm}_7$ are similar to those in the other units. Augite or altered pyroxene is present in most samples, and labradorite is more common than albitised plagioclase. One sample from adjacent to the Jackson Granite (grid ref. 531625) has been hornfelsed to a granoblastic aggregate of quartz, feldspar, and biotite, and pyroxene phenocrysts have been altered to actinolite peppered with opaques.

Sandstones and siltstones in $\underline{Dlm}_8$ are poorly sorted and feldspar-rich. The sandstone associated with the mineralisation west of Blue Range contains more abundant quartz up to 1 mm and also much pyrite.

Samples of $\underline{Dlm}_9$ are almost entirely feldspar-bearing tuffs like those from Dlm_6, but also include albite sandstone. One sample (from grid ref. 736955) is a welded ignimbrite with about 5% albite phenocrysts, and 2% pyroxene phenocrysts completely altered to bastite or uralite; the two alteration products suggest that both clinopyroxene and orthopyroxene were present.

Field relations and age

The stratigraphic position of the Mountain Creek Volcanics is precisely known. Near Cooleman Plain the volcanics rest unconformbaly on uppermost Silurian Blue Waterhole Formation and Cooleman Limestone. They also overlie the mineralogically similar Rolling Grounds Latite, but some of the latite may have been eroded before the basal Mountain Creek Volcanics was deposited. To the east the volcanics unconformably overlie the Upper Silurian Laidlaw and Uriarra Volcanics. At Bowning Hill (YASS) andesite correlatable with the Rolling Grounds Latite, and rhyolite correlatable with the Mountain Creek Volcanics, unconformably overlie lowermost Devonian strata (Link, 1970). The top of the Mountain Creek Volcanics is conformable with the overlying Kirawin Formation, which passes up through the Sugarloaf Creek Formation into the Lower Devonian (Pragian) Cavan Limestone. Thus the Mountain Creek Volcanics must be Lochkovian, and may extend up into the Pragian.

Thickness

If our mapping is correct the Mountain Creek Volcanics must be extremely thick where Dlm_4 and Dlm_5 are well developed. Between Condor Creek and the Goodradigbee River near Wee Jasper, the Mountain Creek Volcanics dip to the west, and only along their western edge is there any repetition of the sequence by faulting. If an average dip of 60^o is assumed then the volcanics in this area would be about 8000 m thick. This figure is probably excessive, however, and a figure of around 5000 m is more likely if unmapped minor faults and dip reversals are taken into account. To the north and south where tuffs predominate the Mountain Creek Volcanics thin markedly. Thus a section running west from Dingo Dell Flat up to the Kirawin Formation would include tuff and about 4000 m of lavas and ignimbrites, but a similar section running north from Dingo Dell Flat, allowing for folding, would only contain about 1300 m of tuff, very minor ignimbrite, and no lava. East of Brindabella, if a syncline is assumed, the tuff is about 1500 m thick. Farther south, in TANTANGARA, where lava and ignimbrite again predominate, the Mountain Creek Volcanics are only about 500 m thick, but an unknown amount has been removed by erosion.

Environment of deposition

The Mountain Creek Volcanics must be almost entirely terrestrial. Great thicknesses of lava and ignimbrite have accumulated northwest of Condor Creek, but these thin markedly northward and southward into airborne and reworked tuff deposits. The interbedding of lavas, tuffs, and ignimbrites, and the marked thickening and thinning of units, may indicate that the rocks accumulated as a large stratovolcano. Widely scattered small areas of sediment probably represent lacustrine and fluviatile beds deposited on the flanks of the volcano, and the pyroclastics predominate away from the eruptive centre. A second volcano that probably built up in the Cooleman area has largely been removed by erosion; the Coolamine Igneous Complex plutons probably represent the roots of this volcanic centre, as they are almost certainly the intrusive equivalents of the Rolling Grounds Latite.

SILURO-DEVONIAN GRANITOIDS

Many granitoid bodies appear to be associated with the Siluro-Devonian felsic volcanics described above. These bodies can be put into several groups according to their age and mineralogy, which can in turn be related to similar volcanic groups. Where a volcanic unit is adjacent to a related granitoid, the granitoid is always the younger - as for the Young Batholith and Goobarragandra Volcanics, the Murrumbidgee Batholith and Paddys River Volcanics, the Ginninderra Porphyry and Laidlaw Volcanics, and the Jackson Granite and Mountain Creek Volcanics.

The earliest and most common plutons of the Young, Murrumbidgee, Gingera, and Kosciusko Batholiths are S-type, according to the criteria of Chappell & White (1974). Likewise the earliest volcanics - Goobarragandra Paddys River, Hawkins, and Walker Volcanics - are also S-type.

Where age relations can be established, such as in the Gingera and Murrumbidgee Batholiths, I-type (Chappell & White, 1974) plutons postdate the youngest S-type plutons. One phase of I-type plutonism (Bugtown Tonalite, tonalite of Ashvale, related stocks and dykes, and possibly the Condor Granodiorite) andedates the Bowning fold episode, and is related to the Jindabyne Suite of I-type granitoids discussed by Hine & others (1978); these plutons have some chemical similarities to the Laidlaw and Uriarra Volcanics.

A second phase of I-type plutonism, which is geographically, mineralogically, and chemically distinct from the earliest phase, postdates the Bowning fold episode and is of Early Devonian age. The Rolling Grounds Latite and Mountain Creek Volcanics are related to this plutonism. The largest plutons in the group are the Boggy Plain Adamellite, Coolamine Igneous Complex, Jackson Granite, and Burrinjuck Adamellite. We use the name Boggy Plain Suite to describe the group as a whole, including the related volcanics.

MURRUMBIDGEE BATHOLITH

Clarke (1860) first reported on rocks of the Murrumbidgee Batholith. Mahony & Taylor (1913) mentioned the granite near Tharwa (MICHELAGO) in their report on the Federal Territory. Browne (1914, 1931, 1944) described the rocks of the southern and eastern part of the batholith, and distinguished blue, white, and pink gneiss. Joplin (1943) was the first to carry out chemical analyses of the blue and white gneisses, which she described petrographically.

Snelling (1960) divided the rocks of the batholith into three different groups: Uncontaminated Granites, Contaminated Granites, and Leucogranites. He considered that the Uncontaminated Granites closely represent the composition of the parental magma of the batholith; that the Contaminated Granites were derived from this parental magma by assimilation of country rocks; and that the Leucogranites were formed by differentiation of this contaminated magma. The three types earlier defined by Browne do not correspond to the classification by Snelling, and will not be considered further.

Joyce (1970, 1973) used the same classification as Snelling. He concluded, mainly on chemical evidence, that all three groups were derived from the partial melting of psammopelitic rocks of the Tasman Geosyncline; and that the Uncontaminated Granites and Leucogranites were formed by the fractional crystallisation of this parental magma, which gave rise to the Contaminated Granites after it had assimilated relict solid material (xenoliths).

Work by White & Chappell (1976) on the Berridale Batholith (south of TANTANGARA) and other batholiths in New South Wales has lead them to the conclusion that the abundant xenoliths in 'contaminated' granites are not partly assimilated country rock but residual source material brought up with the melt fraction, so that the term 'contaminated' is inappropriate, as it implies a foreign origin (unrelated to the granitoid magma) for the xenoliths. The progressive removal of these xenoliths (and possibly xenocrysts) from the magma to produce more and more felsic magmas is an unmixing process, and is related to the viscosity and speed of intrusion of the magma: plutons which are intruded relatively rapidly contain more abundant residual source material, whereas those intruded more slowly are more felsic because their xenoliths had more time to settle out. We therefore propose to abandon Snelling's (1960) classification into three groups. Although a three-fold classification is appropriate for the Murrumbidgee Batholith, it is not suitable as a general classification for all Lachlan Fold Belt batholiths, which should reveal a broad spectrum of compositions between two end members - one of pure melt composition and the other of pure source rock composition.

Because of the large amount of previous work done on the Murrumbidgee Batholith, our work has been confined to a more accurate mapping of its contacts, and an examination of small unnamed intrusions. We have done little additional work on the larger named intrusions unless to solve some problems outlined by previous workers. These larger intrusions are briefly described below.

Bolairo Granodiorite

The Bolairo Granodiorite forms an irregular intrusion north of Bolaro (grid ref. 656168). Outcrops commonly comprise well-rounded unweathered boulders up to 3 m. Discoidal pelitic xenoliths are numerous, and lie parallel to a north-south foliation. Vertical fractures, also north-south, are locally abundant. The contact of the granodiorite with the Yaouk Leucogranite is faulted, but it is intruded by the Westerly Leucogranite northeast of Yarra Glen. Part of it is overlain by Tertiary ferricrete.

In hand specimen this medium-grained rock is dark because of its high biotite content. Blue quartz and plagioclase are also evident. Near the margin of the intrusion the rock tends to be darker than in the centre.

The Bolairo Granodiorite in thin section is similar to the Callemondah Granodiorite, Willoona Tonalite, and Clear Range Granodiorite. Therefore the following description applies in general to all four. The texture is uneven-grained hypidiomorphic. Cataclastic effects are common: quartz and microcline are often granulated, and biotite flakes are bent and ragged. Quartz forms subhedral grains, up to 5 mm, with undulose extinction. Zoned plagioclase, partly altered to sericite and saussurite, forms subhedral prisms up to 5 mm; the oscillatorily zoned cores have a composition of An_{50} or more, whereas the margins are more sodic. Microcline forms rare anhedral poikilitic grains up to 3 mm; crosshatch twinning is common. Biotite forms subhedral flakes, up to 3 mm, with ragged edges; bent lamellae are common. Small secondary muscovite flakes and minor chlorite and epidote occur as alteration products. Biotite is pleochroic: X = light yellow, Y = Z = deep reddish brown. Patches of sericite flakes, commonly with a subhedral rectangular shape up to 6 x 4 mm and containing biotite and plagioclase inclusions, are probably pseudomorphs of cordierite. Apatite, zircon, and opaques occur as accessories and are common in the biotite.

A smaple from near the margin of the Bolairo Granodiorite showed medium-grained quartz, plagioclase, and biotite in a strongly foliated groundmass of quartz, feldspar, and mica. Microcline is completely altered, and white plagioclase grains are altered to sericite and saussurite, often with a thin rim of fresh plagioclase.

Willoona Tonalite

The Willoona Tonalite forms an irregular, lenticular, meridionally trending body west of Girraween (grid ref. 754210). Its northern boundary with the Yaouk Leucogranite is a fault; the other boundaries are intrusive. Sedimentary screens form ridges on both sides of the intrusion. These sediments contain andalusite, which is probably a contact-metamorphic product of one of the bordering intrusions.

In outcrop the tonalite is generally fresh, forming small angular and well-jointed boulders up to 2 m. A north-south foliation is obvious in outcrops, but less clear in hand specimen and thin section. In general appearance the rock is somewhat darker than the Bolairo Granodiorite, and contains more xenoliths.

Callemondah Granodiorite

The Callemondah Granodiorite forms an irregular intrusion elongated north-south, 11 km long and 2 to 3 km wide, east and northeast of Shannons Flat. It is well exposed as generally unweathered boulders, rarely larger than 1.5 m, which are elongate parallel to the pervasive strong meridional foliation.

It is intruded by the Shannons Flat Adamellite, which has partly recrystallised it at grid reference 773267: the biotite now occurs as a mosaic of smaller flakes, and the quartz is composite too, but the plagioclase is little changed. Ghost-like schlieren of the granodiorite, up to 30 cm long, occur in the Shannons Flat Adamellite near the contact at grid reference 771272.

Clear Range Granodiorite

Only a small part of this large xenolith-rich pluton crops out in TANTANGARA. It is similar to the other granodiorites, but in TANTANGARA contains a little more microcline (about 7%).

It is intruded by the Shannons Flat Adamellite at grid reference 789560, where a dyke from the adamellite projects into the granodiorite (Fig. M24); a secondary foliation cuts the contact of the dyke and the granodiorite, and is superimposed on the granodiorite's primary foliation, defined by the alignment of pelitic xenoliths. Snelling (1960) and Joyce (1973) considered that the Clear Range Granodiorite grades into the Murrumbucka Tonalite to the south; our reconnaissance of that area supports this view.

Fig. M24. Contact of dyke-like apophysis (on the left of the freshly exposed surface, which is 20 cm wide) of the Shannons Flat Adamellite with the Clear Range Granodiorite at grid reference 789560.

(GB/1849)

Stewartsfield Granodiorite*

This body is separated from the rest of the batholith by Ordovician sediments and alluvium near Yaouk (grid ref. 629359). It is much richer in microcline (15%) than the other granodiorites in the Batholith, and could almost be termed an adamellite. It also contains fewer xenoliths, but in other respects is similar to the other granodiorites in mineralogy and texture. In one sample from (grid ref. 639336) a garnet xenocryst of 2 mm is strongly fractured and surrounded by a 1-mm-wide reaction rim of sericite and green biotite; green biotite also fills the fractures. The garnet is probably of metamorphic origin, a type II garnet of Birch & Gleadow (1974).

Shannons Flat Adamellite and Yaouk Leucogranite

Snelling (1960) and Joyce (1973) have mapped and described the Shannons Flat Adamellite and the Yaouk Leucogranite as separate units, but we found the contact between them difficult to map, and our interpretation of it on the TANTANGARA map may be unreliable. Our subsequent petrographic work did not supply us with sufficient evidence to convince us that the two types are indeed distinct intrusions, rather than just one laterally variable intrusion. However, the separately named units will be retained until the matter has been conclusively resolved.

The Shannons Flat Adamellite, regarded as a different unit from the Yaouk Leucogranite, is the biggest single intrusion of the batholith, cropping out as a lenticular body up to 15 km wide along the full length of the batholith. In its southern part it extends as a relatively narrow tongue 5 km south of Shannons Flat.

To the west, the Shannons Flat Adamellite intrudes the Upper Ordovician Adaminaby beds at the foot of the Tidbinbilla Range. To the north the boundary between the adamellite and the Adaminaby beds is irregular, and roof pendants crop out at Sugarloaf, Murrays Hill, and on the ridge west of Larrys Creek. As these roof pendants are aligned, they may be the remnants of a screen between separate intrusions of a similar composition, but we found no other evidence to support such a suggestion.

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* Note that the correct spelling of this name is 'Stewartsfield', <u>not</u> 'Stewartfield' as in the TANTANGARA map legend.

To the east the adamellite intrudes the Clear Range Granodiorite, the Paddys River Volcanics, and the Adaminaby beds, and is faulted against the Adaminaby beds by the Bullen Range Fault. An intrusive contact between the adamellite and volcanics is well exposed at grid reference 765873, and magnetite skarns with associated sulphides have developed along the boundary between the two at several localities - e.g., at grid reference 763881, where the skarns have partly replaced a limestone lens within the volcanics.

To the north the adamellite is cut off by the Winslade Fault, but the McDonald Granite Porphyry may be its northern continuation.

Numerous aplite dykes and leucogranite stocks intrude the adamellite south of Paddys River homestead and east of Gibralter Creek. Aplite dyke swarms occur in both radial and concentric patterns surrounding the leucogranite stocks. The dykes are commonly aligned parallel to joints in the adamellite. The most prominent orientation of the dykes is about 045°. Lineaments along Gibralter Creek, the upper Tidbinbilla River, and middle Blue Gum Creek - all in the Shannons Flat Adamellite - parallel this prominent dyke orientation.

The Shannons Flat Adamellite typically contains subhedral to euhedral alkali feldspar megacrysts about 20 mm (rarely to 50 mm) long and 5 to 10 mm wide. They are most distinct on the pinkish-brown weathering skin that develops on the adamellite. They are not evenly distributed throughout the adamellite: in places (e.g., grid ref. 807743) they are absent, and in other places they consitute about 20% of the rock; even in the one outcrop their distribution is irregular, especially where the megacrysts are abundant. At grid reference 767813, an aplite dyke, 10 m wide, contains alkali feldspar megacrysts up to 20 mm long with a similar morphology and in a similar proportion to those in the surrounding Shannons Flat Adamellite; several megacrysts at the boundary between the dyke and adamellite cut across it unchanged. Again, at grid reference 754718 sporadic rounded megacrysts about 20 mm across occur in xenoliths and rhyodacite dykes in the Shannons Flat Adamellite; they are similar in abundance and morphology to those in the surrounding adamellite, and one cuts across an adamellite-xenolith boundary. From these field observations, we conclude that the alkali feldspar megacrysts in the Shannons Flat Adamellite are not phenocrysts, but are most likely to be of late metasomatic origin postdating the major crystallisation of the magma.

Hand specimens of the Shannons Flat Adamellite are medium to coarse-grained, grey-white, and contain clots of biotite constituting about 5 to 10% of the rock. Quartz is commonly rounded and about 4 mm in diameter. Potash feldspar is white with a pale pinkish tinge, and commonly occurs as megacrysts. Plagioclase is white, commonly with yellow to greenish cores, subhedral, and up to 4 mm.

The biotite content appears to be highest towards the north - 15% near Miowera (grid ref. 802760) and on the Corin Dam road at grid reference 739695 - and gradually decreases southward - to only 5 to 7% near Shannons Flat. Near Mount Kelly and west of Gudgenby Hill, a probable gradational contact between the adamellite and the Yaouk Leucogranite is concomitant with a gradual decrease in biotite to about 4% in the leucogranite.

At many localities, biotite schlieren define a foliation. At one locality (grid ref. 789560), a secondary foliation cutting across an intrusive contact between the Shannons Flat Adamellite and Clear Range Granodiorite must be younger than both bodies.

Joints, usually spaced about 5 to 10 m apart, are common in the Shannons Flat Adamellite. The only prominent direction that we established is in the area west of Gibralter Falls (grid ref. 753710), where the joints are vertical and strike at about 090°.

Xenoliths are uncommon in the Shannons Flat Adamellite; unlike those in the granodiorites, they appear to be accidental inclusions rather than cognate xenoliths. The adamellite in cuttings on the Honeysuckle Creek road contains several angular blocks up to 5 m which include hornfelsed sediments, a leucogranite, and, the largest one, a quartz-feldspar porphyry not unlike the volcanic rocks in the Canberra region.

Contact effects of the adamellite on the surrounding Ordovician sediments are only minor. They are best developed near the contact northwest of the Tidbinbilla Nature Reserve, where a tongue of sediments over 1 km wide is almost completely surrounded by adamellite. Spotted cordierite hornfels and recrystallised quartz sandstone crop out within about 100 m of the contact. A pelite at grid reference 728757 contains pinite spots of about 0.5 mm surrounded by a matrix rich in biotite and muscovite, and a metasandstone at grid reference 718766 contains overgrown rounded quartz grains in a matrix with abundant metamorphic biotite flakes about 0.04 mm long.

The Yaouk Leucogranite has been mapped west of the Shannons Flat Adamellite as a south-trending intrusion that is 3 to 10 km wide and extends from the southern boundary of TANTANGARA almost to the Cotter Hut (grid ref. 657530) - a considerably smaller area than the Shannons Flat Adamellite. Exposures are similar to those in the adamellite, except that weathering is deeper. Texture and grainsize are also similar, and like the adamellite the Yaouk Leucogranite contains prominent alkali feldspar megacrysts. In the southwest of its outcrop, later intrusions of fine-grained leucogranite form up to 50% of the exposed rock types.

Petrography

Modal analyses of the Shannons Flat Adamellite and Yaouk Leucogranite by previous workers have given a wide range of results. The average that we derived for the adamellite from the point-counting of three stained slabs of about 50 cm^2 area is: quartz 44%, microcline 35%, plagioclase 16%, and biotite 5%; biotite and microcline probably vary by up to 10% in samples from different locations. Similarly, the average that we derived for three samples from the Yaouk Leucogranite is: quartz 34%, microcline 43%, plagioclase 19%, and mica 4%. Joyce's (1973) modal analyses of the Shannons Flat Adamellite had more plagioclase and biotite and less quartz and microcline. His modal analysis of the Yaouk Leucogranite had more quartz and less microcline, and is intermediate in composition to our analyses of the Shannons Flat Adamellite and Yaouk Leucogranite. As no real boundary between the two rock types could be mapped in the field, rocks of intermediate composition should be expected.

The Shannons Flat Adamellite contains subhedral microcline megacrysts, rarely up to 50 x 10 mm, in a coarse-grained groundmass of perthitic anhedral microcline (4 mm), slightly rounded undulose quartz (4 mm), stumpy subhedral prismatic crystals of plagioclase (about 2 mm), and strained, partly chloritised and epidotised biotite clots (up to 2 mm). The plagioclase is strongly zoned with partly sericitised An_{55} cores and albite-oligoclase rims. The groundmass microcline is more perthitic than the megacrysts. Biotite is pleochroic from pale yellow-brown to red-brown. Apatite, zircon and opaques are rare.

Most samples of the Shannons Flat Adamellite show some form of deformation, such as bent and broken biotite flakes, and quartz with markedly undulose extinction. Some are highly deformed: quartz is recrystallised into a mosaic with sutured internal boundaries, and biotite is broken and recrystallised and has a few flakes of secondary muscovite surrounding it.

Samples with more biotite (as from grid ref. 739695) contain less microcline and are almost granodioritic in composition. Apatite, zircon, and opaques associated with the biotite are much more abundant than in samples with less biotite.

The Yaouk Leucogranite has similar textures to the Shannons Flat Adamellite, and has been similarly deformed. Plagioclase cores are commonly highly sericitised, but when fresh exhibit oscillatory zoning up to An_{50} and albitic rims somewhat broader than in the adamellite. Muscovite is the main mica in most samples, and in some samples biotite is absent.

In summary, owing to the lack of conclusive evidence in support of the published hypothesis that the two rock types represent two different intrusions, and as a boundary between the two is not clearly defined, we suspect that the Shannons Flat Adamellite and Yaouk Leucogranite form one intrusion showing systematic mineralogical changes from most mafic in the area east of Corin Dam to more felsic northwards and especially southwards.

Westerly Leucogranite

The Westerly Leucogranite crops out as a meridional dyke-like body about 1 km wide at the western boundary of the Yaouk Leucogranite northwest of Ashvale (grid ref. 695165), and also as a small wedge 1 km northeast of Yarra Glen. It has been intruded by a hornblende-biotite tonalite northeast of Ashvale. It varies in structure and in mineralogy, and so can be treated as a series of leucogranitic intrusions, of which three types are distinguished.

The most common type is a fine to medium-grained, equigranular rock with a saccharoidal texture. In hand specimen, quartz, feldspar, biotite, muscovite, and in places garnet are evident. In thin section, the texture is distinctly glomerogranular, comprising clusters of feldspar and micas set in quartz. Quartz forms anhedral grains up to 1 mm in clusters up to 4 mm. Plagioclase (An_{10}) forms short prismatic euhedral grains up to 2 mm, only slightly altered to sericite and saussurite. Microcline forms slightly perthitic anhedral grains up to 2 mm; crosshatch-twinning is common. Muscovite up to 2 mm is anhedral and often associated with biotite, which forms recrystallised euhedral flakes up to 1 mm partly or completely altered to opaques and muscovite. Biotite is pleochroic: X = light yellow, Y = Z = dark brownish green. Euhedral garnet up to 1 mm, andalusite (enclosed in muscovite), zircon, and opaques are accessories. The texture and mineralogy (greenish recrystallised biotite, garnet, and andalusite) of this variety are similar to those of the Gang Gang Adamellite in the contact aureole of the Boggy Plain Adamellite, and we suspect that the rock has been hornfelsed by the later hornblende-biotite tonalite east of the leucogranite.

A less common type of leucogranite, with the same mineralogy as the first type, contains phenocrysts of quartz up to 10 mm and microcline up to 20 mm.

The third type is highly weathered, so no thin sections of it were cut. It has conspicuous clots of biotite and muscovite up to 1 cm, and some quartz and feldspar phenocrysts, set in a fine-grained groundmass of quartz, feldspar, and mica. It crops out mainly in the northern part of the Westerly Leucogranite. In its southern part, a large muscovite-bearing quartz vein with a vertical foliation cuts it.

These leucogranites contain few xenoliths, and the only evident foliation is that in the muscovite-bearing quartz vein. The leucogranites have a variety of outcrop styles: on the gentle slopes, groups of small boulders up to 2 m are common; on steeper slopes bigger boulders and bare faces of granite crop out. Exposures are generally moderately to highly weathered.

Contacts with other rock types are intrusive, except for a small section of the wedge-shaped body northeast of Yarra Glen, whose boundaries with the Yaouk Leucogranite and Ordovician sediments are faulted.

In a sample from grid reference 673230 a dark medium-grained inclusion thought to be of the Bolairo Granodiorite would indicate that the Westerly Leucogranite is younger than the Bolairo Granodiorite.

Many dykes and bosses of fine-grained leucogranite similar to the Westerly Leucogranite intrude the Yaouk Leucogranite in the southwestern part of its cutcrop, but these are too small to show on the map.

McDonald Granite Porphyry

Nomenclature

Malcolm (1954) introduced the name McDonald Granite for a high-level sill-like body intruding the Uriarra Volcanics. Because it is porphyritic, we prefer the name McDonald Granite Porphyry.

Derivation of name

The name is derived from McDonald Hill trig station (grid ref. 765909, 1.4 km north of Cotter Dam.

Type locality

The type locality is here designated as a quarry on a forestry road about 900 m northwest of McDonald Hill trig station and 1 km southeast of Uriarra Forestry Settlement, at grid reference 757915. Here, highly weathered granite porphyry boulders crop out on the quarry floor, and bulldozing has uncovered granite surfaces.

Field occurrence

The McDonald Granite Porphyry intrudes the Uriarra and Walker Volcanics north of Cotter Dam in two separate areas: on the slopes of McDonald Hill, and in a narrow belt which can be traced north for about 2.5 km from the type locality. On the slopes of McDonald Hill, the body is about 1.5 km long and 0.5 km wide, and is roughly conformable with the surrounding Walker Volcanics. In the north-trending belt, the body is about 100 to 150 m wide, dips at about 20° to the west, and for the most part is conformable beneath the Tarpaulin Creek Ashstone Member, which, however, it cuts across near the type locality; to the north it is displaced by two minor cross-faults, and is finally cut out by a fault at grid reference 761936.

The McDonald Granite Porphyry crops out poorly as rubbly float and in highly weathered road-cuts. Specimens are composed of about 30% euhedral pink potash feldspar megacrysts up to 40 x 14 mm, partly altered to clay, in a groundmass of granular quartz, weathered yellow-white feldspar, and rare leached biotite. The potash feldspar megacrysts are more abundant and better formed than those in the Shannons Flat Adamellite, but they probably formed in a similar way. The presence of these megacrysts is good evidence for the McDonald Granite Porphyry being an apophysis from the Shannons Flat Adamellite. Apophyses in the roof of larger intrusions are favourable environments for deuteric solutions to accumulate and megacrysts to grow.

Booroomba Leucogranite
(new name)

Nomenclature

Both Snelling (1960) and Joyce (1973) mapped small areas of leucogranite south of Paddys River homestead (grid ref. 790761), but their mapping did not indicate its full extent. In view of the now known greater extent of leucogranite the name Booroomba Leucogranite is introduced for a number of similar bodies which crop out near the junctions of BRINDABELLA, TANTANGARA, CANBERRA, and MICHELAGO. Richardson (in press) has described that part of the leucogranite which crops out in MICHELAGO.

Derivation of name

The name is taken from Booroomba homestead, at grid reference 792711 (BRINDABELLA).

Type locality

The type locality is on the western side of Blue Gum Creek at grid reference 800696 (TANTANGARA), 1.5 km south-southeast of Booroomba homestead. Here, medium-grained muscovite granite crops out as elongate slabs and low exposures up to 10 m wide in which vertical north-south jointing is well developed.

Field occurrence

In the mapped area, the Booroomba Leucogranite has four separate outcrops, which are probably linked at depth. The largest mass occupies the hilly country southeast of Corin Road and west of Booroomba homestead. It extends east into MICHELAGO, and north as far as Gibraltar homestead. Its total area of outcrop is about 45 km^2. The smaller masses are: 1) 1.5 km^2 on Paddys River Road southwest of Paddys River homestead; 2) about 5 km east-southeast of Smokers Gap; and 3) at Booroomba Rocks (grid ref. 803630).

The leucogranite crops out as rather angular blocks owing to its intensive jointing. Where the grainsize is fine, the joints are closely spaced, and the blocks are less than 1 m. Where the rock is coarse-grained, joints are more widely spaced, and boulders are more rounded and average about 2 to 3 m; some tors, however, are much larger.

The leucogranite intrudes the Shannons Flat Adamellite [illegible] two lenses of Upper Ordovician Adaminaby beds north of Booroomba. Surrounding the leucogranite is a multitude of aplite dykes, of which some persist for up to 2 km from the leucogranite. The dykes adjacent to the small northern leucogranite body strike at about 045°. On the western side of the large leucogranite body, aplite dykes parallel the leucogranite boundary, and near Gibralter Falls they occur sparsely in a prominent vertical east-west joint system within the Shannons Flat Adamellite; on the eastern side of this body the aplite dykes are rarer and strike north-south (e.g., at grid ref. 812702). At the southern end of the Gibralter Creek Pine Plantations, aplite dykes are so abundant near the margins of the leucogranite that they almost conceal the leucogranite boundary.

The grainsize ranges from very fine to medium: the margins and associated aplite dykes are much finer than the interior of the large body. The aplite dykes are commonly porphyritic with phenocrysts, 2 to 3 mm, of quartz, feldspar, and biotite in a very fine-grained pale pink groundmass. The leucogranite is commonly highly weathered, especially the coarser-grained samples, and is pale yellow-pink and quite friable (for a granitic rock). Finer-grained samples are less highly weathered and pale pink; they comprise pinkish grey quartz, pale pink feldspar, and small amounts of muscovite and less common biotite. Biotite is present only in fine-grained samples from near the margins of the bodies, and tends to be slightly porphyritic. In the coarser-grained samples muscovite commonly forms rosettes up to 10 mm.

Petrography

The Booroomba Leucogranite is a fine to medium-grained allotriomorphic equigranular rock with an average grainsize of about 3 mm. It is composed essentially of quartz (40%), microcline perthite (35%), and albite (15%). Muscovite forms interstitial flakes averaging 1 mm, and xenomorphic flakes within microcline perthite; it occupies up to 10% of the rock. Biotite (zero to 3%) is usually associated with muscovite, and epidote and opaques are also common interstitial accessories.

A sample from grid reference 759682 contains scattered subhedral grains of garnet, up to 0.3 mm, associated with biotite, epidote, and opaques. Joyce (1973) reported garnets with a high manganese content in leucogranites of the Murrumbidgee Batholith, and concluded that they precipitated as a primary mineral phase from a manganese-rich magma. The abundance and grainsize of the garnet in the Booroomba Leucogranite also suggest that it is a primary mineral phase, and not a xenocryst phase. Birch & Gleadow (1974) have distinguished two types of garnets in felsic volcanics in Victoria: their type I garnets consist of small euhedral garnets free of inclusions and supposedly crystallised directly from the magma; their type II garnets consist of larger, often irregularly shaped grains with abundant inclusions of biotite, apatite, opaques, and quartz, and are supposedly xenocrysts of metamorphic origin. The Booroomba Leucogranite garnets most resemble the type I garnets. Type II garnets also occur in the Murrumbidgee Batholith (see Stewartsfield Granodiorite).

Near the margins of the Booroomba Leucogranite and in many of the associated aplite dykes, the rock is porphyritic with phenocrysts of quartz, feldspar, and biotite. A sample from grid reference 801741 contains rounded partly resorbed phenocrysts of quartz up to 4 mm, deformed phenocrysts of biotite up to 4 mm, and common partly sericitised strongly zoned stumpy prismatic phenocrysts of plagioclase from 1 to 3 mm, in an allotriomorphic equigranular leucogranite groundmass with an average grainsize of 0.3 mm. The phenocrysts are similar in composition and morphology to quartz, biotite, and plagioclase grains in the enclosing Shannons Flat Adamellite, so they are probably contaminants derived from the Shannons Flat Adamellite.

Cow Flat Granite Porphyry

Snelling (1960) first published the name Cow Flat Granite for a high-level intrusion into the Tidbinbilla Quartzite, which together with the Adaminaby beds separates it from the main part of the Murrumbidgee Batholith. Cow Flat Granite Porphyry is a more appropriate name.

The intrusion is named after Cow Flats, on the Cotter River below Bendora Dam. The type locality is at grid reference 662762, on the Bendora water pipeline immediately south of the crossing of the Cotter River. At this locality a cutting for the pipeline has exposed abundant fresh boulders of the porphyry, whose natural outcrop is normally deeply weathered.

The rock is white to pale cream with conspicuous pale grey quartz phenocrysts of about 5 mm . The feldspar phenocrysts - plagioclase and perthitic orthoclase, which are the same colour as the groundmass - make up about 60% of the total rock. Minor biotite and sphene, both less than 0.2 mm, are the only mafic minerals present. The microgranitic groundmass comprises roughly equal proportions of quartz, potash feldspar, and albite of 0.1 mm average grainsize.

One sample (from grid ref. 660765) contains no potash feldspar phenocrysts, and is a leucodacite porphyry. Its only mafic grains are about 2% subhedral phenocrysts of sphene up to 2 mm. Clinozoisite is a common alteration product of the plagioclase.

Unnamed granitoids in the Murrumbidgee Batholith

Tonalite at Ashvale (Smt)

At grid reference 690175, about 1.5 km northwest of Ashvale, a small roughly L-shaped body of tonalite intrudes the Westerly Leucogranite at its boundary with the Yaouk Leucogranite. It is medium-grained and contains rare equidimensional pelitic inclusions. It generally crops out as well-rounded boulders up to 8 m which are fresh to slightly weathered. It has no distinctive fracture pattern and is only weakly foliated.

In hand specimen the tonalite is dark owing to its high biotite and hornblende content. The quartz is grey.

In thin section the texture is distinctly poikilitic: anhedral, weakly undulose quartz grains up to 3 mm enclose laths of randomly oriented plagioclase. The plagioclase forms euhedral laths up to 2 mm enclosed in quartz, biotite, and hornblende; it is oscillatorily zoned from An_{60} to An_{20}, and some cores are altered to sericite and saussurite. Hornblende (up to 2 mm) is subhedral and pleochroic: X = grass-green, Y = light green, and Z = yellowish green; the rims are generally darker than the cores, some of which are tremolite - possibly after augite. Biotite (up to 5 mm) is subhedral and partly altered to chlorite and epidote; it is pleochroic: X = light yellowish brown and Y = Z = dark brown, and commonly intergrown with hornblende. Zircon, apatite, and opaques are accessories. A modal analysis of the tonalite is included in Table M13.

This intrusion is clearly atypical of the Murrumbidgee Batholith: it contains hornblende and no alkali feldspar, is only weakly foliated, and intrudes the leucogranites, yet the other tonalites and granodiorites are strongly foliated and intruded by other plutons in the batholith. It closely resembles the Bugtown Tonalite, 15 km to the west, and the I-type granitoids of the Berridale and Kosciusko Batholiths to the south (Chappell & White, 1976).

Granodiorite at 677240 (Smi)

An elongate body of granodiorite crops out as subangular boulders ranging from 1 to 12 m 1.5 km northeast of Yarra Glen. The rock, which is not foliated, is medium-grained and generally equigranular, and contains scattered equidimensional pelitic xenoliths. The intrusion is at the boundary of the Yaouk Leucogranite with Ordovician sediments; field evidence suggests that it intrudes both.

In thin section the texture is hypidiomorphic. Quartz forms subhedral to anhedral grains up to 7 mm, and is sometimes myrmekitic. Plagioclase forms zoned euhedral to subhedral short prisms up to 3 mm; the composition of its rims is about An_{20}, and of its cores, most of which are altered to sericite and saussurite, about An_{40}. Microcline (up to 3 mm) occurs interstitially and is generally fresh. Biotite (up to 2 mm) forms short euhedral prismatic crystals, generally concentrated in clusters; it is partly altered to chlorite and epidote, and is pleochroic: X = light yellow-brown, and Y = Z = dark brown. Muscovite, probably secondary, is present as small flakes, and opaques, apatite, and zircon are accessories. A modal analysis of the granodiorite is included in Table M13.

The lack of foliation and abundant xenoliths, the presence of dark brown (as distinct from red-brown) biotite, and the apparent intrusion into the Yaouk Leucogranite, suggest that the granodiorite is not part of the main suite of the Murrumbidgee Batholith and may be related to the hornblende-biotite tonalite at Ashvale.

Granodiorite at 643390 (Smi)

A small intrusion of dark medium-grained granodiorite crops out in Ordovician sediments about 2 km west of the western boundary of the batholith 2 km north-northeast of Yaouk. The rock, which is not foliated, contains numerous equidimensional pelitic xenoliths, but lacks phenocrysts.

In thin section the granodiorite displays an even-grained hypidiomorphic texture. Quartz (up to 4 mm) occurs mainly interstitially. Plagioclase, which is euhedral and forms short prismatic grains up to 4 mm, is zoned from about An_{25} to An_{45}, though most grains are altered to sericite and saussurite. Microcline (up to 4 mm) is subhedral, partly altered, and perthitic. Biotite (up to 5 mm) forms euhedral prisms, but is anhedral against plagioclase; it is completely altered to chlorite, epidote, and opaques. A modal analysis is included in Table M13.

Adamellite at 720280 (Sml)

This rock crops out at the boundary between the Shannons Flat Adamellite and the Yaouk Leucogranite west of Bradleys Creek; as shown on the map, it probably intrudes both. Rare inclusions of coarse-grained leucocratic granite confirm that it is younger than the Yaouk Leucogranite. It lacks foliation, phenocrysts, and cognate xenoliths. Subparallel vertical fractures are fairly evenly spaced in two sets at right-angles, resulting in large (up to 10 m) equidimensional unweathered boulders. This medium-grained rock is homogeneous in structure and mineralogy.

In thin section the texture is hypidiomorphic. Quartz (up to 2 mm) is subhedral to anhedral, and myrmekite is common. Microcline (up to 2 mm) is anhedral, ard cross-hatch twinning is general. Plagioclase (up to 2 mm) is euhedral, forms short prisms, and is zoned An_{10-30}; the margins are slightly more sodic than the cores, which are generally altered to sericite and saussurite. Biotite forms elongate flakes up to 2 mm completely altered to chlorite and epidote. Muscovite and minute apatite grains are accessories.

The mode of the adamellite (Table M13) is similar to the mode of the Shannons Flat Adamellite presented by Joyce (1973).

Leucogranite at 692162 (Sml)

This leucogranite, 0.5 km west of Ashvale, forms a small circular intrusion in the Yaouk Leucogranite, which it therefore postdates. The granite is foliated meridionally and vertically , and crops out as small (up to 2 m) moderately to highly weathered angular blocks trending north-south as a result of the foliation. It lacks xenoliths and appears to be homogeneous; it comprises grey quartz, weathered yellow-pink feldspar, and a low percentage of dark minerals.

In thin section the leucogranite is allotriomorphic and the foliation appears to be only slight. Quartz (up to 1 mm) occurs in clusters up to 5 mm, and is anhedral. Plagioclase (An_{10-20}) forms euhedral prisms up to 3 mm and is generally slightly altered; fresh, smaller grains of plagioclase seem to be formed near the edges of microcline grains. Microcline (up to 2 mm) is anhedral and perthitic. Biotite (up to 1 mm) is closely associated with muscovite in elongate clusters and is pleochroic: X = light yellow, and Y = Z = dark brown. Muscovite (up to 1 mm) is primary and also occurs as an alteration product of biotite. Andalusite is an accessory, and forms euhedral grains up to 0.5 mm with reaction rims of muscovite. Other accessories are garnet, opaques, and zircon. A modal analysis is included in Table M13.

The leucogranite has been contact-metamorphosed by the adjacent hornblende-biotite tonalite in the same manner as the Westerly Leucogranite.

TABLE M13. MODAL ANALYSES OF UNNAMED INTRUSIONS IN THE MURRUMBIDGEE BATHOLITH

Rock name	Grid ref.	Qtz	Mic	Plag	Biot/Chl	Musc	Hbl	Others
tonalite	690175	22.4	-	58.8	9.5	-	9.3	-
granodiorite	677240	34.6	13.5	41.4	9.2	-	-	1.3 (epidote)
granodiorite	643390	38.0	7.2	19.6	22.5	6.2	-	6.5 (epidote, opaques)
adamellite	720280	35.2	26.2	31.7	5.8	-	-	1.1 (epidote)
leucogranite	692162	38.0	37.4	19.1	2.5	2.1	-	0.9 (andalusite, garnet, opaques)

Age and sequence of intrusion

Roddick & Compston (1976) have recently completed an isotopic dating project on the Murrumbidgee Batholith. Their results on the Shannons Flat Adamellite and Yaouk Leucogranite are in close agreement and give ages ranging from 415 m.y. to 410 m.y. ($\lambda Rb = 1.42 \times 10^{-11}$/year). Their results on the Westerly Leucogranite give somewhat younger ages (405 m.y. and 408 m.y.), but this pluton has been contact-metamorphosed by a younger mafic pluton. The mica ages for the granodiorites and the Willoona Tonalite are slightly younger (402-410 m.y.) than the Shannons Flat Adamellite, and this conflicts with the apparent sequence of intrusion: granodiorite followed by adamellite followed by leucogranite. However, the error (± 4 m.y.) placed on these ages makes them not significantly different from the Shannons Flat Adamellite, except for one of 402 ± 4 m.y. for the Bolairo Granodiorite; as the Westerly Leucogranite intrudes the Bolairo

Granodiorite this age appears to be too young. Yet the ages that Roddick & Compston (1976) reported for the Westerly Leucogranite may have been reset by the tonalite at Ashvale, which - possibly together with the two granodiorites at grid references 677240 and 643390 - cannot be considered as part of the consanguineous suite that makes up the rest of the batholith and is probably younger by several million years. But K/Ar dating of this tonalite has yielded an age of 414 $\pm$ 6 on a biotite concentrate; compared with the Rb/Sr age for the Westerly Leucogranite this age is a little too old.

The sequence of intrusion - granodiorite, adamellite, leucogranite - supports the restite unmixing model for granitoid genesis proposed by White & Chappell (1976), and leads to the conclusion that all the plutons were derived from the same region of partial melting in the crust; the granodiorites rose rather more rapidly from this region than the adamellites and leucogranites, whose xenoliths and xenocrysts had time to settle out. The tonalite at Ashvale and younger granodiorites (Smi) probably came from deeper levels in the crust.

GINGERA BATHOLITH

Noakes (1946) first introduced the name Gingera Granite for a biotite granite that crops out in the Brindabella Range west of the Cotter River. The name was later published by Joplin & others (1953); Best & others (1964) included in it the biotite granodiorite south of Yaouk. Strusz (1971) used the term Gingera Group for the Gingera, Bendora, Stewartsfield, and Condor granitoids, but we consider that the Stewartsfield Granodiorite is part of the Murrumbidgee Batholith, whereas the Condor Granodiorite is hornblende-bearing and probably not related to the other bodies.

In view of the size (over 200 km^2 outcrop area) and composite nature of the bodies referred to as the Gingera Granite, and their apparent consanguinity, we consider it appropriate to introduce the term Gingera Batholith. We have identified, named, and defined six major plutons, which we have described below in the same order as for the Murrumbidgee Batholith plutons: granodiorites, followed by adamellites, then leucogranites.

McLaughlins Flat Granodiorite

(new name)

Nomenclature

The McLaughlins Flat Granodiorite comprises a series of petrographically and chemically similar igneous bodies which crop out in TANTANGARA west of the Cotter Fault between Yaouk and Adaminaby, and extend into BERRIDALE. These bodies are separated from the rest of the Gingera Batholith by sediments west of Yaouk.

Derivation of name

The name is taken from McLaughlins Flat, 4.5 km north-northwest of Adaminaby Post Office.

Type locality

The type locality is 2.0 km west of Adaminaby on the Snowy Mountains Highway (at grid ref. 576145, BERRIDALE) where many rounded boulders up to 1.5 m lie on the northern side of the highway. The rock is a coarse-grained blue-grey poorly foliated biotite granodiorite. Biotite-rich pelitic xenoliths up to 10 cm are abundant, and are elongated parallel to the biotite foliation in the granodiorite.

Geographical distribution

The granodiorite crops out as a series of irregular bodies of various sizes. Its total area of outcrop in TANTANGARA is about 50 km^2. The main body is about 7 km wide at the southern border of TANTANGARA west of Adaminaby; it narrows northward to about 3 km wide near Fontenoy, and cuts out completely about 1.5 km northwest of Yaouk. The margin of the intrusion is deeply embayed by sedimentary country rock; south of Fontenoy, one such embayment is 5 km long and 1 km wide. One other large elongate granodiorite body is exposed, east of Big Bugtown Hill; it is about 6 km long and 1.5 km wide. Smaller bodies, some only a few metres across, are common.

White & others (1976a) have mapped the southern continuation of the main body for about 3 km into BERRIDALE

Field occurrence

The granodiorite is generally well exposed. Boulders and tors up to 4 m high are widespread both in the southern undulating grassed country and in the steeper forest country to the north. Exposures are poorer near the margins of the bodies where the foliation is more strongly developed and the weathering deeper. Roof pendants are common; one northeast of the Snowy Mountains Highway near Willow Grove is 2 km long and up to 500 m wide. East of Big Bugtown Hill a sedimentary screen less than 1 km wide separates the main body from a smaller body; the screen is over 9 km long, and to the north bends around the smaller body like a fold, indicating either that the structural orientation of the sediments was an important factor in controlling intrusion or that the sediments were folded after they were intruded. The Cotter Fault in the Murrumbidgee valley cuts out the eastern edge of the main body. Near Stuartfield several landslips have occurred: granodiorite boulders have slid down the fault scarp and at grid reference 613282 are more than 50 m east of the fault line.

Hand specimens from all outcrops are similar. Samples from small bodies only a few metres wide are similar in grainsize, texture, colour, and mineral composition to samples from the centres of the larger bodies. The rock is a medium to coarse-grained equigranular granodiorite with grains up to 3 mm. It is composed of white feldspar, pale blue-grey quartz, and black biotite; mafic minerals constitute about 20% of all samples. At some localities (e.g. grid ref. 583210) the alignment of biotite flakes defines a strong foliation, which is best developed near the margins of the larger bodies.

Discoid pelitic xenoliths up to 40 cm are abundant throughout. They show a range in degree of assimilation from bedded metasediments up to granitic patches slightly richer in biotite than the granodiorite. Where the rock is foliated the xenoliths are aligned parallel to the foliation, but much of the strongest foliation is obviously secondary and in places the rock approaches a mylonite.

Petrography

All samples collected are biotite granodiorite. Modal analyses are presented in Table M14.

The rock has a distinctive hypidiomorphic granular fabric with 25 to 50% of stumpy prismatic grains of plagioclase up to 2 mm; rare euhedral plagioclase phenocrysts are up to 5 mm. The plagioclase is strongly zoned with An_{40} cores, and rims as sodic as An_5; the cores are commonly highly sericitised. Between 30 and 40% quartz is present, as anhedral interstitial patches up to 3 mm. In some samples a secondary foliation is well developed, and quartz has been deformed and has recrystallised into composite grains. All samples show some signs of strain, as the quartz invariably shows markedly undulose extinction.

Biotite forms subhedral to anhedral flakes, up to 1.5 mm, with inclusions of apatite, zircon, and opaques. It is pleochroic with X = pale yellow-brown, Y = Z = dark reddish brown, and $2V_x \doteqdot 15^{\circ}$. In most samples the biotite is bent and partly recrystallised, and commonly has associated secondary muscovite. Again in most samples, the edges of biotite flakes are altered to biaxially positive pale green chlorite as a result of weathering.

Microcline is uncommon in the McLaughlins Flat Granodiorite. It forms sporadic interstitial grains up to 2 mm, commonly moulded onto euhedral plagioclase crystals. The microcline has poorly developed cross-hatch twinning and no apparent perthite lamellae. It generally shows undulose extinction.

The accessory minerals apatite, zircon, and opaques are commonly associated with biotite. The apatite forms rare euhedral prisms up to 0.1 mm long; the zircon is common as euhedral grains up to 0.2 mm; and the opaques form subhedral to anhedral grains up to 0.5 mm.

Bendora Granodiorite

Nomenclature

Noakes (1946) introduced the name Bendora granite, and Snelling (1960) first published it when he mentioned it as an example of a contaminated granite west of the Murrumbidgee Batholith. The name was also used by Best & others (1964), who described the rock as a foliated granodiorite. It is here redefined as the Bendora Granodiorite.

Derivation of name

The name is taken from Bendora Creek, which flows northeast across part of the outcrop of the pluton and joins the Cotter River at grid reference 665790.

Type locality

Good exposures of the granodiorite are rare, as weathering is deep. At the type locality (grid ref. 645798) on Warks Road, a few boulders up to 1 m of medium-grained foliated biotite granodiorite are exposed on the side of the road. The rock contains a few white alkali feldspar phenocrysts up to 5 mm and is almost an adamellite in composition.

Field occurrence

The Bendora Granodiorite outcrop is about 10 km long and 2 to 3 km wide, entirely in BRINDABELLA. It extends from just east of Mount Franklin in the south almost to Bendora Road in the north, and occupies most of the area between the crest of the Brindabella Range and the Cotter valley near Bendora Dam. It is highly weathered, and more easily eroded than the sediments to the west, which crop out on the higher parts of the range.

The granodiorite is exposed generally as small tors and rubble, but also as larger tors up to 3 m high and 2 m wide in places (e.g., grid ref. 628755). Roof pendants of the Nungar beds are common and are oriented meridionally. Near grid reference 620785, the granodiorite merges into a series of meridional porphyry dykes. Three aplitic bodies intrude it: on the Bendora Road near Bulls Head, near grid reference 615770, and east of Mount Aggie. The granodiorite's relation to the Ginini Leucoadamellite is unknown, but if the granodiorite-adamellite-leucogranite sequence of intrusion is tenable - as it appears to be for the Murrumbidgee Batholith and elsewhere in the Gingera Batholith - then the leucoadamellite intrudes the granodiorite.

The granodiorite is a medium-grained grey to white rock with about 10 to 15% biotite. It is commonly intensely deformed, displaying 'eyes' of feldspar enveloped by aligned grey quartz and biotite. Xenoliths are not common, and consist mainly of clots of biotite and plagioclase a few centimetres in diameter. In overall appearance the rock is similar to the McKeahnie Adamellite, which crops out to the south.

Petrography

The rock has a hypidiomorphic texture with stumpy subhedral to euhedral strongly zoned plagioclase (30%), and interstitial strained quartz (40%) and microcline perthite (15%), all of about the same grainsize (2 to 3 mm). Red-brown biotite (15%) is bent, and recrystallised round the margins to fine-grained muscovite and biotite intergrowths. Epidote, apatite, zircon, and opaques are associated with the biotite. Most samples contain 2-mm intergrowths of muscovite and minor biotite, probably pseudomorphing subhedral grains of cordierite.

The microcline content of this rock puts it near the boundary of the adamellite and granodiorite fields, and in this respect it is similar to the Stewartsfield Granodiorite in the Murrumbidgee Batholith and to the McKeahnie Adamellite. It differs from the other granodiorites in the Murrumbidgee Batholith and from the McLaughlins Flat Granodiorite in containing more microcline, less biotite and plagioclase, and fewer and smaller xenoliths. A modal analysis is included in Table M14.

McKeahnie Adamellite

(new name)

Nomenclature

This is the body that crops out on Mount Gingera and is probably the one that Noakes (1946) referred to as the Gingera Granite. Our use of the name Gingera for the name of the batholith precludes its use for the name of a subunit of the batholith. We have accordingly chosen the name McKeahnie Adamellite.

Derivation of name

The name is taken from McKeahnie Creek, which flows across part of the pluton outcrop just north of Mount Bimberi.

Type locality

The type locality is on the top of Mount Gingera (grid ref. 611614), where the adamellite is well exposed as elongate tors up to 10 m long. The elongation of the tors parallels a foliation which dips 85° west and strikes at 345°.

Field occurrence

The McKeahnie Adamellite is a meridionally elongate, irregularly shaped body about 23 km long and 2 to 3 km wide. It extends from Ginini Flats in the north to the headwaters of Paytens Creek in the south. It is well exposed, especially on the tops of ridges. Elongate tors many metres high are common, and groups of tors are separated by joint planes parallel to the foliation in the rock.

The rock is a white to grey foliated biotite adamellite. The grey-brown weathering skin is less than 1 cm thick and is commonly absent on faces freshly broken by frost shattering. Biotite, which forms about 10% of the rock, occurs as aligned flakes of about 2 mm, which partly wrap around white feldspar and pale violet quartz up to 4 mm. Xenoliths are uncommon and consist of discoid biotite-rich pelites mostly less than 5 cm; the most common types are less than 2 cm and are made up almost entirely of biotite. A well-developed foliation at all outcrops commonly dips west at 75° to 85° on the western side of the intrusion and east at 75° to 85° on the eastern side of the intrusion, and appears to be parallel to the cleavage in the surrounding sediments.

Mafic dykes intrude the McKeahnie Adamellite at grid reference 601553 and 607642; another intrudes the Bendora Granodiorite at grid reference 626747. The three dykes are similar and contain rare phenocrysts of plagioclase up to 5 x 2 mm and apatite up to 2 x 1 mm in a very fine-grained (0.1 mm) grey-green groundmass consisting of about 60% feldspar; 25% intergrown biotite, chlorite, and actinolite; 5% opaques; 5% calcite; and minor brownish green hornblende, quartz, and epidote; calcite is common in subrounded amygdules up to 2 cm.

Petrography

The McKeahnie Adamellite is similar to the Bendora Granodiorite, but carries a little more microcline perthite. Modal analyses of two samples are included in Table M14. Plagioclase forms stumpy prisms up to 4 mm in random orientation. Cores are oscillatorily zoned up to An_{40} and are commonly sericitised; most grains have narrow rims of An_{5-10}. Some of the prisms are bent and broken. The plagioclase is set between highly strained and partly recrystallised quartz of about 3 mm, and lesser microcline perthite.

Discrete bent and partly recrystallised flakes of biotite from 1 to 2 mm are pleochroic from pale brown to dark red-brown, though some recrystallised margins are brownish green. Secondary muscovite is common around the edges of the biotite flakes, and also forms as very fine-grained intergrowths up to 3 mm, probably after cordierite. Apatite, zircon, and opaques form inclusions in the biotite; the zircon has a dark brown pleochroic halo.

Half Moon Peak Adamellite
(new name)

Nomenclature

We have introduced the name Half Moon Peak Adamellite for a coarse-grained adamellite which crops out on Mount Murray, Mount Morgan, and Half Moon Peak. A poorly known finer-grained stock in the Murrumbidgee valley at Platypus Lodge, included in the Half Moon Peak Adamellite, may be a separate intrusion.

Derivation of name

The name is taken from Half Moon Peak (grid ref. 597434), which forms part of the outcrop of the intrusion.

Type locality

The type locality is on the top of Mount Morgan (grid ref. 612436), where the adamellite is exposed as slightly elongate tors up to 3 m high. Foliation is weakly developed.

Field occurrence

The Half Moon Peak Adamellite occupies most of the high country between the Murrumbidgee River in the south and Mount Bimberi in the north. It is well exposed - somewhat better than the McKeahnie Adamellite, which occupies the lower country to the west - and forms large tors fairly closely spaced over the whole area.

The rock is coarse- to medium-grained with an average grainsize of about 5 mm. Biotite in particular is much coarser than in the McKeahnie Adamellite. Quartz is grey to pale violet and both feldspars are white. At the northern end of the intrusion, north of Mount Murray, white alkali feldspar megacrysts up to 20 x 10 mm are abundant, and the rock resembles parts of the Shannons Flat Adamellite in the Murrumbidgee Batholith.

The Half Moon Peak Adamellite contains xenoliths of the McKeahnie Adamellite near their contact at grid reference 611502, and therefore must be the younger of the two. It is cut by leucogranite dykes at grid reference 625485, and is intruded by the Bimberi Leucogranite.

Petrography

The rock has a coarse-grained hypidiomorphic texture with plagioclase and microcline in roughly equal proportions. The plagioclase is 3 to 5 mm, and is typical for the batholith, as it has zoned cores up to An_{45} and narrow albitic rims. Quartz is just as strained and recrystallised as in the other plutons in the batholith, and forms anhedral grains of 4 to 5 mm between plagioclase prisms. Biotite flakes are bent and partly recrystallised; they are less oriented than those in the finer-grained adamellites in the batholith, and impart only a weak foliation to the rock. Secondary muscovite is common around biotite flakes and often penetrates into the associated biotite; it also occurs in patches up to 4 mm, probably pseudomorphing cordierite. Accessory apatite, zircon, and opaques are associated with and commonly included in biotite. A modal analysis is included in Table M14.

Ginini Leucoadamellite

(new name)

Nomenclature

We have introduced the name Ginini Leucoadamellite for a fine to medium-grained elongate pluton which crops out to the east of the McKeahnie Adamellite east of Mount Gingera and extends northwards for about 12 km to the Bendora Granodiorite east of Mount Franklin.

Derivation of name

The name is taken from Ginini Creek, which flows across the northern end of the pluton and drops over the spectacular Ginini Falls (over 100 m high) at the eastern contact of the pluton with the Nungar beds (grid ref. 635703).

Type locality

The type locality (grid ref. 618653) is on a rough track about 50 m north of its crossing of Stockyard Creek. This is the most accessible good exposure of the pluton, and, although the rock is somewhat more foliated here than elsewhere because it is close to a fault, it is still lighter than the adjacent McKeahnie Adamellite.

Elongate boulders up to 1 m high consist of rare plagioclase phenocrysts up to 5 mm in a foliated fine to medium-grained groundmass of white feldspar, greyish violet quartz, and less than 5% aligned biotite.

Field occurrence

This pluton lies between the McKeahnie Adamellite in the south and the Bendora Granodiorite in the north. It is about 14 km long and 2 km wide. Much of its contact with the McKeahnie Adamellite is faulted, but the fault dies out to the north, and east of Ginini Flats a narrow sedimentary screen separates the two plutons. The relation between the two plutons is obscure. Two generations of aplite dykes intrude the screen east of Ginini Flats, but their relations to the plutons are obscure. The relative ages of the Ginini Leucoadamellite and the Bendora Granodiorite are not evident from their field relations, but we suspect that the granodiorite is older.

The Ginini Leucoadamellite is a medium-grained biotite-poor white rock, commonly exposed as rounded tors up to 10 m in diameter. The rock is deeply weathered and fresh samples are difficult to obtain. Biotite and muscovite are evident in hand specimen. The biotite content is usually about 3 to 4%, but increases to over 5% at some localities near the faulted contact with the McKeahnie Adamellite (e.g., at grid ref. 624617). Patches of tourmaline, and biotite-rich xenoliths up to 2 cm, are common. Numerous finer-grained leucogranite stocks and aplite dykes intrude the leucoadamellite; the larger ones are indicated on the 1:100 000 maps.

At Ginini Falls the contact between the leucoadamellite and the Nungar beds is well exposed near the base of the falls, which apparently developed because of the change in rock resistance at the contact. Joints dipping 60^{o} west are very common in the cliffs surrounding the falls.

Petrography

A modal analysis of a sample from the Ginini Leucoadamellite is included in Table M14. This sample probably has a slightly higher biotite content than the average for the pluton.

The rock is similarly deformed to other plutons in the batholith, and its mineral assemblage is similar too: subhedral strongly zoned plagioclase, quartz, microcline, red-brown biotite, and ?cordierite pseudomorphs. Its average grainsize is 2 to 3 mm, but microcline is locally up to 6 mm. Microcline is more abundant than plagioclase, and biotite makes up less than 5% of the rock. Secondary muscovite is associated with the biotite. Muscovite of probably primary origin in some samples forms both rosettes several millimetres in diameter remote from biotite flakes, and plates interlayered with primary biotite flakes. A feature not evident in the more mafic plutons is the rare subgraphic quartz and feldspar intergrowths in some samples of the leucoadamellite.

Bimberi Leucogranite
(new name)

Nomenclature

We have introduced the name Bimberi Leucogranite for the pluton which occupies most of Mount Bimberi.

Derivation of name

The name is derived from Mount Bimberi (elevation 1912 m), the highest peak on the divide between the Goodradigbee and Cotter Rivers.

Type locality

The type locality is the top of Mount Bimberi (grid ref. 620522), where the leucogranite is well exposed in slabs, pavements, and rounded surfaces close to the ground. Tors are not well developed, and rubbly angular blocks are present between the areas of outcrop. The rock is fine-grained, pale pink, saccharoidal, and poor in biotite.

Field occurrence

The Bimberi Leucogranite is a stock about 4 km long and 1.5 km wide. It intrudes the McKeahnie Adamellite and the Half Moon Peak Adamellite and occupies most of the dome-shaped massif of Mount Bimberi. It extends south to the break in slope about 1 km north of Murrays Gap, and north to within a few metres of McKeahnie Creek.

It is exposed mainly as angular blocks of talus on the steeper slopes, but commonly as slabs and pavements on the crest of Mount Bimberi.

The rock is a fine to medium-grained two-mica granite which weathers to a pale yellowish pink saccharoidal rock; it is finer-grained to the south. Dark minerals make up only 1 to 2%. Phenocrysts (2 to 3 mm) of quartz, biotite, and plagioclase are common at some localities (e.g., grid ref. 616525), and tourmaline is a widespread accessory.

Petrography

The leucogranite is distinct from the more mafic plutons in the batholith. All grains are anhedral and average 1 to 1.5 mm. Quartz and microcline make up 75 to 80% of the rock; the microcline shows coarse cross-hatch twinning. Plagioclase is mostly slightly zoned anhedral albite, but here and there a few larger grains have subhedral cores of andesine. Muscovite is the main mica; it occurs as primary masses and rosettes up to 10 mm long with minor interlayered biotite, and as secondary xenomorphic growths enclosed in microcline. Two types of biotite are present: one is somewhat porphyritic, pleochroic in the characteristic pale yellow-brown to red-brown scheme, and not associated with primary muscovite; the other is interlayered with primary muscovite and is pleochroic from almost colourless to pale brownish green. A modal analysis of a sample from the type locality is included in Table M14.

At grid reference 616525 phenocrysts up to 4 mm of red-brown biotite, rounded quartz grains, and euhedral andesine with albitic overgrowths make up about 20% of the rock. These grains are similar in morphology and size to those in adjacent plutons and are interpreted as contaminants derived from those plutons.

Despite the lack of foliation in hand specimen the pluton has been intensely deformed like all the other plutons in the batholith. Microcline has wavy extinction; muscovite and biotite are bent and broken; and quartz has recrystallised into a mosaic or irregular grains with undulose extinction. Zones of recrystallisation into tiny grains less than 0.01 mm form subparallel bands within and around the margins of original quartz grains.

Unnamed intrusions in the Gingera Batholith

Many unnamed stocks and dykes of aplite and leucogranite (indicated by Sgl) intrude the Gingera Batholith and surrounding sediments. They are particularly common within and adjacent to the Ginini Leucoadamellite and perhaps the Bendora Granodiorite, but appear to be absent from the McLaughlins Flat Granodiorite. Their mineralogy is similar to that of the Bimberi Leucogranite.

TABLE M14. MODAL ANALYSES OF THE GINGERA BATHOLITH

Pluton	McLaughlins Flat Granodiorite	McLaughlins Flat Granodiorite	McLaughlins Flat Granodiorite	Bendora Granodiorite	McKeahnie Adamellite	McKeahnie Adamellite
Sample no.	71840001	71840002	71840024	73840024	72840087	72840095
Grid ref.	589195	583210	597219	648791	611614	612579
Quartz	40.5	37.5	33.6	39.7	34.8	36.8
Microcline perthite	8.0	7.3	6.3	13.1	19.3	20.5
Plagioclase	27.4	27.1	35.5	28.3	29.4	26.8
Biotite	22.8	23.7	16.7	12.0	9.9	11.4
Muscovite	-	4.2	-	5.5	6.0	3.8
Chlorite	-	-	7.1	1.1	0.2	-
Accessories (apatite, zircon, opaques, epidote, tourmaline)	0.4	0.2	0.8	0.3	0.4	0.9

Pluton	McKeahnie Adamellite	Half Moon Peak Adamellite	Ginini Leucoadamellite	Bimberi Leucogranite	Unnamed leucogranite
Sample no.	72840096	72840019	72840093	72840094	72840088
Grid ref.	605553	602407	624617	620522	630651
Quartz	34.5	33.0	40.0	35.8	36.6
Microcline perthite	21.8	27.0	29.1	32.3	40.9
Plagioclase	24.8	25.2	21.1	21.1	13.8
Biotite	16.2	9.0	5.6	2.2	0.4
Muscovite	2.1	4.9	3.8	8.4	8.0
Chlorite	0.3	0.4	-	-	0.2
Accessories (apatite, zircon, opaques, epidote, tourmaline)	0.3	0.5	0.4	0.2	0.1

At grid reference 638497, 1.3 km east of Murrays Gap, a hornblende microtonalite dyke intrudes the Half Moon Peak Adamellite. The rock contains abundant highly zoned plagioclase (An_{80-20}), greenish brown hornblende, dark greenish brown biotite, and undulose interstitial quartz.

At grid reference 607642, a foliated porphyry dyke of tonalite composition intrudes the McKeahnie Adamellite. It contains phenocrysts of strongly zoned (An_{55-10}) plagioclase up to 4 mm in a groundmass with an average grainsize of 0.5 mm, containing zoned plagioclase, quartz, 15% brown biotite, and about 3% blue-green hornblende. Microcline appears to be absent. These two dykes have been deformated in the same way as the rest of the batholith, but their composition distinguishes them from the other rock types.

Porphyry dykes of adamellite composition intrude the sediments adjacent to the main part of the batholith at grid references 641559 and 647632. Small stocks up to several hundred metres wide crop out at various places and are shown on the maps as correlating with the major plutons.

Contact effects

The McLaughlins Flat Granodiorite, Bendora Granodiorite, and McKeahnie Adamellite have had only minor contact metamorphic effects on the adjacent sediments. In thin section, original detrital quartz grains are still identifiable only 1 cm from an intrusive contact. These grains are somewhat overgrown by secondary quartz and set in a matrix of muscovite and biotite. A sandstone sample from grid reference 590605, about 1 m from an outcropping intrusive contact of the McKeahnie Adamellite, contains mostly chlorite and muscovite of metamorphic origin as the matrix minerals and only rare scattered biotite, but biotite is abundant and chlorite absent adjacent to a 1-mm wide quartz vein in the rock. The lack of biotite away from the vein suggests that water had difficulty in moving through the rock, thus retarding dehydration reactions; chlorite would have been metastable in the presence of muscovite. More than about 20 m away from the margin, contact effects cannot be resolved in thin sections, and the rocks have the same assemblage (quartz-sericite-chlorite) as sediments remote from granitoid contacts.

The more leucocratic rocks of the Gingera Batholith have had more intense metamorphic effects than the granodiorites and mafic adamellites. Sediments are spotted, indicating the presence of cordierite, within 50 m of their contacts with the Bimberi Leucogranite and Ginini Leucoadamellite. Thin sections show that the cordierite has completely retrogressed to pinite, and well-formed crystals of biotite are abundant.

Age

Because the Gingera Batholith is similar to the Murrumbidgee Batholith, its age is likely to be Late Silurian. A biotite/whole-rock pair from the McLaughlins Flat Granodiorite gave a Rb/Sr age of 412 ± 8 m.y. (λRb^{87} = 1.42×10^{-11}/year) and an initial ratio of 0.7134 ± 0.001; this age is similar to those that Roddick & Compston (1976) determined for the Murrumbidgee Batholith.

KOSCIUSKO BATHOLITH

Gang Gang Adamellite
(new name)

Nomenclature

As a result of reconnaissance mapping of the Eucumbene-Tumut tunnel line, Hall (1949) gave the name Happy Jacks Granite to the granite cropping out on Happy Jacks Plain (in KOSCIUSKO) and extending north as far as Alpine Hill (in TANTANGARA). However, Williams (1974) has shown that the Happy Jacks Granite does not extend into TANTANGARA, so we have introduced the name Gang Gang Adamellite for the granitoid that extends from the southwest corner of TANTANGARA north of Alpine Hill, and then farther north again to the south end of Boggy Plain east of the Boggy Plain Fault.

Derivation of name

The name comes from Gang Gang Creek, which flows across part of the pluton east of the Boggy Plain Fault.

Type locality

We have designated the type locality for the most common rock type in the pluton, perthitic leucoadamellite, as grid reference 410188, on a rough track near the headwaters of Swamp Creek. At this locality tors of adamellite carrying about 5% biotite are up to 2 m high, and are the freshest exposures encountered in the pluton.

Field occurrence

The Gang Gang Adamellite is a large granitoid forming the northern end of the Kosciusko Batholith. It consists of muscovite and biotite-bearing leucoadamellite and sodic leucogranite. In TANTANGARA the leucoadamellite crops out in two areas separated by the Boggy Plain Fault. The northern area is bounded to the west by the Boggy Plain Fault, roughly along the line of Alpine Creek, and extends to the east to Gang Gang Creek and to the north to the southern end of Boggy Plain, an area of about 14 km^2. The southern area extends from north of Alpine Hill to south of TANTANGARA. This body is elongated along a south-southwest axis and is about 5 km wide, narrowing to 2 km south of Tabletop Mountain. The total area of the southern section is about 30 km^2. White & others (1976a) have mapped about 1.5 km^2 of the Gang Gang Adamellite in BERRIDALE. The topography developed over the body is hilly to undulating, and some areas are deeply dissected. Maximum relief within the granitoid, about 450 m, is from Alpine Hill to the Eucumbene River.

The adamellite is reasonably well exposed; it forms tors mostly less than 2 m wide and float less than 1 m in diameter. In some areas along the Eucumbene River it crops out in bluffs and low cliffs, and east of Tabletop Mountain it forms flat rocky terraces 10 to 20 m wide.

In hand specimen two varieties of the adamellite can be distinguished. Biotite-poor leucoadamellite crops out near the eastern and western margins of the pluton. This is a fine to medium-grained white to cream rock with about 1% biotite. Muscovite is rare in some samples and common in others. Near Tabletop Mountain, biotite-poor leucoadamellite contains about 8% muscovite in groups and rosettes up to 10 mm. The biotite-poor variety is commonly albite-rich, but this is not distinguishable in hand specimen.

Farther from the margins the biotite-poor leucoadamellite grades into an adamellite with about 5% biotite. This is commonly white and medium-grained but in a few places it is pinkish. Biotite and lesser muscovite are scattered throughout.

At the northern end of the adamellite, where it is intruded by the Boggy Plain Adamellite, the Gang Gang Adamellite has been recrystallised. In hand specimen it is finer-grained than normal, saccharoidal, and has phenocrysts of quartz about 3 mm.

Field relations

The Gang Gang Adamellite intrudes Ordovician and Lower Silurian sedimentary rocks. Contacts with the surrounding sediments are generally poorly exposed, but at grid references 394237 and 461245 contacts between the adamellite and micaceous quartzite are sharp. North of Alpine Hill and south of Boggy Plain the adamellite is intruded by the Boggy Plain Adamellite, and has been contact-metamorphosed by it. Several small basic and intermediate stocks related to the Boggy Plain Adamellite intrude the Gang Gang Adamellite at grid references 416182, 382205, and 385211. At several other localities the white leucoadamellite has been altered (?metasomatised) to a pink granite (at grid refs. 380186, 424240, and 449223); this alteration may also be related to the later intrusion of the Boggy Plain Adamellite and related stocks.

Petrography

The Gang Gang Adamellite can be divided into three distinct rock types on their petrographic character: (1) sodic leucogranite, (2) perthitic leuco-adamellite, and (3) metamorphosed perthitic leucoadamellite.

(1) Sodic leucogranite. Rocks of this type are known from two areas; along Alpine Creek and the Snowy Mountains Highway east of Alpine Hill; and southeast of Tabletop Mountain. Sodic leucogranite is allotriomorphic, with an average grainsize of about 2 to 3 mm. Quartz (40-50%) forms anhedral grains up to 4 mm. Plagioclase (An_{5-10}) forms slightly zoned albite-twinned grains up to 2 mm (15-20%). Sodic alkali feldspar (35-45%) forms anhedral grains up to 4 mm. The alkali feldspar has no recognisable antiperthite lamellae, but aligned flecks of sericite throughout the grains may be alteration products of such

lamellae. The alignment of the sericite is best seen on (010) faces where it intersects (001) cleavage at a high angle. This orientation of the sericite flecks is similar to the orientation of perthite and antiperthite lamellae in alkali feldspars. Carlsbad, Manebach, and very fine discontinuous albite twins are common in the sodic alkali feldspar grains. Biotite forms rare chloritised flakes less than 1 mm (less than 2%), and muscovite (1%) forms rare subparallel groups in which the individual flakes are less than 0.5 mm. Opaques are commonly associated with muscovite, and accessory apatite and zircon are rare.

A sample from grid reference 361165 contains perthite (10%) as well as sodic alkali feldspar (10%); the perthite is common in parts of the thin section and the sodic alkali feldspar is common in others. The rock also contains about 30% slightly zoned plagioclase (An_{5-15}), 35% quartz, and 5% muscovite. It is a leucoadamellite.

(2) Perthitic leucoadamellite. This is the most common rock type in the Gang Gang Adamellite. Near the eastern and western margins of the body there is virtually no biotite, but towards the centre the biotite content increases to over 5%. The rock is composed of anhedral quartz (35-40%) up to 4 mm, microcline (30-40%) also up to 4 mm, zoned plagioclase (An_{5-20}) from 1 to 2 mm (20-30%), and mica (about 6-8%). The microcline contains film, vein, and patch perthite lamellae and is commonly twinned on the albite, pericline, and Manebach laws, and less commonly on the Carlsbad and Baveno laws. Rarely the albite component of the perthite occupies up to 50% of a particular perthite grain; such albite patches exhibit albite twinning. Muscovite and brown biotite both range between zero and about 8% of the rock. When biotite is rare muscovite is common, and vice versa. Muscovite commonly occurs as groups in which individual flakes are up to 0.5 mm. Biotite up to 1 mm is pleochroic from pale brown-yellow to dark brown and is commonly chloritised. Zircon and opaques are commonly associated with the biotite, and many biotite flakes have pleochroic haloes around zircon inclusions. In a few samples biotite has been partly recrystallised into a mosaic of smaller grains.

(3) Metamorphosed perthitic leucoadamellite. This rock type was derived from the perthitic leucoadamellite by contact metamorphism from the later Boggy Plain Adamellite. It crops out on the northern slopes of Alpine Hill and along the ridge which forms the divide between Boggy Plain and Alpine Creek. It has a fairly similar modal composition to the perthitic leucoadamellite type, from which it differs in a number of ways.

Grain boundaries of most of the minerals are irregular, and quartz has commonly recrystallised into composite grains, some of which show triple-point junctions. The average grainsize is less than 1 mm, but some perthite and quartz grains are up to 3 mm. The potash feldspar phase of the alkali feldspar does not exhibit well developed cross-hatch twinning, and is probably more disordered than the potash feldspar in the unmetamorphosed rocks. Perthite lamellae are mainly patch perthite with interconnecting veins, whereas film and vein perthite prodominate in the unmetamorphosed rocks. Biotite has a distinctive pale yellow-brown to green pleochroism.

Plagioclase is less common in the metamorphosed rocks (10-20%) than in the unmetamorphosed rocks (20-30%), and is more calcic (An_{20}). Also, where the perthite lamellae of alkali feldspar are twinned, they are more calcic (An_{15} or possibly An_{20}) than the albite lamellae in the alkali feldspars of the unmetamorphosed rocks. Therefore it appears that there has been a loss of sodium from the rock during metamorphism; this may be significant if a metasomatic origin for the sodic leucogranite is postulated.

Muscovite is more abundant (up to 10%) in the metamorphosed rocks than the unmetamorphosed ones. As well as occurring as interstitial flakes and groups (probably premetamorphic muscovite), it forms xenomorphic grains within perthite, and flakes up to 0.5 mm within plagioclase.

Andalusite is common, constituting up to 5% in samples from grid references 443277 and 416242 (i.e., the highest proportions are nearest to the Boggy Plain Adamellite contact). It forms subhedral to euhedral prisms up to 2 x 1 mm, commonly associated with micas - particularly muscovite - and plagioclase. If it is not embedded in muscovite it has a very narrow rim of muscovite. Its association with plagioclase is probably due to the association of muscovite with plagioclase. Andalusite is separated from potash feldspar by a narrow reaction rim of muscovite. The muscovite may be a retrograde product from an initial stable assemblage of andalusite and potash feldspar; if so, then the rock must have been heated to temperatures above about 550 ^{o}C (Evans, 1965). Alternatively, the low water content of this recrystallised granitoid may have retarded mineral reactions, and the potash feldspar and andalusite were not in equilibrium with one another even though they are separated by only 0.1 mm in some samples.

Several samples of the metamorphic perthitic leucoadamellite contain rare grains of garnet up to 1 mm. It is not known whether these are of metamorphic origin or not, but they have not been observed in the unmetamorphosed rocks.

Age

The stratigraphic control indicates that the Gang Gang Adamellite is younger than the lower Llandoverian Tantangara Formation and older than the probable Lower Devonian Boggy Plain Adamellite. It is probably of a similar age to other Kosciusko Batholith intrusives and to the Murrumbidgee Batholith, and so is placed at slightly older than the Silurian-Devonian boundary. An attempt to date the rock was unsuccessful because the biotite is partly altered to chlorite, and a biotite/whole-rock isochron would be of little value.

Lucas Creek Granite

Nomenclature

The Lucas Creek Granite is an elongate granite body trending south from Gang Gang Mountain to the Hughes Creek valley, on the southern border of TANTANGARA. Within the Sheet area this granite crops out over a length of 10 km and may be up to 2 km wide. The Bega 1:250 000 geological map (Hall, Rose, & Pogson, 1967) shows the intrusion extending 2 km farther south, but White & others (1976a) found no evidence of it in BERRIDALE.

Stevens (1958a) first used the name without defining it, and Walpole (1964; appendix, p. 41) later used it.

Derivation of name

The granite is named from Lucas Creek, which drains the northern end of its outcrop.

Type locality

The type locality is along a power transmission line 500 m north-northeast of the Providence Portal turnoff from the Snowy Mountains Highway (grid ref. 470217).

Lithology

The Lucas Creek Granite comprises two rock types: a leucocratic two-mica granite which crops out north of Lake Eucumbene, and a biotite adamellite which crops out south of the lake. Outcrop around the lake is poor and the relation between the two rock types is unknown. The leucogranite comprises medium-grained (3-4 mm) equigranular grey quartz and white feldspar crystals, with scattered black biotite crystals. The adamellite is similar, except that biotite crystals are more abundant, and the rock is coarser-grained, with crystals up to 6 x 4 mm.

Biotite forms anhedral to subhedral crystals, is strongly pleochroic (X = pale yellow-brown, Y = Z = dark red-brown), and rarely is partly altered to chlorite. Muscovite is rare, forms small anhedral crystals, and in part is an alteration product of biotite. Microcline is present, commonly as perthite, and forms anhedral crystals; it is generally little altered. Plagioclase forms little-altered anhedral to subhedral crystals which are commonly oscillatorily zoned; its composition ranges from An_{5-15} in the leucogranite to An_{5-40} in the adamellite. Quartz occurs as anhedral crystals commonly showing strain under crossed nicols; it is commonly graphically intergrown with microcline. Evidence of pressure-induced recrystallisation and minor shearing along grain boundaries is common.

The modal composition of three samples of the Lucas Creek Granite is shown below in Table M15.

Relations

The Lucas Creek Granite intrudes both the Nungar beds and Tantangara Formation. The granite/sediment contact is not exposed, apparently because the granite has been more affected by weathering near its margin. Quartzite close to the contact is penetrated by numerous small quartz veins. The eastern contact of the granite where it is intersected by the Murrumbidgee-Eucumbene tunnel is faulted, and is marked by an abundance of vein quartz. Towards the south its western boundary is the Tantangara Fault. Porphyry dykes and stocks cropping out on Nungar Ridge, to the north of the pluton, are probably related to it.

The adamellite listed in Table M15 is similar modally and in grainsize to the Half Moon Peak Adamellite in the Gingera Batholith.

Its age is presumed to be Late Silurian.

TABLE M15. MODAL ANALYSES OF THE LUCAS CREEK GRANITE

Sample no.	71840037	71840202	71840235
Grid ref.	467220	468217	457175
Rock type	Leucogranite	Leucogranite	Adamellite
Quartz	35.3	47.3	34.7
Microcline	41.2	35.7	29.3
Plagioclase	18.4	10.4	23.1
Biotite	3.1	2.8	10.9
Muscovite	1.7	3.1	1.3
Accessory	0.3	0.7	0.7

YOUNG BATHOLITH

Adamson (1960) first published the name Young Granite for the northern part of a large area of granitoid extending from Canowindra (100 km west of Bathurst) in the north almost to Yarrangobilly (YARRANGOBILLY) in the south. Later, Best & others (1964) gave the name Burrinjuck Granite to the southern part of this batholithic mass. Ashley & Basden (1973) have revised the nomenclature for the batholith, which they have named the Young Granodiorite, and have restricted the application of the name 'Burrinjuck' to the chemically distinct and probably younger and unrelated massive pink adamellite at Burrinjuck Dam. Cramsie, Pogson, & Baker (1975) have also separated the Burrinjuck Adamellite from the Young Granodiorite, and our mapping, geochemistry, and geochronology results fully concur with this view. However, the term Young Granodiorite is a stratigraphic name, and implies that the batholith is not composite, but one large uniform pluton. Although published analyses and descriptions are somewhat similar (for a review see Ashley & Basden, 1973), we doubt that the whole batholith can be treated as a single pluton, and in fact have mapped out distinct phases in BRINDABELLA. We have therefore restricted the name 'Young' to a structural term, the Young Batholith, and have named the individual plutons separately. Barkas (1976) has used the term Burrinjuck-Young Batholith, but this is an added complication in view of the arguments of Ashley & Basden (1973), so we have not used it.

We have included in the Young Batholith a number of small probably related plutons which crop out in TANTANGARA, but are separated from the main mass by the Goobarragandra Volcanics.

Both S-type and I-type granitoid suites are present within the Young Batholith. Bodies included within the S-type suite are the Spicers Creek Adamellite, Broken Cart Granodiorite, and Couragago Granodiorite. The I-type suite has several features which distinguish it from other I-type suites in the region (see GEOCHEMISTRY AND PETROGENESIS, Silurian I-type granitoids and volcanics), and we have named it the Coodravale I-type Suite.

Broken Cart Granodiorite
(new name)

Nomenclature

We have introduced this name for a medium-grained biotite granodiorite which occupies much of the southwestern corner of BRINDABELLA between Brindabella Road and the Goobarragandra River.

Derivation of name

The name is taken from Broken Cart Creek, which flows northwest across the southern part of the pluton to join the Goobarragandra River at grid reference 408750.

Type locality

The type locality is here defined as a group of tors on the eastern side of Barnetts Road at grid reference 413917, about 1.3 km south of Brindabella Road.

Field occurrence

The Broken Cart Granodiorite is a large body elongated meridionally, about 33 km long and up to 11 km wide. Its western limit has not been fully defined as it extends into TUMUT west of Myers Creek. North of Myers Creek the western boundary is intrusive against a Micalong Swamp Basic Igneous Complex gabbroic stock and the Goobarragandra Volcanics. The southern boundary of the pluton is a faulted wedge in TANTANGARA. The eastern and northern boundaries are intrusive into the Goobarragandra Volcanics.

Outcrop consists of tors up to 5 m high widely scattered over the whole area, and rounded boulders and slabs in some of the more deeply incised creeks. On the plateau south of Brindabella Road, outcrop is rare. A poorly exposed fine to medium-grained granodiorite about 2 x 1 km cropping out on the eastern side of Andy Andy Range south of Jacks Hill (grid ref. 376727) has been included in the Broken Cart Granodiorite for the present, though it is probably a separate intrusion.

The Broken Cart Granodiorite is a medium-grained (3-5 mm average) rock composed of blue-grey quartz, white feldspar, and between 10% and 20% biotite. At many localities, including the type locality, rare pale greenish blue patches up to 5 mm are almost certainly pseudomorphs of cordierite. Xenoliths are common in the granodiorite; they are mostly about 10 to 20 cm, somewhat rounded, rarely flattened, and appear to be randomly oriented. Biotite and plagioclase with lesser quartz make up most of the xenoliths, but altered cordierite is also present in many. Foliation in the granodiorite is weak compared with that in the granodiorites of the Murrumbidgee and Gingera Batholiths.

A finer-grained (0.5 to 1 mm) porphyritic marginal phase of the Broken Cart Granodiorite is present along the eastern boundary of the body south of Brindabella Road. It is up to 1.5 km wide east of Big Dubbo Hill, and comprises phenocrysts of quartz, plagioclase, and altered cordierite 3 to 6 mm in a groundmass of biotite, quartz, and feldspar. A similar porphyritic marginal phase is present on the western edge of the intrusion, west and southwest of Dubbo Falls Cascades (grid ref. 396778). Here the groundmass to the porphyry is very fine-grained, especially on the northern end of Feints Range and in the Goobarragandra River valley, and the porphyry is virtually indistinguishable from the porphyritic Goobarragandra Volcanics. This porphyry has quartz, plagioclase, and biotite phenocrysts, and may be a slightly older intrusion as it is cut by dolerite dykes related to the Micalong Swamp Basic Igneous Complex, which have not been observed in the main mass of the Broken Cart Granodiorite. A basic dyke which cuts the Broken Cart Granodiorite at grid reference 418862 may be an alkali basalt of Tertiary age.

Contacts between the Micalong Swamp Basic Igneous Complex and the Broken Cart Granodiorite have been observed at grid references 383843, 378847, 396838, 404831, and 407830. At the first two of these localities the granodiorite is unaltered, being neither hornfelsed nor contaminated by the basic rocks. At the other three localities the granodiorite is evidently contaminated. In a creek bed at the last locality (grid ref. 407830), veins of highly contaminated granodiorite intrude and surround angular blocks of dolerite, so the granodiorite is the younger. Thin sections (see below) show that the same relation holds for the other four localities, so the Broken Cart Granodiorite must be younger than the stock of Micalong Swamp Basic Igneous Complex cropping out at the headwaters of Myers Creek. Our mapping shows that large embayments, roof pendants, and possibly rafted blocks of basic rock occur within the Broken Cart Granodiorite, suggesting that the granodiorite had great difficulty in assimilating and intruding the basic rocks.

Leucogranite is associated with the Broken Cart Granodiorite in three places. On the eastern side of the Andy Andy Range and extending down to Feints Creek, a leucogranite stock about 2 km in diameter crops out west of the Kennedy Range Fault. The outcrops are large tors, up to 10 m wide, of strongly weathered, medium-grained, white, two-mica granite. Muscovite is more common than biotite, and total mica content is about 6 to 10%. Tourmaline is a common accessory, forming patches and rosettes up to several centimetres long, and in a sample from grid reference 383748 one grain of topaz about 2 x 0.5 mm is associated with muscovite. Another leucogranite, which is about 500 m across, is about 2 km north of the Brindabella Road/Barnetts Road junction; it is poorly exposed, strongly weathered, medium to coarse-grained, and almost free of biotite. Leucogranite is also present west of Myers Creek in an area of difficult access.

Petrography

Two modal analyses of the Broken Cart Granodiorite, and one of an associated leucogranite are given in Table M16. The granodiorite is even-grained hypidiomorphic with an average grainsize of 3 to 4 mm. It contains rare phenocrysts of plagioclase up to 8 x 6 mm and quartz to 6 mm. The plagioclase is euhedral to subhedral, with broad oscillatorily zoned cores of An_{30} to An_{50} and narrow rims of An_{15-20}. Quartz is anhedral and possesses weak moderately undulose extinction. Anhedral microcline, commonly only 1 to 2 mm, contains film and vein perthite. Biotite is commonly strained and bent and is pleochroic from pale yellow-brown to red-brown; in many samples the red-brown colour is darker than in biotites from the Murrumbidgee and Gingera Batholiths. Opaques, zircon, apatite, and secondary muscovite are associated with the biotite. Cordierite altered to a mass of sericite flakes is present in some samples; it is subhedral, averages about 4 x 2 mm, and commonly contains inclusions of biotite.

At some localities (e.g., grid refs. 423951 and 436785) microcline is more abundant than elsewhere in the intrusion, though never as abundant as plagioclase, and the rock would be classed as an adamellite.

Samples from the northeastern part of the Broken Cart Granodiorite, between Brindabella and Nottingham Roads, are finer-grained (1-2 mm) than elsewhere in the intrusion, non-porphyritic, and contain about 3% hornblende. The hornblende has X = yellow-green, Y = green, and Z = blue-green, and commonly has cores of tremolite after augite. These hornblende-bearing rocks contain only 3 to 4% microcline, and are tonalites. A separate pluton has not been mapped in this area, but may well exist; alternatively the hornblende may be due to contamination with basic rocks.

Samples from grid references 396838 and 404831 have been contaminated with basic rocks. They contain about 40% plagioclase (An_{45-55}) without sodic rims, 25% very pale yellow-green actinolite (some with blue-green rims), 20% interstitial subpoikilitic quartz, 5% opaques, and about 10% xenomorphic poikilitic red-brown biotite up to 4 x 2 mm; much of the plagioclase is phenocrystic and up to 6 x 4 mm but the other minerals, except biotite, average only 1-2 mm. In other samples of the granodiorite from close to the contact with Micalong Swamp Basic Igneous Complex, contamination is rare. A sample from within 1 m of a gabbro contact at grid reference 383843 is a normal granodiorite with red-brown biotite (15%), quartz, and plagioclase phenocrysts up to 4 mm, and an average grainsize of 1 mm. A thin section through a granodiorite-dolerite contact from grid reference 396838 shows the granodiorite to be richer in microcline than elsewhere in the intrusion, and finer-grained (0.5-1 mm); in the same sample, one xenolith of dolerite 4 mm across is present within the granodiorite, which is clearly the younger of the two.

Xenoliths are common in the Broken Cart Granodiorite, and two cognate types have been observed with the assemblages:

- plagioclase-biotite-quartz-cordierite (altered)
- plagioclase-biotite-quartz-muscovite

The plagioclase forms subhedral zoned laths 0.1 to 0.3 mm, and biotite is dark red-brown and present in amounts up to 35%, interleaved with muscovite in the second assemblage. Quartz commonly encloses the other minerals present.

Couragago Granodiorite
(new name)

Nomenclature

We have introduced this name for the large body of granodiorite which crops out on the plateau west of Wee Jasper. The body is separated from the Broken Cart Granodiorite by a screen of Goobarragandra Volcanics, which has been intruded by meridionally oriented basic dykes.

Derivation of name

The name is derived from Couragago station (grid ref. 408070).

Type locality

The type locality is here given as the exposures at grid reference 411126, on the southern side of Yass Road about 300 m east of the road to Hilltop. The exposures are about 50 m from Yass Road, and consist of tors up to 2 m high of medium-grained pale grey granodiorite with about 10% biotite.

Field occurrence

The Couragago Granodiorite occupies a large area of the northern part of the Kiandra Tableland (see GEOMORPHOLOGY) in BRINDABELLA and TUMUT. It is about 20 km long and 10 km wide in BRINDABELLA, and extends for an unknown distance to the west in TUMUT.

The topography developed over the intrusion is flat to undulating as a result of Tertiary (early Miocene or older) planation, and, as a result, exposure is sparse in some of the flat areas surrounding Cowrajago Hill. In the more undulating areas, especially south of Yass Road, exposure is fair to good and consists of rounded tors and boulders mostly less than 2 m wide. The tors are distinctly smaller than those developed in the Broken Cart Granodiorite.

The most common rock type is a fine to medium-grained pale grey biotite granodiorite, often with phenocrysts of plagioclase and lesser quartz usually less than 10 mm. Biotite is less abundant than in the Broken Cart Granodiorite and represents only about 10% or less of the rock, though locally (such as at grid ref. 439111) about 15% biotite is present. The quartz in the Couragago Granodiorite is a pale violet-grey, not bluish as in the Broken Cart Granodiorite.

On the northern margin of the body the rock is porphyritic, with phenocrysts of quartz and plagioclase up to 4 mm and of biotite 1-2 mm in a microcrystalline groundmass.

At its southern end a stock of leucogranite of about 10-km^2 outcrop area is associated with the Couragago Granodiorite, and leucogranite forms a marginal phase about 4 km long and 300 m wide on the eastern side of the granodiorite, where it intrudes an elongate basic stock of the Micalong Swamp Basic Igneous Complex. The contact between the granodiorite and the leucogranite is sharp, but near grid reference 423090 the granodiorite is poorer in biotite, richer in microcline, and contains primary muscovite, and is really an adamellite, so gradational contacts may exist at depth. The leucogranite is mostly fine-grained and pale pink, but pegmatitic aggregations up to a few centimetres are common; they are composed of quartz, pale pink feldspar, and muscovite. Near grid reference 416016 the leucogranite contains abundant dark grey patches up to 1 cm of unknown significance; a thin section shows them to be large xenomorphic crystals of quartz containing about 30-40% interconnected inclusions of sericite and minor biotite.

We did not see any contacts between the Micalong Swamp Basic Igneous Complex and the Couragago Granodiorite, but the granodiorite is neither contaminated nor recrystallised near contacts. Large pods and embayments of basic rocks occur within the granodiorite but basic dykes are absent. These criteria suggest that, like the Broken Cart Granodiorite, the Couragago Granodiorite is the younger, and that the magma had great difficulty in intruding and assimilating the older basic rocks.

Petrography

Two modal analyses of the Couragago Granodiorite are given in Table M16. Compared with the Broken Cart Granodiorite, it is richer in microcline and poorer in biotite; sample 73840302 is strictly an adamellite. Several other samples collected were visually estimated to be adamellites, but we consider that the average composition is just within the granodiorite field. A more detailed study may prove otherwise.

Textural relations between minerals are similar to those in the Broken Cart Granodiorite, but the average grainsize is less (2 mm). Plagioclase forms euhedral to subhedral laths up to 4 mm but mostly around 2 mm, with oscillatorily zoned cores An_{30-50} and narrow An_{15-20} rims. Quartz is anhedral and possesses weakly undulose extinction. Microcline (1-2 mm) is present as interstitial grains with film and vein perthite lamellae. Biotite is characteristically red-brown, but in some samples is dark brown with only a slight reddish tinge. Accessories are invariably associated with and included in the biotite. Altered cordierite has not been seen.

Hornblende was evident in only one sample, from grid reference 429101, where the rock is fine-grained (average <1 mm) and is probably part of a later stock or dyke, though field relations are obscured by lack of outcrop. The rock is a granodiorite containing abundant quartz (probably about 50%), only 5%

microcline perthite, 5% dark brown biotite, and 3% hornblende with X = pale yellow brown, Y = green with a brownish tinge, Z = dark blue green, and absorption X < Z < Y. Allanite, a common accessory in this rock, is not present in any of the other samples from the Couragago Granodiorite; it forms pale yellow or orange partly metamict subhedral zoned crystals of about 0.3 mm.

The leucogranite associated with the Couragago Granodiorite consists mainly of quartz and microcline with lesser, zoned albite-oligoclase and intergrown muscovite and minor biotite. Unlike the biotite in the granodiorite the biotite in the leucogranite is brownish green, which may be due to interlayered chlorite.

Spicers Creek Adamellite
(new name)

Nomenclature

We have introduced this name for a small body of medium-grained adamellite which crops out about 3 km north of Yarrangobilly Mountain.

Derivation of name

The name is taken from Spicers Creek (in the Upper Cotter SMA 1-Mile Series Sheet area), which is about 3 km east of the pluton.

Type locality

The intrusion is similar in composition and texture throughout. At the type locality (grid ref. 382527) fresh specimens are medium-grained, pale grey, and have pale yellow-green phenocrysts of plagioclase up to 10 mm. Biotite is abundant.

Field occurrence

The spicers Creek Adamellite crops out over an area of 1200 by 500 m about 3 km west of Spicers Creek. It lies to the west of the Starvation Point Adamellite (see below), from which it is separated by a screen of intensely jointed Goobarragandra Volcanics about 200 m wide. Intrusive contacts between the granodiorite and Goobarragandra Volcanics have not been seen in the field.

The adamellite crops out as tors up to 2 m wide, and is generally better exposed than the Starvation Point Adamellite. The rock is extremely weathered, and ironstained from the breakdown of biotite. Fresh specimens are rarely obtainable from the cores of boulders even 1 m in diameter.

Petrography

The modal composition of a sample from the type locality is shown in Table M16. The rock is allotriomorphic and contains rounded strongly sericitised phenocrysts of plagioclase up to 3 mm in a medium-grained groundmass of quartz (1 mm), perthite (up to 1.5 mm), albite-oligoclase, and biotite flakes almost completely altered to chlorite. Opaques, epidote, and apatite are rare accessories. Graphic quartz-potash feldspar intergrowths are uncommon. The rock is similar to the Couragago Granodiorite, but has a little more biotite.

Starvation Point Adamellite

(new name)

Nomenclature

The Starvation Point Adamellite crops out a few hundred metres east of the Spicers Creek Adamellite, but obviously is a separate intrusion.

Derivation of name

The name is taken from 'The Peaks' Parish map, which shows Starvation Point on the crest of the Fiery Range about 3.3 km northeast of the intrusion. There is no closer available name.

Type locality

At the type locality (grid ref. 391532) the rock is pink, fine to medium-grained, and contains about 10% of greenish black hornblende. White plagioclase phenocrysts up to 5 mm are widely scattered throughout.

Field occurrence

The Starvation Point Adamellite is about 1.5 km^2 in area of outcrop, slightly larger than the Spicers Creek Adamellite. It crops out as tors and angular blocks up to 1 m wide, in a relatively flat valley to the west of the Fiery Range. Together with the Spicers Creek Adamellite it is surrounded by higher hills except to the west, where the area is drained by a valley 300 m wide.

The adamellite intrudes the Goobarragandra Volcanics, and is contaminated near its edges. There it becomes more porphyritic with plagioclase and quartz phenocrysts up to 5 mm, and hornblende gives way to biotite. A recrystallised sample from near the margin at grid reference 389524, mapped as part of the pluton in the field, is probably a hornfelsed volcanic rock as it contains rounded embayed quartz phenocrysts. Elsewhere exposure is poor near the margins, and the extent of the contact aureole is unknown, though it cannot be more than about 150 m.

Petrography

Modal analyses of two samples of the Starvation Point Adamellite are given in Table M16. These rocks are quite different from the Spicers Creek Adamellite and the granodiorites farther north. In the Starvation Point Adamellite, quartz is less abundant, and orthoclase, as distinct from microcline, is roughly equal in abundance to plagioclase. Hornblende is present in large amounts in the sample from the type locality (sample 71840318), but in the other sample, from nearer the edge of the pluton, biotite is more common than hornblende.

The rock consists mainly of subgraphic quartz-orthoclase intergrowths averaging 1.5 mm, in which quartz is the main partner. These are moulded around subhedral highly sericitised plagioclase, and orthoclase perthite of 1 to 2 mm. The plagioclase cores commonly contain prehnite as an alteration product, and epidote, prehnite, pumpellyite, and chlorite form interstitial alteration products. Hornblende forms subhedral to euhedral elongate prisms and needles up to 2.0 x 0.8 mm; it is pleochroic, with X = pale yellow-brown, Y = green, and Z = brown. A few euhedral yellow allanite crystals (0.2 to 0.3 mm) are also present. Biotite is mostly chloritised, but when fresh is dark brown.

Kennedy Range Adamellite

(new name)

Nomenclature

We have introduced this name for a small pluton which crops out at the northern end of Kennedy Range.

Derivation of name

The name appears on the Currango 1:50 000 Sheet, but is called Kennedy Ridge on the TANTANGARA map.

Type locality

The type locality is at grid reference 402638, where a few boulders of fine-grained pale pink adamellite crop out. This is the closest reasonable exposure to vehicular access.

Field occurrence

The Kennedy Range Adamellite crops out over an area of about 2 km^2. At its centre is a prominent hill at the head of a tributary of the Goobarragandra River (grid ref. 405642). The intrusion has been considerably disturbed by faulting and by the later intrusion of gabbro. It intrudes the Goobarragandra Volcanics and has associated widespread aplitic dykes which have been found up to 2 km southwest of the nearest adamellite outcrop.

The adamellite is well jointed and in places brecciated, and is strongly weathered. Exposure is poor and consists mainly of float and joint blocks of about 20 to 30 cm. The rock is pale pink to white, medium-grained, and non-porphyritic. Both biotite and hornblende are present. Xenoliths of finer-grained rock of similar composition are common throughout; they are rounded, disc-shaped, and are mostly about 5 cm in diameter.

The associated aplites are pinker than the granite, fine-grained, and contain rare plagioclase phenocrysts up to 3 mm.

Petrography

Modal analyses of a sample from the type locality and of an aplite dyke are given in Table M16. The adamellite contains strongly zoned plagioclase (An_{40} to An_{10}) up to 2 mm, whose euhedral boundaries are rimmed by microperthite. Some of the plagioclase crystals have highly sericitised cores. The plagioclase occurs together with quartz-orthoclase-perthite intergrowths (1 mm), and clots of anhedral green-brown hornblende and dark brown biotite. The rock is partly recrystallised, and a granoblastic texture is present in areas rich in quartz and potash feldspar. Rare grains of hypersthene (1 mm) are surrounded by opaques, hornblende, and biotite. The rock has probably been metamorphosed by a gabbro which crops out only 100 m away, and is considered to have intruded the adamellite. A sample from grid reference 401635 is less recrystallised than that from the type locality, and contains a 5-mm xenolith composed of hornblende, biotite, plagioclase, and quartz with an average grainsize of 0.2 mm.

The aplite associated with the adamellite is allotriomorphic equigranular and consists of quartz, potash feldspar, plagioclase, and minor brown-green hornblende and brownish biotite. The potash feldspar is weathered brown, and the plagioclase black-brown. The plagioclase is zoned and tends to be slightly porphyritic with an average grainsize of about 0.5 mm. Although there are no graphic intergrowths of quartz and potash feldspar, poikilitic quartz is present, and contains rounded plagioclase laths.

The Kennedy Range Adamellite is similar to the Starvation Point Adamellite in that it contains hornblende and is poorer in quartz than the rest of the Young Batholith in the mapped area. It is, however, significantly richer in orthoclase, and the hornblende is less euhedral.

Coodravale Granodiorite

(new name)

Nomenclature

We have introduced this name for a pluton which crops out south of Wee Jasper Creek.

Derivation of name

The pluton is named after Coodravale, a property on the Goodradigbee River at grid reference 539120. There is no closer available name.

Type locality

The type locality is at grid reference 499113 on the side of the ridge about 250 m south of Yass Road, where angular blocks up to 0.5 m of a fine-grained pinkish grey plutonic rock with about 10% mafic minerals crop out.

Field occurrence

The Coodravale Granodiorite is a small (4.5 km^2) east-west oriented pluton about 5 km long and up to 1.5 km wide which occupies most of the ridge immediately south of Yass Road north of Mount Wee Jasper. The northeast side of the pluton is cut by the Long Plain Fault.

Exposure is poor: small angular blocks and float predominate. The rock is fine-grained, pale pink to grey with up to 10% greenish mafic minerals, often in clots up to 3 mm. Plagioclase forms scattered, somewhat rounded phenocrysts up to 3 mm, but quartz phenocrysts are absent.

The western part of the pluton appears to intrude a basic stock of the Micalong Swamp Basic Igneous Complex. This relation is borne out by the distribution of basic dykes; these are common immediately south, adjacent to the basic stock, but are rare within the pluton outcrop (one, for example, intruding the granodiorite at grid reference 498113, near the type locality). These dykes are definitely part of the Micalong Swamp Basic Igneous Complex and indicate that the Coodravale Granodiorite was intruded when basic magma was still active.

Petrography

The Coodravale Granodiorite is a fine, even-grained (average size 1 mm) hornblende and biotite-bearing rock with a composition close to the granodiorite-adamellite boundary. A modal analysis (Table M16) shows that a sample from the type locality contains plagioclase in the proportion 69% of total feldspar and is thus a granodiorite. Other samples, such as that from grid reference 474104, are probably adamellites.

Quartz is commonly of euhedral beta-habit with optically continuous overgrowths intergrown with adjacent feldspar. Plagioclase has irregular outer margins of albite and rectangular-shaped strongly zoned cores which when fresh are zoned up to An_{60} in some crystals; the cores, however, are mostly saussuritised. Orthoclase perthite forms equant crystals (0.5 mm) and irregular grains interstitial to plagioclase and quartz and intergrown with quartz. Hornblende forms discrete euhedral prisms up to 2 mm long with X = pale yellowish brown, Y = greenish brown, and Z = brownish green, but a greener less euhedral variety is commonly intergrown with biotite. Biotite is in roughly equal abundance to hornblende, and occurs as intergrown, mostly chloritised patches up to 3 mm. When fresh the biotite is pleochroic from pale yellowish-brown to dark brown. Opaques, epidote, allanite, and chlorite are common accessory minerals.

The eastern end of the pluton along with a large area of Goobarragandra Volcanics east of Mount Wee Jasper has been strongly recrystallised, apparently by contact metamorphism from a later pluton which does not crop out at the surface. The buried pluton may be part of the Micalong Swamp Basic Igneous Complex, but it is more likely to be related to the Lower Devonian Burrinjuck Adamellite.

In the field the Coodravale Granodiorite resembles the fractionated rocks from the Micalong Swamp Basic Igneous Complex, but under the microscope the two are easily distinguished. Quartz and opaques are more abundant in the latter, and biotite and orthoclase are rare. The amphibole in the fractionated Micalong Swamp rocks is a very dark greenish black ferrohastingsite.

The Coodravale Granodiorite is similar to the Starvation Point Adamellite and Kennedy Range Adamellite, yet the Coodravale Granodiorite is over 40 km north of the other two plutons.

Age and relations of the Young Batholith

All the plutons that we have mapped in the Young Batholith intrude the Goobarragandra Volcanics, of Wenlockian and possibly Ludlovian age. However, their relations with the Micalong Swamp Basic Igneous Complex are less simple. The Broken Cart Granodiorite intrudes the basic complex, but a fine-grained porphyritic intrusion at the southwestern margin of the granodiorite (probably a separate intrusion) contains basic dykes. That these dykes are much less common in the porphyritic intrusion than in the adjacent Goobarragandra Volcanics

TABLE M16. MODAL ANALYSES OF THE YOUNG BATHOLITH

Pluton	Broken Cart Granodiorite	Broken Cart Granodiorite	Couragago Granodiorite	Couragago Granodiorite	Spicers Creek Adamellite	Leucogranite in Broken Cart Granodiorite	Starvation Point Adamellite	Starvation Point Adamellite	Kennedy Range Adamellite	Aplite near Kennedy Range Adamellite	Coodravale Granodiorite
Sample no.	73840368	72840286	73840323	73840302	71840380	72840238	71840318	71840381	71840410	71840409	73840347
Grid ref.	413917	419860	411126	369073	382527	411950	391532	385532	402638	398632	499115
Quartz	41.2	38.8	39.7	44.3	39.4	34.3	30.7	35.7	27.9	31.3	31.5
Microcline	11.9	14.3	15.9	19.4	16.5	36.1					
Orthoclase							24.8	27.2	34.7	36.4	17.1
Plagioclase	27.2	33.0	34.1	27.9	27.0	21.5	29.1	24.3	29.9	26.7	38.2
Hornblende							8.6	3.5	4.2	1.3	5.7
Biotite	15.4	13.1	10.2	7.9	16.1 (mostly chloritised)	0.5	5.9	8.4 (mostly chloritised)	2.5	4.0	5.1
Cordierite (altered)	2.1										
Muscovite	1.8	0.5		0.1		7.4					
Others (epidote, chlorite, opaques, apatite, zircon)	0.4	0.3	0.1	0.4	1.0	0.2	0.9 (includes allanite, prehnite, and pumpellyite)	0.9 (includes allanite and prehnite)	0.8 (includes hypersthene)	0.3	2.4 (includes allanite)

implies that the basic dykes and possibly the whole of the Micalong Swamp Basic Igneous Complex were being intruded over quite a long time. Some dykes, the later ones, intruded the country rock just before the Broken Cart Granodiorite reached its final emplacement position. Basic dykes intrude the Coodravale Granodiorite but are less common than in the adjacent Goobarragandra Volcanics. The Couragago Granodiorite appears also to have intruded the Micalong Swamp Basic Igneous Complex, though the evidence is not so good, and is intruded by the Burrinjuck Adamellite of Early Devonian age. The Spicers Creek Adamellite is similar to the Couragago Granodiorite and probably has a similar age.

The Starvation Point Adamellite, Kennedy Range Adamellite, and Coodravale Granodiorite are quite different from the other plutons of the Young Batholith, and are probably not chemically related - they are I-type granitoids. The Kennedy Range Adamellite appears to have been hornfelsed by a basic intrusion, yet the Coodravale Granodiorite intrudes another basic intrusion.

Geochemical evidence indicates a strong probability that the Goobarragandra Volcanics and the Young Batholith are related, and that the plutons of the batholith have intruded their own volcanic pile. It therefore seems that the Goobarrangandra Volcanics, the Micalong Swamp Basic Igneous Complex, and the Young Batholith all developed at about the same time in the middle to Late Silurian. It is puzzling why contamination between the basic and granitic magmas was not more widespread. Perhaps the tonalite in the northeast of the Broken Cart Granodiorite represents such a contaminated product.

MINOR S-TYPE INTRUSIONS

There are several S-type intrusions in BRINDABELLA and TANTANGARA which are too small to be worth naming. These have been denoted as 'Sgs' on the maps, and include the small prophyritic stock at grid reference 470455 that Crook & others (1973) referred to as the Mufflers Creek Granite.

Most of the intrusions are quartz-plagioclase porphyries with a fine-grained granitic to graphic groundmass of quartz, potash feldspar, and albite. Biotite phenocrysts are common, and in some samples potash feldspar is also a phenocryst phase (e.g., grid ref. 433432). Chloritised and pinitised euhedral cordierite is present as crystals of about 1 to 2 mm in some bodies, such as the one near Mufflers Creek and those near Belconnen (grid ref. 798011).

One stock near Port Phillip Gap (grid ref. 452483) contains common xenocrysts of pale pink garnet up to 10 mm, with inclusions of biotite and plagioclase. The garnets are surrounded by completely chloritised reaction rims, which are interpreted as having been mostly cordierite and lesser hypersthene-similar to the garnet rims in the nearby Kellys Plain Volcanics. The chloritised rims generally contain vermicular chlorite intergrown with chlorite in a different optical orientation. The vermicular chlorite was probably the original hypersthene. In addition to the cordierite surrounding the garnet, euhedral and anhedral altered cordierite are common phenocrysts in the rest of the rock. This stock near Port Phillip Gap and the one near Mufflers Creek may have been feeders for the Kellys Plain Volcanics.

BUGTOWN TONALITE
(new name)

Nomenclature

In the Canberra 1:250 000 Sheet area (Best & others, 1964), the elongate pluton occupying much of the Bulgar Creek valley was accurately shown but not given a name. Owen & others (1974a) included the pluton in the McLaughlins Flat Granodiorite as a hornblende-bearing more mafic phase. As the absence of hornblende from, and the high initial Sr^{87}/Sr^{86} ratio in, the McLaughlins Flat Granodiorite classify it as S-type, the hornblende-bearing pluton requires a separate name as it is similar to I-type granitoids which crop out to the south (Hine & others, 1978).

Derivation of name

We propose that the pluton be termed the Bugtown Tonalite, after Bugtown on Bulgar Creek, at grid reference 125673 on the Tantangara SMA 1-Mile Series Sheet. On the TANTANGARA map, Bugtown is shown about 3 km to the east, on the Yaouk-Adaminaby road.

Type locality

The type locality is here given as at grid reference 533180 on the Snowy Mountains Highway. Here, boulders up to 1 m of foliated medium-grained hornblende-biotite tonalite with a few rounded xenoliths crop out next to a small road-cut.

Field occurrence

The Bugtown Tonalite is about 9.5 km long and 1 to 1.5 km wide, the long axis bearing 020^{o}. The pluton erodes more easily than the adjacent sediments, which have been strongly hornfelsed, and occupies most of the Bulgar Creek valley. About 1 km north of the Snowy Mountains Highway, Goorudee Rivulet has formed a V-shaped valley to the west and east of the pluton outcrop, but where it flows across the outcrop the relief is much more subdued.

The pluton is generally poorly exposed as widely scattered tors usually less than 1 m wide. The only area where tors are more closely spaced is on the eastern side of the pluton near Glenwood (grid ref. 545200). A moderate to strong secondary foliation, present throughout the pluton, is aligned slightly east of north, not quite parallel to the long axis of the pluton.

Petrography

The composition of the Bugtown Tonalite ranges from hornblende-biotite tonalite to hornblende-biotite granodiorite. Two modal analyses are:

Rock type	Granodiorite	Tonalite
Sample no.	71840034	72840046
Grid ref.	540217	533180
Quartz	33.1	30.1
Orthoclase	6.2	0.1
Plagioclase	37.4	50.2
Biotite	18.7	11.2
Hornblende	4.0	7.7
Accessories (apatite, zircon, allanite, opaques, epidote)	0.6	0.7

The pluton is zoned: it comprises tonalite at the southern and northern ends and granodiorite in the centre. Tonalite appears to be the most abundant rock type.

Plagioclase is present as strongly zoned An_{65-30} stumpy prisms mostly less than 1 mm, but there are also widely scattered phenocrysts up to 3 mm. The prisms commonly have broad oscillatorily zoned calcic cores and narrow normally zoned rims. Quartz forms intergranular composite patches up to 4 mm, commonly enclosing plagioclase; the patches have internal sutured boundaries and strong undulose extinction, indicative of post-crystallisation deformation. Some plagioclase crystals are also bent or broken, but mostly they act as rigid blocks within the more easily deformed quartz. Alkali feldspar when present forms small interstitial grains; it is non-perthitic, and has a wavy extinction and low 2V, indicating orthoclase.

Biotite is always more common than hornblende and occurs mostly as subhedral books 1 to 2 mm thick. It is pleochroic from pale straw yellow to greenish brown, and in most crystals the edges are greener than the cores. Pleochroic haloes are common, and alteration to chlorite, epidote, and sphene is widespread. Subhedral to anhedral hornblende averaging 1 to 2 mm is evenly distributed throughout the rock, and is present in amounts up to 8% at the type locality. It is pleochroic with X = pale yellowish green, Y = yellowish green, and Z = bluish green; $X < Y < Z$. Biotite and hornblende in places are intergrown in patches up to 4 mm.

Magnetite is the most abundant accessory but allanite, zircon, and apatite are also present. The allanite forms euhedral crystals up to 1 mm long.

Samples of tonalite from near grid reference 545200 differ from the rest of the pluton: they have no hornblende, abundant muscovite, and biotite pleochroic from pale yellow to red-brown; subhedral patches of sericite and chlorite probably pseudomorph cordierite, and potash feldspar is absent. Although the plagioclase is unaltered and normally zoned from An_{45} to An_{20}, the rest of the rock is made up of roughly equigranular equant grains which, despite strong subsequent deformation, resemble a hornfels texture. This small area of granitoid is probably an earlier S-type intrusion which has been intruded and hornfelsed by the Bugtown Tonalite, and then deformed along with it.

Contact effects

The Bugtown Tonalite has imposed on the surrounding sediments a strong metamorphic effect up to 1.5 km from the contact on the western side of the pluton, and 1 km on the eastern side. Cordierite spots are evident 1 km to the west of pluton at grid reference 522193, and andalusite is evident in a metapelite 700 m west of the pluton at grid reference 529204. The metamorphic minerals antedate the strong deformation in the area, which is thus probably responsible for the secondary foliation in the tonalite.

Age

The Bugtown Tonalite intrudes the Lower Silurian Tantangara Formation. It antedates a deformation event which has strongly affected the fault block bounded to the west by the Tantangara Fault, and to the east by the Cotter Fault. To the north, rocks deformed by this event were unconformably overlain in the earliest Devonian by the Kellys Plain Volcanics, which were not affected by the deformation. Thus the Bugtown Tonalite can be stratigraphically dated as between Early Silurian and earliest Devonian.

Mineralogically the tonalite is similar to the I-type Jindabyne Suite plutons of Hine & others (1978). As most of the Jindabyne Suite granitoids intrude the S-type granitoids in the Kosiusko Batholith, the Bugtown Tonalite is probably similarly younger than the adjacent S-type plutons in the Gingera and Kosciusko Batholiths, but still of Late Silurian age.

UNNAMED JINDABYNE SUITE I-TYPE PLUTONS (Sgi)

West and northwest of the Bugtown Tonalite outcrop but east of the Tantangara Fault are several small intrusive bodies, all containing hornblende, that are here provisionally assigned to the Jindabyne Suite of I-type granitoids (Hine & others, 1978). Although some may eventually prove to be unrelated to that suite, none appear to be related to the Boggy Plain Suite of I-type granitoids, which are mineralogically distinct and crop out only to the west of the Tantangara Fault.

The largest of these unnamed bodies is a granodiorite about 1200 x 300 m cropping out east of Gravel Hut (grid ref. 498260). It contains dark brown biotite, minor pale green hornblende and orthoclase, and strongly zoned euhedral plagioclase.

A hornblende-biotite tonalite is exposed over an area of about 0.15 km^2 on Nungar Creek (grid ref. 484295). Samples are highly weathered; plagioclase is completely saussuritised, and hornblende and biotite are mostly chloritised, but here and there fresh dark red-brown biotite and pale green hornblende are evident.

On the southern edge of Nungar Plain (grid ref. 492269) a hornblende-biotite granodiorite outcrop about 300 m in diameter contains saussuritised euhedral plagioclase, dark red-brown biotite, green hornblende, and orthoclase.

At grid reference 515279 a hornblende-quartz diorite is exposed. It contains very calcic plagioclase, up to An_{85}, abundant brown to pale brown hornblende and minor red-brown biotite.

At grid reference 463219 a hornblende-quartz microdiorite dyke intrudes the Lucas Creek Granite. It contains zoned plagioclase up to An_{80}, and about 30% euhedral greenish brown hornblende, some of which surrounds partly uralitised clinopyroxene. Opaques, sphene, and biotite are accessory phases.

All these intrusions are hornblende-bearing intrusives with little or no potash feldspar, and abundant strongly zoned euhedral plagioclase. In these respects they are similar to the Bugtown Tonalite and the Jindabyne Suite. They do, however, show quite a range in the colour and proportions of hornblende and biotite. Some of the biotites are red-brown and similar to biotites from S-type intrusives. Magnetite is absent in the pluton at Nungar Creek, whereas it is a constant accessory in the Jindabyne Suite (Hine & others, 1978). Sphene is absent in the Jindabyne Suite (Hine & others, 1978), but is present in the hornblende-quartz microdiorite at grid reference 463219.

CONDOR GRANODIORITE

The 'Condor granite' was briefly described by Malcolm (1954) as a hornblende microgranite which intrudes Ordovician sedimentary rocks and the Mountain Creek Volcanics, and was therefore thought to be Early Devonian or younger, but we found no evidence of its intrusion into the Mountain Creek Volcanics. The body is marked on the 1964 Canberra 1:250 000 geological sheet, and Strusz (1971) described it as a hornblende-biotite granite of unknown affinity. It is now known to be a granodiorite.

The Condor Granodiorite is named after Condor Creek, which flows across its outcrop. The ground is flat and marshy around the creek, and there is no exposure, but north of the creek the land begins to rise steeply and is densely planted with pine trees, and a few tors up to 2 m high occupy the steeper parts, near the base of the Mountain Creek Volcanics. The pluton is roughly rectangular, about 1200 by 700 m.

A sample from the type locality, near the centre of the outcrop at grid reference 667904, contains plagioclase 35%, quartz 35%, orthoclase 15%, biotite 6%, actinolite 5%, and minor augite, magnetite, epidote, chlorite, zircon, and apatite. Subhedral plagioclase grains averaging 1 mm have broad oscillatorily zoned cores of An_{30-45} and narrow albitic rims; quartz (0.3 to 1 mm) is interstitial to the plagioclase, but also occurs as rounded grains. Orthoclase, rarely with patch and vein perthite developed, is common and up to 1 mm. Mafic minerals occur in aggregates up to 4 mm of intergrown biotite, pale green actinolite, augite, magnetite, and quartz. A sample from near the edge of the intrusion (grid ref. 669903) is a tonalite and contains more mafics, especially augite, while orthoclase is rare; this suggests that the pluton is zoned.

The Condor Granodiorite is apparently older than the Mountain Creek Volcanics, and is probably related to chemically similar Jindabyne Suite I-type granitoids farther south. It is probably Late Silurian in age.

GINNINDERRA PORPHYRY
(new name)

Nomenclature

We have introduced the name Ginninderra Porphyry for a red intrusive porphyry which crops out in BRINDABELLA around the lower reaches of Ginninderra Creek and northwest to The Horseshoe.

Derivation of name

The porphyry is named after Ginninderra Creek, the lower part of which flows through the southern end of the intrusion.

Type locality

The type locality of the Ginninderra Porphyry is designated as the lower Ginninderra Falls (grid ref. 774033), where the unit is well exposed. Excellent exposures may also be seen along the Murrumbidgee River between Cusacks Crossing and Ginninderra Creek when the water level is low.

Distribution

The Ginninderra Porphyry crops out over 18 km^2 in three separate intrusions in BRINDABELLA. By far the largest stretches for 8 km from south of Ginninderra Creek to north of The Horseshoe in a belt up to 2.5 km wide. Evidence from the Ginninderra Creek/Murrumbidgee River area suggests that the porphyry is a sill intruding the Laidlaw Volcanics. Farther north, near The Horseshoe, it appears to have a stocklike shape.

The two minor intrusions together crop out over less than 1 km^2 in the northeast, at grid references 795127 and 787157. Both are similar in field appearance to the main mass of Ginninderra Porphyry, but are too weathered to thin-section for reliable identification, and so are only tentatively included in the unit.

In most of the area the Ginninderra Porphyry is well exposed, usually as rounded boulders up to 1 m. Columnar-jointed porphyry at a locality north of Ginninderra Creek (grid ref. 783041) has well-developed columns up to 40 cm in diameter and 10 m high plunging steeply to the northeast, implying that the cooling surface of the intruson dips at about 15^{o} to the southwest. Columnar jointing is also well developed in the gorge of Ginninderra Creek between the upper and lower waterfalls (grid ref. 782032 to 775033), where the columns reach a height of 30 m and a diameter of 1 m; the dip of the cooling surface implied by these columns is about 10^{o} to the west. Farther north no columnar joints are evident in the porphyry, suggesting that it has lost its sill-like form.

Porphyries similar in appearance to the Ginninderra Porphyry also crop out in CANBERRA on the southeast slopes of Mount Taylor and on Mount Neighbour. In both places the intrusions appear to be sills; the one on Mount Taylor lies between the Laidlaw Volcanics and the underlying unnamed volcanics, and the Mount Neighbour sill is within the Laidlaw Volcanics.

Petrography

The Ginninderra Porphyry is uniform in field appearance. Phenocrysts of quartz, pale green to pale pink plagioclase, and dark green mafic minerals are set in a fine-grained red matrix. Phenocrysts are commonly up to 6 mm and quartz crystals may be over 10 mm. Scattered megacrysts of pink euhedral potash feldspar up to 3.5 cm long are also typically present, but are never abundant - usually about 3 to 5 per square metre of outcrop. When the megacrysts are more common a rough alignment may be present.

Thin sections show that the rock is a quartz-albite-pyroxene-biotite porphyry with a coarse microcrystalline groundmass of quartz, potash feldspar, and plagioclase. Quartz forms large (to 10 mm) euhedral, often strongly embayed phenocrysts, and rarely shows evidence of strain under crossed nicols. Albite is generally slightly smaller than quartz, usually less than 5 mm, and forms subhedral to euhedral crystals, many of which contain concentric zones of sericite - indicating that they have formed as a result of albitisation of more calcic plagioclase.

Both biotite and pyroxene generally form aggregates up to 5 mm of small subhedral crystals less than 1 mm long, commonly mixed with albite. Both biotite and pyroxene may, however, also be present as isolated phenocrysts up to 1.5 mm long. Biotite forms subhedral to euhedral crystals and is always altered to green chlorite and iron oxide. The pyroxene is altered to chlorite, iron oxide, and quartz, and is recognised by its characteristic eight-sided basal section. Crystal outline cannot distinguish between clinopyroxene and orthopyroxene, but since there is no calcite present as an alteration product, and since augite appears relatively resistant to alteration, the pyroxene is considered to be an orthopyroxene, probably hypersthene.

Accessory minerals include euhedral apatite, which is fairly common and may be up to 0.4 mm, zircon, and minor epidote as an alteration product. Allanite, similar in appearance to that in the Laidlaw Volcanics, is a rare accessory.

The groundmass, which forms 60-70% of the rock, is composed of potash feldspar and quartz with some albite, and has a microhypidiomorphic granular texture. Crystal size averages about 0.10 mm; larger crystals are up to 0.15 mm across. Potash feldspar, which is altered to a turbid brown colour, forms about 50% of the groundmass; quartz forms 40% and albite 10%. Under high magnification very fine hematite dust is evident in the potash feldspar, and it is this which must give the groundmass its distinctive red colour.

Relations and age

The Ginninderra Porphyry intrudes the Laidlaw Volcanics and is overlain unconformably by the Mountain Creek Volcanics. It is therefore of Late Silurian age. Its intrusive nature is evident in a small gully on the south side of the upper Ginninderra Falls, where a small dyke of the porphyry intrudes the Laidlaw Volcanics about 3 m below the main contact between the two units. Since the porphyry is chemically similar to the Laidlaw Volcanics, and since xenoliths apparently of Ginninderra Porphyry occur in the Laidlaw Volcanics, even though the porphyry intrudes the volcanics, the Ginninderra Porphyry is considered to be the intrusive equivalent of the Laidlaw Volcanics.

Thickness

The Ginninderra Porphyry forms a sill in the south whose minimum thickness is at least 150 m. Farther north, towards The Horseshoe, it appears to become a stock-like body, since the boundary is little affected by topography.

BOGGY PLAIN ADAMELLITE
(new name)

Nomenclature

Ivanac & Glover (1949) mapped granitic rocks north of the Happy Jacks Granite and called them the Boggy Plain granite. The name is considered valid, except that the most abundant rock type is an adamellite, and the body is defined herein.

Derivation of name

The name is taken from Boggy Plain, a grassy plain surrounded by tree-covered low hills about 2 km east of Tantangara Mountain. The plain is about 5 by 2 km and is drained to the north by Boggy Plain Creek.

Type locality

The type locality for the adamellite is designated as grid reference 428315 at the northern end of Boggy Plain, where the most common rock type, hornblende-biotite adamellite, crops out on a low grassy ridge as rounded tors up to 10 m high. The tors are elongate, parallel to prominent meridionally trending joint planes. A more accessible reference locality of a similar rock type is on the Snowy Mountains Highway at grid reference 387264.

Field occurrence

The Boggy Plain Adamellite is a large composite stock of over 40 km^2. It is slightly elongate east-west, about 9 km long and 5 km wide. The eastern third has been displaced about 5 km northwards by the Boggy Plain Fault. This eastern section underlies the entire area of Boggy Plain. The western section crops out in the depression surrounded by Tantangara Mountain, Sawyers Hill, Four Mile Hill, and Alpine Hill, and includes the hilly country near Connors Hill and the flat country at Rocky Plain.

The adamellite is well exposed, commonly as tors and boulders up to 10 m high. Fresh samples are relatively easy to obtain except for the more felsic types.

The most common rock type is a massive pink well-jointed medium-grained hornblende-biotite adamellite. This occurs in all the western two-thirds of the stock except for a minor occurrence of granodiorite at grid reference 431241. On Boggy Plain the stock is more complex. At the northern end the rock is mainly hornblende granodiorite. Towards the south, adamelliite, then more granodiorite, and finally gabbro are present. These have been shown separately on the TANTANGARA map.

Petrography

The Boggy Plain Adamellite is formed by two main and several minor rock types. The main ones are hornblende-biotite adamellite and clinopyroxene-bearing granodiorite.

Hornblende-biotite adamellite. This appears to be the most abundant type present in the intrusion, and crops out over much of the area from the Eucumbene River and Snowy Mountains Highway north to the southern slopes of Tantangara Mountain, and also in the central part of Boggy Plain.

The adamellite is more leucocratic towards the centre of the pluton (10% dark minerals) compared with the margin (15% dark minerals). This is most noticeable on Boggy Plain, where the leucocratic variety crops out near grid reference 428313 and is surrounded on three sides (the fourth being a fault) by darker adamellite. It is also noticeable on the Snowy Mountains Highway: between Connors Hill and Rocky Plain Creek the leucocratic variety crops out, but on the western margin of the pluton near Sawyers Hill the darker variety is present.

The adamellite is medium-grained and consists of dark mafic minerals, pink potash feldspar, white plagioclase, and grey quartz. Its grainsize is even, averaging 2 to 3 mm, with a marked lack of phenocrysts. Foliation is almost completely absent.

The plagioclase is subhedral to anhedral and generally zoned in the normal sense, though oscillatory zoning also occurs. Its composition ranges from An_{50} to An_{25}, the more calcic cores being commonly saussuritised. Some myrmekite boundaries are present against orthoclase. Orthoclase ($2V_x = 45^o$), mostly microperthitic, is generally anhedral and commonly sericitised. Typically plagioclase forms about 35% and orthoclase 20 to 25% of the adamellite.

The biotite is strongly pleochroic (X = straw yellow, Y = Z = brown), and commonly contains apatite, zircon, and opaque inclusions; its alteration to chlorite is minor, but widespread. Hornblende is subhedral to anhedral and pleochroic (X = pale yellow-brown, Y = green, Z = olive green, absorption $X < Y < Z$). Twinning on (100) is common, $2V_x = 70^o$ and $Z \wedge c = 26^o$. Biotite and hornblende generally each form 5 to 10% of the rock. Diopsidic augite is commonly present in minor amounts; it is enclosed by hornblende, and is colourless with $2V_z = 45^o$, generally twinned on (100), and has possible fine-scale exsolution lamellae parallel to (001).

Anhedral quartz forms 25 to 30% of the rock, and generally has relatively few inclusions. Accessory minerals include magnetite, zircon, apatite, and sphene. Modes of three adamellites are listed in Table M17.

The adamellite contains rare pink aplite dykes up to 0.5 m thick. A sample from grid reference 432316 is composed of about 40% orthoclase perthite, 40% quartz, and 20% oligoclase, all of about 1 mm grainsize. Rare biotite occurs as irregular flakes less than 0.5 mm.

<u>Clinopyroxene-bearing granodiorite</u>. Granodiorite crops out in two large areas at the north and south ends of Boggy Plain, and also in a small area on the Snowy Mountains Highway (grid ref. 431241). It is massive, with even-grained dark green or black mafic minerals, white plagioclase, and grey quartz crystals. The grainsize is 2 to 3 mm, and phenocrysts are absent. The field relations of the granodiorite and adamellite are uncertain. The two apparently grade into one another at the south end of Boggy Plain, although there is a sharp contact in the north of the plain. No exposures showing this sharp contact were seen, though outcrops of the two rock types were found only 2 m apart.

Unlike the adamellite the granodiorite comprises subhedral to anhedral plagioclase, clinopyroxene, and hornblende poikilitically enclosed in quartz and orthoclase. The plagioclase is strongly zoned with a compositional range of An_{60} to An_{30}; oscillatory zoning is common in the cores, and saussuritisation is widespread. Anhedral orthoclase is generally microperthitic and commonly sericitised, and rarely has myrmekitic grain boundaries when in contact with plagioclase. Plagioclase generally forms 35 to 45%, orthoclase less than 10%, and quartz about 20% of the rock. Plagioclase is commonly enclosed in orthoclase, locally giving a monozonitic texture.

The clinopyroxene appears to be a diopsidic augite, is colourless to pale green with $2V_z = 55\text{-}60^o$, and is in a similar form to that in the adamellite - that is, as relict crystals surrounded by a reaction rim of hornblende. However, reaction to produce hornblende has not been as complete in the granodiorite as in the adamellite. The diopsidic augite is commonly twinned on (100), has exsolution traces parallel to (001) and (100), and forms from 5 to 10% of the rock. Hornblende forms about 10 to 20% of the rock, and is similar to the hornblende present in the adamellite. Biotite occurs as anhedral flakes, and has similar properties to the biotite in the adamellite; it forms less than 10% of the granodiorite. Accessory minerals include magnetite, zircon, apatite, and sphene. The modal compositions of three granodiorite samples are shown in Table M17.

<u>Minor rock types</u>. Apart from the two major rock types described above there are two small bodies of more basic composition within the pluton, both on Boggy Plain.

At the northern end of Boggy Plain a two-pyroxene gabbro (not shown on the map) forms a rim about 300 m wide along the northern edge of the granodiorite. The rock (see modal analysis in Table M17) is dark grey and is formed by medium-grained subhedral phenocrysts of hypersthene, augite, and plagioclase in a fine to medium-grained groundmass of plagioclase, clinopyroxene, orthopyroxene, hornblende, biotite, and quartz. In some places cumulophyric groups of pyroxene up to 10 mm are abundant. The hypersthene shows typical pleochroism: X = pink, Y = neutral, Z = pale green; $2V_x$ is very low for hypersthene, possibly about 45^o, and the hypersthene has exsolution lamellae of clinopyroxene parallel to (100). Augite has $2V_z = 50^o$ and has exsolution lamellae of opaques parallel to (001) and (100). Minor reaction of the pyroxenes has produced hornblende with $2V_x = 70^o$, X = pale green, Y = green, Z = green, and absorption $X < Y < Z$. Plagioclase is euhedral to subhedral and zoned from An_{65} to An_{40}; cores are commonly oscillatorily zoned. Many of the plagioclase laths have minute inclusions of octahedral opaques and minor irregular exsolved orthoclase; rarely the larger laths have abundant rounded orthopyroxene inclusions. Biotite occurs as irregular flakes commonly adjacent to pyroxene. Quartz is interstitial and commonly poikilitically encloses plagioclase and pyroxene.

At the southern end of Boggy Plain a biotite-bearing two-pyroxene gabbro similar to that to the north crops out over an area greater than 1 km^2. Hypersthene is the main mafic phase, and both hypersthene and augite have narrow reaction rims of hornblende. Biotite occurs as anhedral grains up to 2 mm embedded between plagioclase laths. Quartz is interstitial and orthoclase is rare. A sample from grid reference 444278 contains xenocrysts of olivine up to 1 mm with $2V_x = 80^o$. These are surrounded by reaction rims of orthopyroxene, with $2V_x = 70^o$ (bronzite), distinct from the rest of the orthopyroxene in the rock, which has a low 2V and is probably hypersthene or ferrohypersthene. Also present in the sample are microxenoliths up to 2 mm of orthopyroxene ($2V_x = 50^o$) and plagioclase about 0.1 mm with a granular texture and triple-point boundaries; these are metamorphosed cognate xenoliths.

Near the contact of the gabbro with the Gang Gang Adamellite, quartz and orthoclase are more abundant, and many of the mafic grains occur in cumulophyric groups. Both two-pyroxene-quartz gabbro (see modal analysis in Table M17) and granodiorite are present in this area.

Contact effects

The Boggy Plain Adamellite has imposed a strong contact metamorphic aureole on the surrounding country rocks. Elevated hornfelsic ridges completely surround the pluton, even in the adjacent Gang Gang Adamellite. The most distant noticeable effect of the pluton on the surrounding rocks is on the northwest side of the Sawyers Hill/Tantangara Mountain hornfelsed rim. Tuff in the Temperance Formation up to 2 km from the contact contains metamorphic biotite and actinolite. The actinolite occurs as a reaction rim around original

TABLE M17. MODAL ANALYSES OF THE BOGGY PLAIN ADAMELLITE

Rock type Sample no. Grid ref.	Adamellite 73840486 430313	Adamellite 71840181 438318	Adamellite 71840201 384263	Granodiorite 71840189 435292
Quartz	33.2	27.1	27.3	19.1
Orthoclase	29.3	22.6	20.8	11.0
Plagioclase	28.4	34.6	34.8	44.1
Biotite	4.6	8.7	6.7	8.2
Hornblende	3.8	5.3	8.4	12.3
Clinopyroxene	-	0.5	1.2	4.9
Orthopyroxene	-	-	-	-
Accessories (magnetite, sphene, apatite, zircon)	0.7	1.2	0.8	0.4

Rock type Sample no. Grid ref.	Granodiorite 71840191 439291	Granodiorite 71840183 445324	Two-pyroxene-quartz gabbro 73840179 444275	Two-pyroxene gabbro 71840185 426329
Quartz	21.7	17.4	9.6	2.7
Orthoclase	4.2	5.4	2.1	0.2
Plagioclase	44.2	42.4	49.7	55.1
Biotite	7.4	8.7	3.5	4.9
Hornblende	16.6	18.3	16.9	0.4
Clinopyroxene	5.3	7.2	12.7	17.1
Orthopyroxene	-	-	4.4	19.3
Accessories (magnetite, sphene, apatite, zircon)	0.6	0.6	1.1	0.3

clinopyroxene grains, and the biotite is present as recrystallised patches within the matrix and commonly as patches in the cores of partly altered clinopyroxene grains. These effects cannot be caused by the regional metamorphism in the Temperance Formation as the area is in the unrecrystallised and albite-prehnite zones.

An interesting effect on samples from within the unrecrystallised zone on the ridge northwest of Black Walters Creek (grid ref. 375285) is the formation of biotite and actinolite without albitisation of original igneous and detrital plagioclase; a fluid phase was apparently not available to remove the anorthite component from the plagioclase. In this respect the contact metamorphism differs from the older regional metamorphism in which albitisation was widespread and proceeded at much lower grades than in the actinolite and biotite zones.

Another contact-metamorphosed rock type about 2 km from the Boggy Plain Adamellite contact is a Silurian quartz-plagioclase porphyry dyke which intrudes the Boltons beds at grid reference 409296. Plagioclase phenocrysts remain unalbitised, but original biotite phenocrysts have been completely recrystallised, and blue-green actinolite needles are associated with the biotite.

Contact metamorphism of the Boltons beds and Tantangara Formation has produced three recognisable zones. An outer biotite zone 1 to 2 km from the contact is characterised by the assemblage quartz-biotite-muscovite-(chlorite), in which the biotite (about 0.02 mm) is present as anhedral red-brown flakes. Cordierite spots up to 1 km from the contact and abundant within 200 m of it characterise the cordierite zone, the assemblage being quartz-biotite-cordierite-muscovite. In the outer parts of the zone the cordierite occurs as scattered rounded poikiloblastic grains (0.5 mm) in rocks of pelitic composition. Closer to the contact the cordierite grains have a subhedral prismatic shape and are up to 1 mm by 0.6 mm; many of them have their c-axes aligned parallel. The inner zone, within 25 m of the contact, has a mineralogy similar to the cordierite zone, but the rock has been completely reconstituted to an equigranular rock with an average grainsize of 0.2 mm, though biotite and muscovite are commonly 0.5 mm long. Cordierite is now no longer poikilitic and has recrystallised into many smaller grains (0.2 mm) commonly separated by quartz and biotite of a similar size.

Contact metamorphic effects on the Gang Gang Adamellite have been described in the section on that pluton.

Age

The Boggy Plain Adamellite intrudes the probably Upper Silurian Gang Gang Adamellite. It is mineralogically and chemically similar to the Coolamine Igneous Complex and is therefore likely to be of similar age. The Coolamine Igneous Complex is Early Devonian and this age is suggested for the Boggy Plain Adamellite. K-Ar dating indicates an age of about 417 m.y. Rb-Sr dating indicates an age of about 406 m.y. (see GEOCHRONOLOGY for a more detailed discussion on the isotopic ages).

GURRANGORAMBLA GRANOPHYRE

Nomenclature

Stevens (1958b) gave the name Gurrangorambla Granophyre to a pink felsic rock which forms much of the Gurrangorambla Range south of Cooleman Plain and Seventeen Flat, but he designated no type locality for the unit. Best & others (1964) subsequently used the name Gurrangorambla Range Granophyre on the 2nd edition Canberra 1:250 000 geological map, but as the terminology of Stevens has priority it is followed herein.

Derivation of name

The granophyre is named from the Gurrangorambla Range, a prominent ridge separating the Cave Creek drainage basin from creeks flowing south into Tantangara Reservoir.

Type locality

We have designated as the type locality of the intrusion the summit area of Tom O'Rourkes Peak (grid ref. 484535) at the western end of the Gurrangorambla Range.

Distribution

The Gurrangorambla Granophyre crops out in five distinct places in the Cooleman area. The largest body extends from Tom O'Rourkes Peak to Blue Waterhole Saddle along the Gurrangorambla Range and covers an area of about 5 km^2. A second, smaller area (just over 1 km^2) is farther east along the Gurrangorambla Range around Howells Peak and is in effect a continuation of the first area, though the two are separated by a later, intermediate intrusion. Stevens considered that these two bodies, at least in part, form a subhorizontal sheet, but was uncertain if it is extrusive or intrusive. It is now considered that the granophyre forms an elongate intrusive body which has steeply dipping contacts with the surrounding rocks, as the boundary appears to be little affected by topography.

The third area of outcrop of the unit covers about 0.5 km^2 southeast of Spencers Hut, where the granophyre may form a series of sills - or possibly dykes - since contact-metamorphosed sediments are present within the area of outcrop however, exposure is poor and individual boundaries could not be mapped. The boundary shown on the TANTANGARA map therefore represents the maximum extent of the granophyre in this area.

The fourth area covers about 1.25 km^3 in The Pockets area, and is a continuation of the body around Howells Peak, displaced northwards about 3 km along the Mount Black Fault. The fifth area of outcrop, which is small, is on the Goodradigbee River about 0.5 km downstream of the junction with Cave Creek.

Petrography

A feature of the Gurrangorambla Granophyre is its marked similarity at all outcrops. Samples that have been contact-metamorphosed by later intrusions have recrystallised into a white to pink saccharoidal rock, but unmetamorphosed samples are typically fine-grained pinkish grey to pinkish purple rocks which weather to pale pink. Uncommon phenocrysts of feldspar are best seen as white crystals on weathered pink surfaces. Scattered throughout the rock are patches of green chlorite less than 1 mm.

Widely scattered phenocrysts of subhedral sericitised plagioclase, up to 1 mm, and scattered microphenocrysts about 0.3 mm of subhedral opaques and chlorite, possibly after pyroxene or hornblende, are set in a groundmass (95%) of alkali feldspar, opaques, sericite, and chlorite, all about 0.04 mm, poikilitically enclosed in rounded granophyric growths of quartz about 0.6 mm in diameter. In some areas the poikilitic quartz grains are separated by patches up to 0.5 mm containing no quartz. In a few places there are patches of calcite about 0.5 mm in diameter. Quartz occupies about 35% of the rock and alkali feldspar probably about 50%.

Relations and age

The Gurrangorambla Granophyre appears from field evidence to be the oldest of the intrusive bodies in the Cooleman area. Evidence near Blue Waterhole Saddle indicates that it is intruded by one pluton of the Coolamine Igneous Complex, which is in turn intruded by the Jackson Granite. Furthermore, the granophyre intrudes the Kellys Plain Volcanics, of early Lochkovian or possibly late Pridolian age. The most likely age of the granophyre is Lochkovian.

No extensive extrusive equivalents of the granophyre are known, but a small area of pale cream rhyolite at grid reference 527543 (not shown on the TANTANGARA map) may be the remnants of a small extrusive equivalent older than the Rolling Grounds Latite.

COOLAMINE IGNEOUS COMPLEX
(new name)

Nomenclature

We have given the name Coolamine Igneous Complex to a series of intrusions of varied composition (ranging from pyroxene-bearing adamellite and granodiorite, through quartz monzodiorite, quartz gabbro, and gabbro, to pyroxenite) which crop out in the Cooleman area, are closely related mineralogically and geochemically, and appear to be of closely similar age. Palmer (1972) used the name Coolamine Diorite for these bodies, a usage which is not considered to be strictly applicable because of their wide range in composition and occurrence as several separate intrusions. To aid the description the separate bodies have been given structural names in the text.

Derivation of name

The complex is named from Coolamine homestead (grid ref. 507580), on the track from Long Plain to Blue Waterholes.

Type locality

We have designated no type locality because of the wide compositional and textural variations shown by the bodies forming the complex.

Distribution and petrography

Ten individual plutons form the complex in the Cooleman area, the southernmost cropping out on Currango Plain and the northernmost on the western side of McLeods Ridge.

1. Currango Plain pluton. This is a meridionally elongate intrusion 700 m long and 200 m wide. It intrudes the Kellys Plain Volcanics and is partly obscured by alluvium. The rock is conspicuous because of its spotted cumulophyric texture of aggregates of mafic minerals (30-40%) up to 10 mm evenly distributed in a pale green feldspathic groundmass.

Sample 71840304 from grid reference 547485 is a pyroxene-bearing granodiorite. It contains aggregates up to 6 mm of anhedral grains of augite and altered anhedral grains of orthopyroxene. The orthopyroxene has in most places been completely altered to an optically continuous chlorite and ?talc intergrowth aligned parallel to the c-axis of the original orthopyroxene. Most aggregates are monomineralic and composed of either augite or altered orthopyroxene averaging about 1 mm, but some contain both minerals together, and, rarely, plagioclase is interstitial. The aggregates have reaction rims of actinolite, brown biotite, and minor opaques, and are set in a groundmass of subhedral plagioclase and anhedral interstitial quartz and orthoclase perthite. The plagioclase forms phenocrysts up to 3 mm, commonly with wide calcic (An_{50-60}) cores and narrow sodic rims (An_{15-25}); the cores are mostly altered to sericite, epidote, and rarely calcite. The modal analysis of this sample is shown in Table M18.

A sample from grid reference 547484 is a biotite-bearing hypersthene-quartz monzogabbro. Like sample 71840304 it contains aggregates of pyroxene crystals in a quartz-feldspar groundmass. The aggregates are up to 7 mm, and some comprise single augite grains up to 6 mm. Augite (10%) has $2V_z = 50^o$ and is commonly twinned. Unlike sample 71840304, much of the orthopyroxene (20%) is unaltered; it has $2V_x = 70\text{-}80^o$ (bronzite) and is up to 2 mm. Plagioclase grains (40%) are commonly saussuritised, but some have cores up to An_{80}; all have rims of An_{15-25}. Quartz 10% and perthitic orthoclase (8%) are interstitial and commonly intergrown. Biotite (7%) and actinolite (3%) form reaction rims around pyroxene aggregates, and biotite is common in the groundmass.

2. Mosquito Creek pluton. This pluton crops out on the Mosquito Creek Trail north of Mosquito Creek, around grid reference 505510. It is meridionally elongate, and is 2 km long and about 500 m wide. It is a composite body consisting mainly of even-grained pyroxene granodiorite intruded at the northern and southern ends by circular stocks of glomeroporphyritic rock similar to the Currango Plain pluton. The northern stock is about 300 m in diameter and the southern stock about 500 m in diameter.

The northern stock is a pyroxene-bearing granodiorite with about 24% plagioclase, 18% quartz, and 12% orthoclase. The plagioclase is highly altered and up to 1 mm. Quartz and orthoclase are anhedral and average 0.3 mm. Aggregates containing augite and lesser altered orthopyroxene are up to 6 mm and have reactions rims up to 1 mm of pale green amphibolite and opaques.

The southern stock is a biotite and orthopyroxene-bearing granodiorite. It is composed of about 30% saussuritised subhedral plagioclase (broad An_{60-70} cores and narrow fresh An_{20} rims) up to 2 mm, 20% micrographic intergrown quartz and orthoclase, and 50% mafics. The mafics consist mainly of chloritised orthopyroxene and lesser augite in aggregates up to 4 mm. Some of the aggregates have been partly disaggregated, as micrographic quartz and orthoclase have penetrated along grain boundaries within the aggregates, and individual grains of chloritised orthopyroxene occur away from aggregates. Brown biotite flakes up to 2 mm long are scattered throughout the rock and also concentrated around the pyroxene aggregates. Those around the aggregates are alteration products of pyroxene, whereas those in the groundmass are primary. Chlorite and calcite are common interstitial fillings and alteration products of calcic plagioclase.

3. <u>Seventeen Flat pluton</u>. This is the largest intrusion in the Coolamine Igneous Complex. It crops out on Seventeen Flat and the Gurrangorambla Range east of Blue Waterhole Saddle as rounded boulders of massive dark homogeneous rock with a pale brown crumbly weathering skin. The intrusion is 4 km long and up to 1.5 km wide, and is elongate northeasterly. It is irregular in shape with lobate boundaries, and is probably connected to the Mosquito Creek pluton at depth. It intrudes the Cooleman Limestone, Pocket Formation, Gurrangorambla Granophyre, and Kellys Plain Volcanics, and is intruded by the Jackson Granite.

The rock consists mostly of biotite and orthopyroxene-bearing granodiorite. It contains 30-40% plagioclase, 15-30% quartz, 5-10% orthoclase, 5-10% biotite, and 25-30% pyroxene. Plagioclase has broad euhedral cores up to 1 mm of An_{60-70} and narrow rims of An_{15-20}. Quartz and orthoclase are interstitial and subpoikilitic. Sample 71840447 (grid ref. 527530, see modal analysis, Table M18) contains poikilitic quartz up to 4 mm enclosing saussuritised plagioclase; augite almost completely altered to actinolite; and orthopyroxene completely altered to actinolite and intergrown talc and chlorite; orthoclase forms uncommon subpoikilitic grains up to 2 mm.

Pyroxene in the Seventeen Flat pluton is almost entirely altered - the orthopyroxene to chlorite, talc, and actinolite, and the clinopyroxene to actinolite. The pyroxene has been completely disaggregated, but here and there cumulophyric groups still occur, and any augite grains in the cores are unaltered. Biotite occurs as individual grains, and as grains adjacent to altered pyroxene.

Sample 71840363 (grid ref. 540534) is not typical of the Seventeen Flat pluton, containing no biotite and much less quartz (see modal analysis, Table M18). The quartz forms micrographic intergrowths with orthoclase.

A sample from grid reference 532551 has been contact-metamorphosed by the Jackson Granite. It contains porphyroblasts of quartz up to 1 mm, and biotite that has recrystallised to a mosaic of many flakes. Actinolite (altered from augite) has abundant opaque inclusions.

A sample from grid reference 527536, from a western extension of the pluton 1 km from outcrops of the Rolling Grounds Latite, is much finer-grained than the rest of the pluton as the groundmass quartz and feldspar grains are less than 0.1 mm. The rock is a pyroxene granodiorite-porphyry; it contains phenocrysts of unaltered augite, completely altered orthopyroxene, and saussuritised plagioclase, all up to 1.5 mm. This western extension of the pluton may have been a feeder for the extrusion of lava of the Rolling Grounds Latite.

4. Skains Hill pluton. This body is about 2.5 km northeast of Skains Hill and forms a prominent high-peaked hill west of Harris Hut. It is elongate north-northwesterly, about 1.7 km long and 0.4 km wide, and intrudes the Kellys Plain Volcanics. The rock is mottled pink, green, and grey, and is fine to medium-grained.

Samples of the intrusion contain about 40% plagioclase, 10-15% quartz, 10% orthoclase, 20% augite, 10% altered orthopyroxene, 4% opaques, and minor biotite and apatite (see modal analyses of samples 71840457 from grid ref. 476562 and 71840458 from grid ref. 477555 in Table M18). Plagioclase forms phenocrysts up to 3 mm with An_{40-50} cores and narrow An_{10-20} rims. Augite ($2V_z = 50^o$) forms subhedral to anhedral grains up to 1.5 mm with orthopyroxene exsolved parallel to (100) in the cores. Orthopyroxene is subhedral and pseudomorphed by a mosaic of chlorite, talc, and actinolite. Some of the pyroxene grains occur in partly disaggregated cumulophyric groups. Quartz and orthoclase, commonly intergrown, form interstitial grains less than 1 mm.

Sample 71840457 (grid ref. 476562) contains rare microxenoliths up to 5 mm composed of anhedral to subhedral augite and altered plagioclase and orthopyroxene, all about 0.7 mm. The xenoliths have a gabbroid texture.

5. Cave Creek complex. About 2 km north of Harris Hut and adjacent to Cave Creek, at least six separate bodies have intruded the Blue Waterhole Formation, Cooleman Limestone, and Kellys Plain Volcanics. Even-grained granodiorites up to 300 m wide crop out at grid references 490572, 485579, and 479567. Microgranodiorites crop out at grid references 487576, 488577, and 491578: these bodies are less than 200 m wide. At grid reference 487575 a microgranodiorite intrusion is intruded by a coarser even-grained granodiorite. Pyroxene granodiorite at grid reference 488568 has rounded embayed quartz xenocrysts up to 1 mm, which may be derived from contamination by the Kellys Plain Volcanics. The adjacent Rolling Grounds Latite also contains xenocrysts of rounded embayed quartz.

The microgranodiorite contains about 10% quartz, 40% plagioclase, 40% actinolite, and minor orthoclase, calcite, and opaques, all about 0.1 mm. The rock may be a microtonalite, as orthoclase is rare.

The even-grained granodiorite contains subhedral plagioclase grains up to 3 mm, with broad oscillatorily zoned cores about An_{50-60} and narrow albitic rims. Augite and hypersthene have mostly been altered to actinolite and chlorite, but many actinolite grains have cores of augite. Brown biotite, quartz, and perthitic orthoclase are all anhedral and up to 2 mm. A modal analysis of the rock is given in Table M18 (sample 71840460 from grid ref. 491572).

Sample 71840453 (grid ref. 485579) is similar to the even-grained granodiorite, except that it contains more orthoclase and is thus an adamellite (see modal analysis, Table M18).

6. Cooleman Mountains pluton. Granodiorite crops out as an elongate body on the northwest margin of the Cooleman Plain, on the eastern slopes of the Cooleman Mountains between grid references 487584 and 500610. The pluton is 2.7 km long and up to 0.5 km wide. The exposures are slightly rounded grey boulders up to 2 m across in which aplite and quartz veins are absent and mesoscopic xenoliths are rare. The granodiorite intrudes the Cooleman Limestone to the east, but dacite rubble obscures the contact with the Kellys Plain Volcanics to the west. However, a sample of the Kellys Plain Volcanics from within 100 m of the granodiorite intrusion (grid ref. 484581) is a recrystallised dacite with abundant intergrowths of recrystallised biotite, strongly suggesting contact metamorphism.

The granodiorite is similar to the even-grained granodiorite of the Cave Creek complex to the south, and is probably part of the same intrusion. Plagioclase (30-50%) forms subhedral grains up to 3 mm, some with broad patchily zoned cores (An_{50-60}) and narrow An_{20} rims, whereas others are more evenly zoned from An_{60} to An_{20}. Augite is almost completely altered to actinolite and hypersthene is partly altered to chlorite and actinolite. Subhedral brown biotite up to 2 mm is common (10%). Quartz and orthoclase perthite are anhedral, up to 1 mm, and commonly intergrown. A modal analysis of sample 71840471 (grid ref. 490596) is shown in Table M18.

A sample from grid ref. 501609 contains common unaltered grains of augite up to 1 mm with actinolite reaction rims. Some of these augites have two sets of exsolution lamellae: one parallel to (100) and one parallel to (001). The lamellae parallel to (100) exsolved as orthopyroxene, and the lamellae parallel to (001) probably exsolved as pigeonite (Hess, 1960) later inverting to orthopyroxene. Also in the sample are two adjacent subhedral grains of tourmaline 3 mm long. The tourmaline is zoned, with cores pleochroic from pale green to dark green, and rims pleochroic from pale brown to dark bluish brown.

At the northern end of the Cooleman Mountains pluton, clinopyroxenite crops out as rounded boulders less than 1 m in an area 500 m long and 200 m wide. The pyroxenite is separated from the granodiorite by 100 m of poorly exposed Blue Waterhole Formation and Kellys Plain Volcanics. Veins of pink potash feldspar and yellow-green epidote are common throughout the pyroxenite, which is composed of 90% subhedral to anhedral grains of augite ($2V_z = 60$) mostly about 0.4 mm. Orthoclase is interstitial, and orthoclase, chlorite, and epidote occur in irregular veins, and in patches up to 5 mm in diameter. Subhedral phenocrysts of augite are up to 4 mm. The augite phenocrysts are zoned, with cores more Mg-rich (lower maximum extinction angle) than the rims; the difference between the extinction angle for the cores and for the rims is up to 5^{o}, and the maximum extinction angle on the finer-grained augites is $Z \hat{} c = 44^{o}$. The rock may be similar to amphibolitised pyroxenite xenoliths from the Mountain Creek Volcanics. Some samples also contain plagioclase and are thus mela-monzogabbros.

7. <u>Coolamine homestead pluton</u>. This body crops out on Cooleman Plain 100 m northeast of Coolamine homestead. It is elongate east-northeasterly, is about 800 m long and 300 m wide, and intrudes the Blue Waterhole Formation and Cooleman Limestone. The rock is homogeneous throughout, [illegible] the groundmass tends to be finer-grained towards the east. The eastern end of the intrusion is within 150 m of outcrops of Rolling Grounds Latite, and it is almost certainly a feeder for the latite.

A sample from grid reference 506582 contains phenocrysts of euhedral plagioclase (An_{50}) up to 2 mm, subhedral to anhedral augite up to 1 mm, altered orthopyroxene up to 0.6 mm, and a few rounded quartz phenocrysts up to 1 mm. The phenocrysts occur in a groundmass of granophyric quartz and potash-feldspar intergrowths (0.3 mm), and minor biotite and opaques. A few microxenoliths composed of plagioclase, augite, and altered orthopyroxene are up to 4 mm. The plagioclase phenocrysts and the plagioclase in the microxenoliths are both An_{50}, and have narrow sodic rims where they are in contact with the groundmass.

8. <u>McLeods Trail pluton</u>. Granodiorite porphyry crops out as sparse subangular boulders on the McLeods Trail west of the trig station on Mount Jackson, and on a rounded ridge southwest of the trig. The porphyry intrudes

the Blue Waterhole Formation and Kellys Plain Volcanics and is about 2 x 1.5 km. The southern end of the intrusion is cut by an offshoot of the Mount Black Fault.

The rock is fairly homogeneous throughout, although the main mafic component in the north is augite and that in the south is altered orthopyroxene. Samples consist of scattered euhedral phenocrysts of altered labradorite (3 to 5 mm) with sodic rims, abundant subhedral labradorite (1 to 2 mm), augite partly pseudomorphed by actinolite, and subhedral orthopyroxene pseudomorphed by chlorite (both 1 to 2 mm). These are set in a groundmass of micrographic and granular quartz and orthoclase. Opaques are commonly associated with the altered mafics. Many of the unaltered augite grains contain exsolved lamellae of ?orthopyroxene parallel to (100) and (001). The groundmass of samples from grid references 520599 and 519604 has recrystallised into a granoblastic texture, so the intrusion may have been emplaced by multiple injection, the earlier material having been hornfelsed by later injections of magma.

9. <u>Circuits Mountain pluton</u>. This body is the northernmost pluton of the Coolamine Igneous Complex. It crops out on the western side of McLeods Ridge northwest of Circuits Mountain. The intrusion is elongate meridionally, parallel to the strike of the enclosing sediments, and is probably a sill; it is about 3.5 km long and up to 0.8 km wide. It intrudes the Blue Waterhole Formation which dips about 50° to 60° east. It encloses an inlier of recrystallised limestone about 20 m wide at grid reference 540666, and about 500 m north of this (grid ref. 542671) a doline about 10 m deep occurs within gabbro, indicating the presence of limestone beneath.

The body contains two varieties of rock, gabbro and granodiorite: it is roughly zoned, with a core of granodiorite and a rim of gabbro. The boundary between the two rock types is quite sharp: at some localities (e.g., at grid ref. 544674) gabbro and granodiorite crop out less than 10 m apart.

The gabbro is a fine to medium-grained mottled dark green and white rock which crops out as rounded boulders up to 5 m across. At grid reference 534667 medium-grained gabbro crops out as a number of discontinuous cliffs up to 30 m high. The granodiorite is poorly exposed as angular blocks and float less than 0.5 m; larger exposures are highly jointed and fractured, and strongly weathered to a grey friable rock. The granodiorite is a fine to medium-grained white rock with about 10% dark minerals - mostly biotite.

Gabbro. The gabbro is a quartz-hornblende gabbro with abundant zoned hornblende moulded onto and partly penetrated by plagioclase laths. The hornblende forms subhedral to anhedral grains up to 2 mm. Its cores have $2V_x = 80^{o}$, and X = very pale yellow-brown, and Y = Z = brown with a reddish tinge; its rims have $2V_x = 70^{o}$, X = very pale yellow, Y = pale green with a brownish tinge, Z = pale green with a bluish tinge, and absorption $Y > Z > X$. In many grains the change from brown cores to green rims is sharp. Some of the smaller hornblende grains do not have brown cores, but have irregular cores of augite - the hornblende rims being deuteric. The brown hornblendes are probably primary basaltic hornblendes. Widely scattered throughout the rock are patches up to 2 mm of intergrown chlorite, actinolite, and opaques; these are probably alteration products of orthopyroxene.

Plagioclase occurs as abundant subhedral to euhedral laths up to 2 mm but mostly less than 1 mm. The laths are strongly zoned, with cores up to An_{75} and narrow rims of An_{20-30}. Quartz, calcite, and orthoclase perthite form rare interstitial grains up to 2 mm. Also present are irregular blebs of opaques up to 0.6 mm commonly surrounded by sphene up to 0.4 mm, and euhedral needles of apatite up to 0.8 x 0.05 mm. The apatite is commonly included in large brown hornblende plates. A modal analysis of sample 72840217 (grid ref. 544674) is shown in Table M18.

A sample from grid reference 534666 is a biotite-bearing two-pyroxene gabbro. It contains about 10% anhedral to subhedral brown flakes of biotite up to 1 mm, and about 5% anhedral grains of hypersthene ($2V_x = 60^{o}$) up to 2 mm partly altered to actinolite. The biotite commonly surrounds irregular patches of opaques.

Granodiorite. This is a hornblende-biotite granodiorite. It is hypidiomorphic with subhedral to euhedral laths of zoned plagioclase (An_{40} cores and narrow An_{20} rims) up to 2 mm (40%), anhedral quartz (25%) up to 1.5 mm, and anhedral orthoclase perthite (20%) up to 2 mm. Biotite (10%) occurs as brown partly chloritised flakes (pleochroic from yellow-brown to almost black) up to 1.5 mm scattered throughout. Opaques (3%) are subhedral octahedra up to 0.4 mm. Hornblende (2%) occurs as scattered green to brown-green subhedral grains up to 0.6 mm. Apatite is a minor accessory, and epidote and sphene are alteration products of rare clusters of mafic minerals.

A sample from grid reference 535657 is a metagranodiorite. It contains phenocrysts of sericitised plagioclase (30%) up to 0.8 mm, pale green-yellow actinolite pseudomorphing pyroxene up to 1 mm (10%), and a few grains of augite (5%) up to 1 mm surrounded in turn by actinolite and then fine-grained brown biotite. Brown biotite (13%) also occurs with chlorite (2%) as common recrystallised patches throughout. The groundmass of the rock consists of recrystallised granoblastic quartz (30%) and orthoclase (10%) with an average grainsize of 0.1 mm. Some quartz porphyroblasts are up to 0.7 mm. This sample has been contact-metamorphosed and indicates that intrusion was probably by multiple injection.

Contact effects. At grid reference 532662 a white contact-metamorphosed Blue Waterhole Formation marl crops out within 10 m of the contact. It is composed of anhedral diopside (30%) as porphyroblasts up to 1 mm in a granoblastic aggregate of quartz, plagioclase (An_{30}), diopside, and sphene, with an average grainsize of 0.2 mm. Some of the plagioclase grains are up to 0.5 mm. The presence of diopside in the rock indicates hornblende hornfels facies metamorphism, and the temperature must have been at least 400^{o}C.

10. Peppercorn Creek pluton. About 500 m northeast of Peppercorn Hut a stock about 400 x 200 m crops out as white rounded boulders up to several metres. The rock is conspicuous because of the presence of about 20% mafic minerals which occur as cumulophyric clots up to 10 mm evenly distributed throughout the rock. The body is homogeneous throughout and has no observable chilled margins. It intrudes the Upper Ordovician Temperance Formation.

The rock contains about 50% strongly zoned (An_{70} cores, An_{30} margins) subhedral to euhedral plagioclase laths averaging 0.3 mm but up to 3 mm, interstitial plates of quartz and orthoclase about 0.5 mm, and minor patches of chlorite. Scattered throughout are aggregates up to 8 mm wide of mafic minerals (20%); these contain many grains of augite and chloritised orthopyroxene, most of which are anhedral but some are euhedral. A few augite grains have irregular blebs of pyroxene (?orthorhombic) exsolved within them. Some of the aggregates are richer in augite, whereas others are richer in altered orthopyroxene. The aggregates are in a reaction relation with the rest of the rock: their margins have been altered to brown-green hornblende, opaques, and chloritised biotite. Opaques are more common around the margins of orthopyroxene-rich aggregates than augite-rich aggregates.

A modal analysis of sample 71840463 (grid ref. 482616) is shown in Table M18.

A thin section of the Temperance Formation from within 10 cm of the contact with the Peppercorn Creek pluton (grid ref. 487616) shows that there was virtually no contact metamorphism. The rock contains fragments and crystals of augite and plagioclase in a cherty matrix. The matrix is almost isotropic and is recrystallised only to the same extent as other tuffaceous cherts in the Temperance Formation. It therefore seems that the Peppercorn Creek pluton was intruded into its present position in a cool semi-solid state.

Age and relations

Several bodies of the Coolamine Igneous Complex intrude the Upper Silurian Cooleman Limestone and Blue Waterhole Formation. Bodies also intrude the Kellys Plain Volcanics, which unconformably overlie the Cooleman Limestone and Blue Waterhole Formation. The complex is therefore no older than latest Silurian.

Stocks of the Coolamine Igneous Complex are almost certainly feeders for the Rolling Grounds Latite. On Cooleman Plain the intrusives and the extrusives are closely associated, and fine-grained samples of parts of the Seventeen Flat pluton, Cave Creek complex, and Coolamine homestead pluton are similar in hand specimen to the latite. Both the intrusives and the extrusives contain phenocrysts of augite (commonly with (100) exsolution) and chloritised orthopyroxene. Analyses of the latite are similar to analyses of rocks from the Coolamine Igneous Complex (see GEOCHEMISTRY AND PETROGENESIS). Thus it is almost certain that the age of the Coolamine Igneous Complex is Early Devonian, the same as the Rolling Grounds Latite.

The relative ages of the various bodies within the Coolamine Igneous Complex are unknown. In the Mosquito Creek pluton, cumulophyric rocks intrude even-grained granodiorite, so it is possible that bodies with this spotted cumulophyric texture are later than the even-grained rock. It is also possible that the cumulophyric rocks grade into more even-grained rocks at depth, as the cumulophyric rocks only occur as small stocks and apophyses less than 500 m in diameter.

The mineralogy of the Coolamine Igneous Complex is similar to that of many small stocks to the south and southwest, including those near Mount Nattung trig station, at Hell Hole Creek, and east of Gooandra homestead. The complex

TABLE M18. MODAL ANALYSES OF THE COOLAMINE IGNEOUS COMPLEX

Pluton	Currango Plain	Seventeen Flat	Seventeen Flat	Cave Creek	Cave Creek	Skains Hill	Skains Hill	Peppercorn Creek	Cooleman Mountains	Circuits Mountain
Sample no.	71840304	71840363	71840447	71840453	71840460	71840457	71840458	71840463	71840471	72840217
Grid ref.	547485	540534	527530	485579	491572	476562	477555	482616	490596	544674
Quartz	20.4	7.6	20.2	24.7	25.9	14.3	11.7	12.1	14.3	2.9
Plagioclase	30.6	47.6	34.2	25.2	43.3	41.2	39.7	54.0	50.4	46.0
Orthoclase	16.3	9.2	10.3	20.1	11.4	9.1	12.8	9.7	6.2	2.3
Augite	4.5	32.8	26.6	7.2	9.8	22.0	19.2	5.0	8.3	3.0
Hypersthene (mostly altered)	13.0	)	)	6.0	)	8.1	11.3	7.4	5.0	-
Amphibole	4.7	-	-	9.6	-	-	-	4.5	4.0	41.1
Biotite	6.6	-	6.5	5.6	7.0	-	1.1	2.0	10.1	-
Chlorite	2.4	-	-	-	-	-	-	2.7	-	-
Opaques	0.5	2.3	1.9	1.6	2.2	4.2	3.8	2.3	1.2	3.0
Apatite	0.2	0.5	0.3	-	0.4	1.1	0.4	0.2	0.5	0.6
Calcite	0.8	-	-	-	-	-	-	0.1	-	1.1
Anorthite content of plagioclase cores	50-60	60-70	60-70	40-50	50-60	40-50	40-50	60-70	50-60	60-70
Rock type	Pyroxene granodiorite	Quartz monzogabbro	Pyroxene granodiorite	Pyroxene adamellite	Pyroxene granodiorite	Pyroxene granodiorite	Quartz monzodiorite	Quartz monzogabbro	Quartz monzodiorite	Quartz gabbro

also resembles parts of the Boggy Plain Adamellite. Chemical features indicate that all these plutons form a distinct suite of I-type granitoids, the high-potassium I-type suite of Owen & Wyborn (1976), here renamed the Boggy Plain Suite because we feel it is more appropriate to name the suite after its most important pluton rather than after its particular chemical characteristics.

JACKSON GRANITE

Nomenclature

Joplin & others (1953) first published the name Jackson Granite on the first-edition Canberra 4-mile Geological Sheet, and Best & others (1964) used it on the second edition. Previously, Walpole (1952) had used both Jackson granite and Jackson granodiorite when referring to the same intrusion. Stevens (1958b) gave the name Black Mountain Granite to a granite cropping out south of Cave Creek, which we consider to be a part of the Jackson Granite displaced south-southeast by the Mount Black Fault. The name Black Mountain Granite is thus a junior synonym of the Jackson Granite.

Derivation of name

The granite is named from Mount Jackson trig station (altitude 1648 m), about 5.4 km north-northeast of Blue Waterholes.

Type locality

The type locality is here designated as Mount Jackson trig station (grid ref. 540613), where medium to coarse-grained pink granite cut by rare fine-grained aplitic veins is extensively exposed.

Distribution

The Jackson Granite crops out in three separate areas: on Mount Black, on Mount Jackson, and at the northern end of McLeods Ridge. The largest of these is the Mount Jackson mass, covering a roughly semicircular area of 16 km^2, whose diameter is formed by the Mount Black Fault. The granite forming Mount Black, south of Cave Creek, covers an area of 2.8 km^2 and is considered to be part of the Mount Jackson mass displaced about 3.5 km to the south-southeast along the Mount Black Fault. The other outcrop of the Jackson Granite covers an area of about 3.5 km^2; although it is probably a separate pluton, it is mineralogically similar and has been described along with the main body.

Lithology

The Jackson Granite crops out as rounded tors commonly up to 10 m high, and as slabs and cliffs on steeper slopes - for example, at grid reference 563678 there are sloping cliffs up to 100 m high. Exposure is good; the concealed outcrop between boulders is never more than a few metres. Jointing has no preferred orientation and is not reflected in the topography. Weathering is deep (greater than 2 m) on the ridges, but where the Goodradigbee River has cut a deep gorge through the granite south of Koorabri almost continuous relatively fresh exposure occurs along the river banks.

The rock is a medium to coarse-grained pink granite with pink potash feldspar up to 10 mm. Biotite is generally fine-grained, commonly bleached white, and occupies less than 5%. Pink aplite dykes are present at some outcrops. At a few localities, such as the top of Mount Black (grid ref. 538548), the granite is fine-grained with an average grainsize of 1 mm. On the western side of McLeods Ridge (to the west of Mount Ginini), there are many small isolated intrusions of Jackson Granite, some less than 2 m wide. These small intrusions are medium-grained and white to pale pink, with plagioclase and biotite much more common than in the main bodies; they are adamellite.

Xenoliths are absent from most of the granite outcrops, but within 50 m of the contacts with the Blue Waterhole Formation in the lower Peppercorn Creek and Goodradigbee River valleys they are abundant as angular blocks up to 1 m of chert and cherty siltstone. Also present are subrounded xenoliths of blue-grey porphyritic rhyodacite (probably Kellys Plain Volcanics) and grey-green andesitic rock (probably the Rolling Grounds Latite). At some localities (e.g., at grid ref. 563712) xenoliths of rhyodacite, latite, and Blue Waterhole Formation averaging 10 to 20 cm form about 50% of the rock (Fig. M25). Also present in the Peppercorn Creek valley, but farther from the contact, are rounded xenoliths up to 10 cm of fine-grained amphibolite.

The most typical granite is allotriomorphic equigranular with an average grainsize of 3 to 4 mm. Quartz and perthitic potash feldspar are abundant, each comprising between 35 and 45% of the rock. The quartz forms

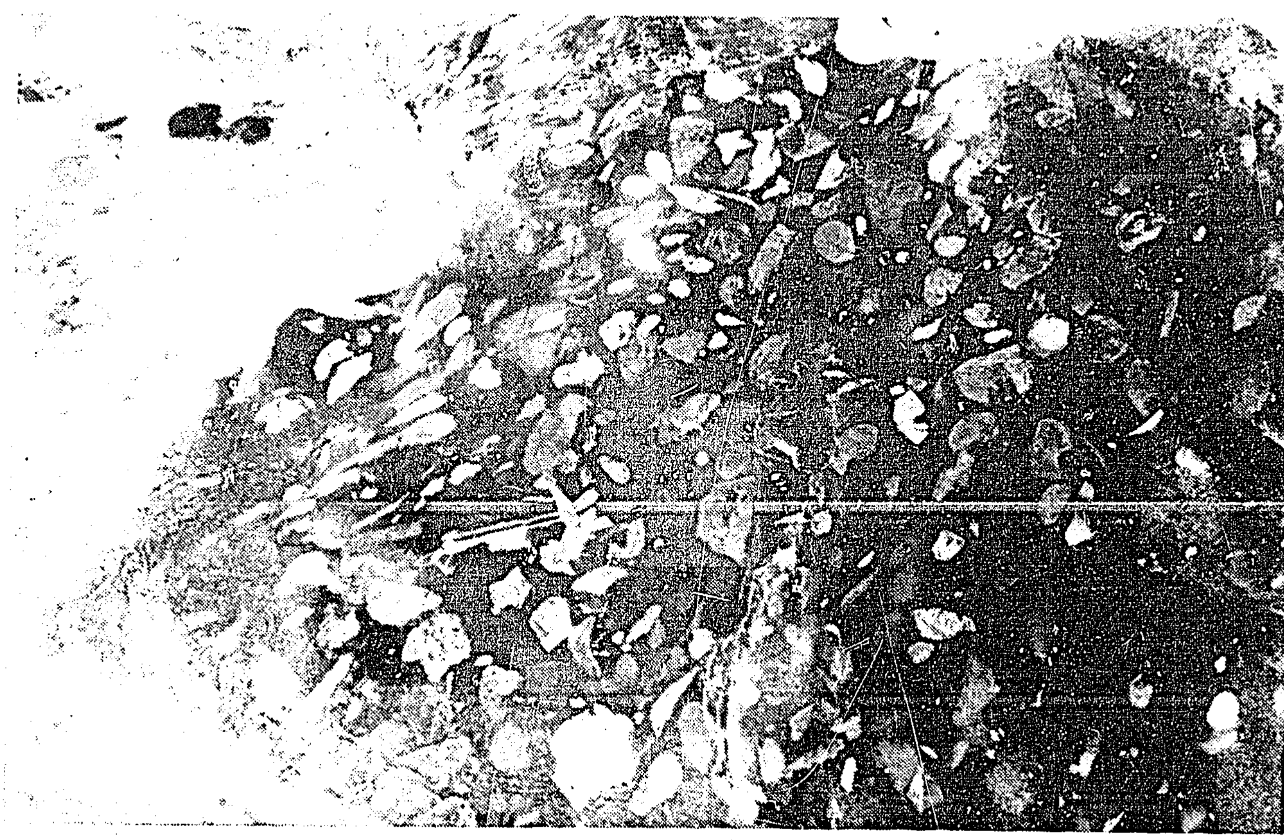


Fig. M25. Xenoliths - mainly of the Blue Waterhole Formation and Kellys Plain Volcanics - in the Jackson Granite at grid reference 563712.

(GA/1856)

anhedral grains, commonly slightly rounded when over 3 mm. Some of these large grains may have been beta-quartz. Smaller quartz grains are highly angular.

The potash feldspar occurs as sericitised xenomorphic grains with fingers penetrating between adjacent quartz grains to give a subpoikilitic texture. Twinning is common on the Baveno law and less common on the Carsbad law; cross-hatch twinning is absent. In some samples (e.g., from grid ref. 540613) poikilitic grains of perthite up to 10 mm contain abundant peripheral inclusions of quartz, minor albite, and rare biotite; their inclusion-free centres are probably original feldspar phenocrysts on to which overgrowths have been deposited around adjacent quartz grains, which now form inclusions. Perthite exsolution lamellae are abundant in all potash feldspar grains. The lamellae occur as film, vein, and patch perthite; some of the patches are up to 1 mm. In some rocks, vein and patch perthite lamellae are multiply twinned on the albite and pericline laws. In some grains there is a tendency for perthite lamellae to be more abundant at the edges of the grain and absent at the centre. In a sample from grid reference 532559, a 3-mm grain is surrounded by a rim of albite, giving the grain a rapakivi texture; the albite rim is optically continuous with the perthite lamellae, and the lamellae are more abundant towards the edge of the grain.

Plagioclase (less than 15%) occurs as subhedral to anhedral zoned grains up to 3 mm, with An_{20} cores and albite rims; rare cores are as calcic as An_{40}, and most are highly sericitised. Biotite is present in amounts less than 5%, and is more common in the coarse-grained samples, such as from grid reference 538548, where it occurs in groups; in most samples it forms scattered partly chloritised dark brown grains up to 1 mm. Opaques, euhedral to subhedral sphene up to 3 mm long, and apatite are associated with the biotite, and fluorite forms rare interstitial grains in biotite-poor rocks.

At grid reference 553678, on McLeods Ridge, an adamellite intrusion 2 m in diameter contains subhedral plagioclase (45%) up to 2 mm (zoned with An_{40} cores and An_{20} rims), subhedral orthoclase perthite (30%) up to 3 mm, anhedral quartz (18%) up to 2 mm, and partly chloritised biotite (7%) up to 1 mm. Opaques, apatite, and zircon are associated with the biotite. The orthoclase grains in this sample do not exhibit overgrowths, and do not have perthite lamellae concentrated near the rims.

A sample from grid reference 563707 is an amphibolite xenolith composed of about 50% pale green hornblende, 5% biotite, 20% plagioclase, 15% orthoclase, and 10% quartz, generally with all grains less than 0.2 mm. In some parts of the xenolith, orthoclase, quartz, and green hornblende, all up to 2 mm, together form porphyroblastic groups. A few subhedral grains of plagioclase up to 1.5 mm with sericitised rims are also present; these may be relict igneous phenocrysts.

Age and relations

The Jackson Granite intrudes the Upper Silurian Cooleman Limestone and Blue Waterhole Formation, both of which are strongly hornfelsed near the contact; wollastonite forms masses up to 30 cm at grid reference 563708. The granite also intrudes and has recrystallised the Lower Devonian Mountain Creek Volcanics; this is especially noticeable at grid reference 536622. As chemical evidence implies that it is genetically related to the Mountain Creek Volcanics, we conclude that its age is also Early Devonian. It is also similar lithologically to the Burrinjuck Adamellite, which has been dated at 415 ± 8 m.y. by K/Ar and 399 ± 8 m.y. by Rb/Sr.

A biotite separate of a sample from grid reference 535553 gave a K/Ar age of 413 ± 8 m.y.; the same biotite separate plus whole rock gave a Rb/Sr age of 324 ± 6 m.y. and initial ratio 0.7063 ± 0.0001 ($\lambda Rb^{87} = 1.42 \times 10^{-11}$/year). The K/Ar age is in very good agreement with the Burrinjuck Adamellite K/Ar date, but the anomalously young Rb/Sr age suggests that the biotite has lost radiogenic strontium.

BURRINJUCK ADAMELLITE

Nomenclature

Best & others (1964) first used the term Burrinjuck Granite to describe the pink adamellite at Burrinju[illegible]d also the granodiorite that extends to the south as far as the Goo[illegible] River. Ashley & Basden (1973) revised the nomenclature and proposed that the Burrinjuck Dam outcrops be referred to as the Burrinjuck Adamellite, and the granodiorite to the south be included in the Young Granodiorite. We have followed Ashley & Basden in their use of the term Burrinjuck Adamellite.

Derivation of name

The name is derived from Burrinjuck Dam, whose dam wall is built on the outcrop of the intrusion.

Type locality

The type locality is designated at the area immediately north of Burrinjuck Dam wall, where good exposures of partly weathered fine to medium-grained pink adamellite crop out in quarries and road-cuts.

Field occurrence

The Burrinjuck Adamellite is an elongate body extending from just east of Bundaleer (grid ref. 428157) to Burrinjuck Dam, 11 km to the north, and into YASS. Near Bundaleer the body is less than 1 km wide, but it widens to the north to reach a maximum width of 4.5 km immediately south of Burrinjuck Dam. Cramsie & others (1975) have mapped about 12 km^2 of the Burrinjuck Adamellite in YASS.

The adamellite is particularly well exposed between Hilltop (grid ref. 421203) and the Murrumbidgee River. In this area huge tors up to 10 m high are common, and the concealed outcrop between smaller exposures is never more than a few metres. In many areas there is almost 100% exposure in the form of rocky pavements, slabs, joint faces, and sloping cliffs. South of Hilltop the adamellite has been planed off by ?Early Tertiary erosion, and much of the area has subsequently been covered by late Miocene basalt flows. Where the adamellite is exposed on this planed area it forms scattered rounded hillocks, and tors from a few metres to over 10 m wide.

The adamellite is medium to coarse-grained over most of its outcrop area, but on the eastern edge for about 4 km south from Burrinjuck Dam fine-grained aplitic granite crops out for about 200 m west from the contact; the aplitic phase then grades into the coarser-grained phase. Samples are massive equigranular and composed of greyish quartz and conspicuous pink alkali feldspar, with lesser white plagioclase and about 5% biotite. The grainsize ranges from about 4 to 5 mm in the coarser-grained phase, to less than 2 mm in the aplitic phase. At some localities (e.g., grid ref. 432213) biotite and plagiclase form phenocrysts in the aplitic phase.

Xenoliths are rare in the adamellite, but amphibolite xenoliths have been found at several localities. They are disc-shaped and rarely exceed 100 mm. They are particularly common at grid reference 417245.

The adamellite is commonly strongly weathered, and samples crumble easily. Samples with fresh biotite are difficult to obtain. Weathering imparts an overall pinkish brown colour to the rock owing to the breakdown of alkali feldspar and biotite.

For most of its eastern margin the adamellite is faulted against the Middle Devonian Hatchery Creek Conglomerate by the Long Plain Fault, but to the north the fault swings eastward and the adamelliite intrudes the Goobarragandra Volcanics. The western margin of the adamellite is an intrusive contact against the Young Batholith in the south, and the Goobarragandra Volcanics in the north. The adamellite also intrudes a hornblende dolerite stock (part of the Micalong Swamp Basic Igneous Complex) near grid reference 410235. At grid reference 403235 a vein of contaminated adamellite intrudes hornblende dolerite, and nearby in the bed of Jeremiah Creek the adamellite is highly contaminated with hornblende and plagioclase. Also in this vicinity a limestone lens within the Goobarragandra Volcanics has been hornfelsed by the intrusion of the Burrinjuck Adamellite. The limestone, about 100 m wide, is completely recrystallised to a pure white marble with a grainsize of about 10 to 20 mm. A few bands of calc-silicate minerals are present within the marble. Felsic volcanics from the Goobarragandra Volcanics have also been extensively hornfelsed within 150 m of the contact with the Burrinjuck Adamellite. Adjacent to the fine-grained aplitic granite on the eastern margin contact effects are not so strong.

Petrography

The modal analyses of two samples are given below.

Sample no.	73840385	73840471
Grid ref.	418245	445254
Quartz	42.3	44.7
Orthoclase perthite	30.4	27.3
Plagioclase	21.8	23.3
Biotite (+ chlorite)	3.7	3.8
Sphene	1.7	0.5
Opaques	0.1	0.4

The adamellite is hypidiomorphic equigranular with an average grainsize of about 2-4 mm, though some alkali feldspar megacrysts are up to 6 mm and a few quartz grains are larger than 4 mm. The larger quartz grains are rounded and partly resorbed, and were probably originally beta-quartz. Alkali feldspar is most likely orthoclase, as cross-hatch twinning is absent; it is commonly twinned on the Carlsbad and Baveno laws. Film, vein, and patch perthites are well developed in most alkali feldspar grains. The orthoclase in the alkali feldspar grains is crowded with a dusting of iron oxide inclusions, colouring the orthoclase reddish brown in plane polarised light. Plagioclase forms subhedral zoned grains of about 2 mm with partly saussuritised An_{25-35} cores and An_{5-15} rims. Myrmekite is common along the boundaries of plagioclase with orthoclase.

Biotite forms scattered subhedral flakes, about 1 mm, which are pleochroic from pale yellow-brown to very dark brown, though most are partly to completely chloritised. Euhedral zircon, opaques, sphene, and apatite are associated with the biotite. Euhedral sphene is also common as scattered crystals up to 1 mm long. It is pleochroic from pale yellow-brown to orange-brown and rarely exhibits lamellar twinning.

The aplitic granite on the eastern side of the intrusion is similar to the main mass except that the grainsize is somewhat smaller (less than 2 mm), and alkali feldspar is more abundant than quartz. Fluorite is also present in the aplitic granite, as pale violet interstitial grains up to 0.6 mm, and as purple grains associated with opaques and biotite.

Where the Burrinjuck Adamellite has intruded a dolerite stock related to the Micalong Swamp Basic Igneous Complex, the adamellite has been heavily contaminated by the dolerite. The products of contamination contain up to 40% plagioclase with An_{50} cores and An_{20} rims, and 20% subhedral hornblende. The hornblende has $Z \wedge c = 18^{o}$, $2V_{x} \doteqdot 55^{o}$, X = pale yellowish-green, Y = greenish brown, Z = bluish green, and absorption Y > Z > X. Quartz, orthoclase perthite, biotite, sphene, opaques, and apatite are also present in the contaminated rocks. One sample also contains augite in the cores of some of the hornblende grains.

Contact metamorphism

A strong contact aureole up to several hundred metres wide surrounds the Burrinjuck Adamellite. Where the adamellite intrudes a dolerite stock the dolerite has been hornfelsed into a mosaic of polygonal green-brown hornblende, andesine, and minor quartz, all about 0.1 mm. Hornfelsed felsic volcanics from the Goobarragandra Volcanics contain poikiloblastic grains of blue-green hornblende, subpoikiloblastic diopside, and polygonal mosaics of plagioclase, orthoclase, quartz, and biotite. Minerals from the contact-metamorphosed limestone include wollastonite, diopside, prehnite, vesuvianite, and hydrogarnet. The presence of wollastonite indicates that temperatures of 500-700^{o}C were reached, the precise temperature depending on the partial pressure of CO_2 (Winkler, 1974, p. 127).

Age

The Burrinjuck Adamellite intrudes the Silurian Goobarragandra Volcanics and the Young Batholith. Cramsie & others (1975) show it intruding the Lower Devonian Mountain Creek Volcanics on their map. The adamellite is mineralogically and chemically similar to the Jackson Granite and the Gurrangorambla Granophyre, and we suggest that all three are related to the Mountain Creek Volcanics. The adamellite would therefore be of Early Devonian age.

A Rb/Sr determination on biotite/whole-rock separates from a sample from grid reference 418245 yielded an age of 399 $\pm$ 8 m.y. ($\lambda Rb^{87} = 1.42 \times 10^{-11}$/year) and an initial ratio of 0.7051 $\pm$ 0.0001. The same biotite separate gave a K/Ar age of 415 $\pm$ 8 m.y.

MINOR INTRUSIONS OF THE BOGGY PLAIN I-TYPE SUITE

Between the Tantangara and Long Plain Faults there are many small mafic to intermediate intrusions which are mineralogically and chemically similar to parts of the Boggy Plain Adamellite and Coolamine Igneous Complex. The intrusions are relatively undeformed, and intrude rocks as young as the Upper Silurian Gang Gang Adamellite. Like the Boggy Plain Adamellite and Coolamine

Igneous Complex they are all thought to be of Early Devonian age. Two types of intrusions have been shown on the TANTANGARA map: an even-grained type (Dgk), and a type containing cumulophyric groups of pyroxene crystals (Dck). One of the even-grained types, the Hell Hole Creek Adamellite (Crook & others, 1973) denoted as Dhh on the TANTANGARA map, has been described separately (see below). There are also several stocks and dykes, some less than 5 m wide, which are mostly too small to be shown on the TANTANGARA map; these are mainly cumulophyric types such as those from grid references 362255 and 416349.

The even-grained types are hornblende-biotite granodiorites, adamellites, and rare quartz monzodiorites with an average grainsize of 0.5 to 1 mm. The hornblende is green or brownish green, and commonly encloses cores of clinopyroxene; others have actinolitic cores after pyroxene. One sample from grid reference 436419 also contains fresh orthopyroxene in the cores of some of the hornblende crystals. Plagioclase is strongly zoned, with cores of An_{70} and rims commonly as sodic as An_{20}. The potash feldspar is orthoclase, and accessories include magnetite, sphene, apatite, and zircon. One adamellite from grid reference 450471 contains accessory sphene and allanite together. The modal analyses of five samples, including three from the Hell Hole Creek Adamellite, are given in Table M19.

TABLE M19. MODAL ANALYSES OF MINOR INTRUSIONS OF THE BOGGY PLAIN I-TYPE SUITE

Pluton	Unnamed	Unnamed	Hell Hole Creek Adamellite		
Sample no.	71840411	71840412	71840413	71840414	71840415
Grid ref.	436419	437422	447423	449418	449416
Quartz	12.3	20.1	32.2	30.2	23.0
Orthoclase	8.5	14.1	19.5	15.5	6.7
Plagioclase	43.8	41.0	35.8	34.7	32.8
Hornblende	15.8	8.4	6.5	9.0	20.5
Clinopyroxene	4.1	-	0.7	1.3	8.9
Orthopyroxene	1.7	-	-	-	-
Biotite	13.2	15.2	4.6	8.3	7.1
Accessories	0.6	1.2	0.7	0.5	1.0

The types with a cumulophyric texture form a wider range of rock types, from gabbro (grid ref. 388288) through quartz monzodiorite and granodiorite to adamellite. The conspicuous evenly distributed mafic clots in these rocks consist of rounded groups up to 6 mm of pyroxene crystals. Some groups contain only clinopyroxene, some only orthopyroxene, and some both pyroxenes. In a few samples the pyroxenes are arranged with their c-axes in a radial pattern, and in some of them a single pyroxene crystal shaped like an hour-glass extends from one side of a clot to the other. The geometrical arrangement of crystals in these groups indicates that the groups are not accidental microxenoliths, but are formed by the aggregation of pyroxene crystals suspended in a melt, although the pyroxene crystals themselves may have been xenocrysts rather than minerals that crystallised from the melt. The cumulophyric groups of pyroxenes are surrounded by narrow reaction rims of green or greenish brown hornblende. The hornblende is optically continuous only on individual pyroxene crystals. Opaques and biotite are also commonly present in the reaction rims. In many samples the pyroxene has been altered to uralite which is optically continuous with the surrounding hornblende. Some of the more mafic rocks, such as the quartz monzogabbro from Kiandra (Browne & Greig, 1923) and samples from grid references 416182 and 388288, contain olivine inclusions in some of the orthopyroxene crystals in the cumulophyric groups.

The pyroxene groups are embedded in a groundmass of similar composition to the even-grained rock types, except that hornblende is much less common and quartz and orthoclase rarer in the more mafic samples.

Hell Hole Creek Adamellite

Field occurrence

Bein (1969) and Crook & others (1973) used the name Hell Hole Creek granite for a subcircular intrusion that crops out in the eroded core of the semicircular Peak Back Ridge, which is drained by Hell Hole Creek - from which the unit takes its name. We have renamed the unit the Hell Hole Creek Adamellite because in most samples the alkali feldspar and plagioclase contents are roughly equal. The adamellite forms a marked topographic low over an area of about 2.5 km^2, which is surrounded by hills of the more resistant contact-metamorphosed Tantangara Formation. The adamellite crops out as small boulders generally less than 1 m but in places up to 2 m. It is deeply weathered, and fresh rock is difficult to obtain. Over much of the area it is covered by thick scrub, and the boundaries shown on the map are partly based on photo-interpretation.

Type locality

The type locality for the intrusion is here designated as a clearing on Hell Hole Creek at grid reference 449418, where scattered boulders of adamellite up to 2 m diameter are fairly common; this is the only clearing within the outcrop of the body.

Field relations

The contact of the intrusion with the surrounding rock is exposed where Hell Hole Creek leaves the Peak Back Ridge at grid reference 449416, where a medium to fine-grained granodiorite is in sharp contact with quartzite and hornfels of the Tantangara Formation. Metamorphism near the contact reaches the hornblende hornfels facies, and thermal effects of the granitoid, in the form of spotted shale, are present over 1 km from the contact (e.g., at grid ref. 452438).

Petrography

The adamellite is a relatively uniform reddish pink, weathering to pale pink. It consists of scattered pale green plagioclase phenocrysts up to 5 mm in a granular matrix of pink, black, and white potash feldspar, mafic minerals, plagioclase, and quartz grains 2 to 3 mm in diameter. Near the margin of the intrusion the rock is medium grey, weathering darker, even-grained with a grain-size of 1 to 2 mm, and has less potash feldspar than the rest of the intrusion, indicating zoning from granodiorite at the rim to adamellite in the core.

The adamellite has a hypidiomorphic texture with euhedral to subhedral plagioclase and mafic crystals surrounded by anhedral quartz and potash feldspar. The plagioclase is almost completely saussuritised except for narrow sodic rims, but here and there fresh labradorite is present in the cores of some grains. The anhedral potash feldspar is generally strongly stained a turbid brown, and in a few places forms graphic intergrowths with quartz. In contrast to plagioclase, which everywhere forms 30 to 35% of the rock, the amount of potash feldspar decreases from 20% near the centre of the intrusion to less than 7% at its margin. Quartz forms anhedral interstitial crystals, and shows a trend in abundance similar to the potash feldspar, decreasing from over 30% near the centre to 20% at the contact.

Biotite is present in fairly constant amounts, from 5 to 8%, and usually forms subhedral crystals commonly partly or completely replaced by chlorite; it is strongly pleochroic : X = pale yellowish brown, Y = Z = dark brown. A colourless clinopyroxene is fairly common near the edge of the intrusion (8.9% in sample 71840415, Table M19), but is rare towards its centre. This clinopyroxene, probably augite, is almost everywhere rimmed by green hornblende and is partly replaced by it. The reduction in the amount of augite towards the centre of the intrusion is partly the result of a more complete replacement of augite by hornblende, but it is also due to an overall reduction in all mafic minerals towards the centre. Hornblende also occurs as euhedral crystals without pyroxene cores. It is pleochroic - X = pale green, Y = green, and Z = dark green - has an extinction angle of 22^{o} on 010 sections, and $2V_x = 75^{o}$. Alteration of hornblende to chlorite with minor epidote is fairly common. Accessory minerals include apatite, zircon, sphene, and opaque minerals.

The modal compositions of three rocks from the Hell Hole Creek Adamellite are shown in Table M19. Sample 71840413 was from near the centre of the intrusion, 71840415 was from within 1 m of the contact against the Tantangara Formation, and 71840414 was collected at the type locality, roughly midway between the other two samples.

An intrusion on the western edge of the Peak Back Ridge appears to be related to the Hell Hole Creek Adamellite. It crops out on the ridge at grid reference 435422, and extends east towards the Hell Hole Creek Adamellite in the valley 220 m below. Detailed relations between the two intrusions could not be determined with certainty owing to the thick scrub, but they are probably not in contact with one another at the surface. The composition of this second intrusion ranges from quartz monzodiorite to granodiorite; it is medium grey, and consists of dark mafic minerals set in a white granular matrix of feldspar and quartz. Grainsize increases from about 1.5 mm near the margin to about 3 mm through most of the intrusion. The rock has a hypidiomorphic granular texture and a mineralogy similar to that of the Hell Hole Creek Adamellite; differences include more biotite (15%) and less quartz (10-20%). In addition, hypersthene, showing characteristic pale pink pleochroism, occurs near the contact with country rock; it, and the augite also present, are enclosed by hornblende. Towards the centre of the intrusion, replacement of pyroxene by amphibole is complete, and hornblende and biotite are the only mafic minerals present. The plagioclase is commonly fresher than in the Hell Hole Creek Adamellite and has cores of An_{65}.

Modal compositions of two rocks from the pluton are shown in Table M19. Rock 71840411 is from the margin and 71840412 from near the centre of the body.

MICALONG SWAMP BASIC IGNEOUS COMPLEX
(new name)

Nomenclature

Very little previous work has been done on the basic rocks cropping out on the western edge of BRINDABELLA. On the Canberra 1:250 000 Sheet (Best & others, 1964) they were poorly delineated and marked simply as 'ib' (intermediate and basic intrusions). Strusz (1971) stated that what is now termed Goobarragandra Volcanics includes numerous (but not delineated) basic intrusions and 'the large area of "ib" around Micalong Swamp may fall into this category.'

Owen & others (1974a) mapped two basic intrusions in the Fiery Range, TANTANGARA, and suggested that they correlate with the basic intrusions in BRINDABELLA. This correlation has been confirmed, as a series of basic stocks and dykes is now known to extend along the western edge of the Canberra 1:250 000 Sheet area, from the headwaters of the Yarrangobilly River in the south to the northernmost stock 5 km south-southeast of Burrinjuck Dam. The total meridional extent of these rocks is over 60 km. There are similar basic rocks along the eastern edge of the Wagga Wagga 1:250 000 Sheet area.

We here propose that all of these basic intrusions on the western edge of the Canberra 1:250 000 Sheet area be named the Micalong Swamp Basic Igneous Complex. To separately name the larger stocks at this stage would be inappropriate, as all the stocks are closely related and the rock-type variation within individual stocks is greater than that between stocks.

Derivation of name

The name is taken from Micalong Swamp, which forms the headwaters of Micalong Creek (grid ref. 385900) in BRINDABELLA.

Type section

We have not selected a type section, but easily accessible representative samples may be collected from Micalong and Wee Jasper Roads near Yankee Ned Hill, and from Wee Jasper Road just south of its junction with Yass Road (grid ref. 463113).

Field occurrence

In BRINDABELLA and TANTANGARA the Micalong Swamp Basic Igneous Complex consists of many stock-like bodies, of which 12 are 1 km^2 or more in outcrop area, and widespread meridionally oriented swarms of basic dykes. The largest stocks lie within a discontinuous belt 2-3 km wide and 33 km long, from around Micalong Swamp northwards to Wee Jasper Creek. North and south of this central belt the bodies are smaller.

Access north of Micalong Swamp is good because of the extensive network of forestry tracks within the Buccleuch State Forest, and the relatively flat grazing land north and west of the forest. To the south the Kiandra Tableland is deeply dissected by the Goobarragandra River and its tributaries, and vehicular access to the stocks is severely limited.

Exposure is generally widespread but mostly as float embedded in a rich red soil. Most of the exposure north of Micalong Swamp has been produced by bulldozers bringing rounded boulders to the surface in road-cuts. The size of the boulders is generally proportonal to the grainsize of the rock, and boulders up to 2 m are common. In the coarser-grained rock types rare tors are up to 4 m high (e.g., at grid refs. 388957 and 399055). In the more dissected areas, boulder float still forms the main type of exposure, though exposure in a number of stream sections is excellent (e.g., grid refs. 407830 and 382739). Closely spaced meridionally trending basic dykes intruding the Goobarragandra Volcanics are well exposed in road-cuts at grid references 369930 and 365921, and in the creek bed at grid reference 432983 (Fig. M26). Elsewhere, evidence for the presence of basic dyke swarms is a chaotic mixture of boulders of Goobarragandra Volcanics and dolerite. Such presumed swarms are mostly next to the larger stocks within the Goobarragandra Volcanics. Basic dykes are rare in the Young Batholith, but have been observed in the Coodravale Granodiorite at grid reference 498113, and are common in the porphyritic marginal phase of the Broken Cart Granodiorite in the Goobarragandra River valley at the northern end of

Feints Range. A weathered basic dyke 1.5 m wide in a road-cut at grid reference 418862 in the Broken Cart Granodiorite may be Tertiary and not related to the Micalong Swamp Basic Igneous Complex. Basic dykes also intrude the main stocks off the complex: this is mostly inferred from the presence of fine-grained dolerite float mixed with gabbroic float, but is evident in outcrops on the eastern side of Yankee Ned Hill (grid ref. 382957).

A fine to medium-grained gabbro with about equal proportions of plagioclase and mafic minerals is the main rock type in the twelve larger stocks. This rock type is greenish grey and mostly quite fresh, with a weathering skin of only a few millimetres. Listed below are several less common geographically restricted varieties of gabbro.

Olivine gabbro is uncommon; it crops out only in small areas at grid references 393629, 391970, and 363715. At the first of these localites it forms a band 30 cm wide which can be traced for 10 m, and is pitted because the olivines have partly weathered out. At the other two localities it occurs as boulders up to 70 cm across. The fresh rock at grid reference 391970 has a spotted texture due to darker olivine-rich patches up to 10 mm across set in the feldspar-rich groundmass.

Magnetite gabbro predominates in two areas: one occupies most of Yankee Ned Hill, and the other - occupying over 3 km^2 of outcrop - is near the junction of Wee Jasper and Yass Roads northwest of the Coodravale Granodiorite. The magnetite gabbro is darker than the gabbro elsewhere in the complex, and commonly contains elongate crystals of hornblende; it strongly attracts a small magnet tied to a length of string. The rock is generally more weathered than the gabbros richer in feldspar, and ranges in grainsize from very fine-grained to samples with crystals averaging 4 mm, such as at grid reference 382956.

Leucogabbro is the main rock type at the northern end of a stock around grid reference 402056, where it forms tors up to 2 m high. The rock is strongly banded, with alternating light and dark bands from 1 cm to 30 cm wide (Fig. M27). Plagioclase crystals are aligned parallel to the banding and probably accumulated, as a result of crystal settling, to form rhythmic layers, which dip 50^{o} to the south-southwest. Some of these layers are so depleted in mafic minerals that they form anorthosites containing about 90% plagioclase. Leucogabbro also crops out at grid references 402626 and 389985.

Gabbro pegmatite is locally abundant in all the stocks. It is composed mainly of feldspar, hornblende, and augite in grains up to 2 cm. In places the

Fig. M26. Dolerite dykes intruding the Goobarragandra Volcanics at grid reference 432983.
(GB/1819)

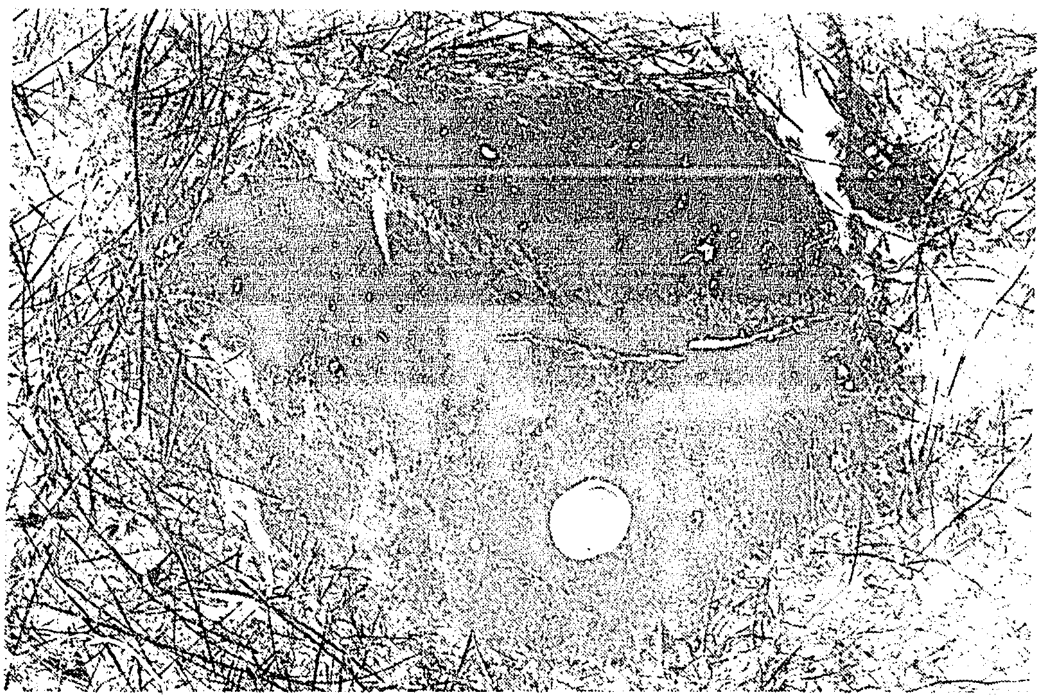


Fig. M27. Banded gabbro at grid reference 402052.
(GB/1840)

hornblende is markedly zoned. The pegmatites commonly form patches up to 30 cm, or bands up to 10 cm wide, apparently along joint planes; both are exposed at grid reference 388957.

At one locality (grid ref. 456129) a hornblende pyroxenite containing no plagioclase was found in float. This is the only known ultramafic rock in the complex.

Several of the larger gabbroic stocks contain areas of pale fine to medium-grained hornblende-quartz-feldspar rock which appear to be felsic differentiates of the gabbroic rocks. There are three main areas of outcrop of this rock type, which is denoted as Sim on the BRINDABELLA map:

(i) north of Wee Jasper Creek, immediately south of the Long Plain Fault;
(ii) along Yankee Ned Creek east of Halls Block (grid ref. 402975); and
(iii) about 7 km north-northwest of Cowrajago Hill (around grid ref. 375190).

In addition to these main outcrops, dykes of a similar rock type crop out on the eastern side of Yankee Ned Hill at grid reference 382957, and on the next hill east at grid reference 389959. Both these dykes are over 20 m wide and trend roughly meridionally. The dyke on Yankee Ned Hill is cut by nearly parallel dolerite dykes. The felsic rocks crop out as tors less than 1 m high, and are more weathered than the gabbroic rocks.

Petrography

There are three major groups of rock within the Micalong Swamp Basic Igneous Complex: dolerites, gabbros, and tonalites, the last also including quartz diorites and leucogranodiorites. The dolerites come from the dyke swarms and have a grainsize of less than 1 mm; the gabbros form the major part of the stocks; and the tonalites are differentiates of the gabbros and form a relatively minor part of some of the stocks. In addition to these major groups there are rare pyroxenites and contaminated gabbros; the fine-grained gabbro at grid reference 408235 has been hornfelsed by the later Burrinjuck Adamellite. For the convenience of describing the rock types within the general gabbro group, five subgroups have been distinguished, but it must be stressed that they form a differentiation continuum, which makes such grouping arbitrary.

1. Dolerites.

These rocks are mostly even-grained with an average grainsize of 0.5 mm. Samples with a grainsize of greater than 1 mm generally come from the stocks and not the dykes, and have been termed gabbros. Two types of dolerite are common. The most abundant type has a subophitic texture, but in most samples the pyroxene has been completely uralitised. Some samples, such as that from grid reference 376953, have infrequent unaltered clinopyroxene with uralitised rims. Plagioclase is euhedral to subhedral and mostly around 1.0 x 0.5 mm; both Carlsbad and albite twins are common. The composition ranges from An_{60} in the cores to around An_{30} in the narrow rims; the zoning is even, and oscillatory zoning is rare. Quartz, opaques, and apatite are common accessory minerals.

The other dolerite type is generally finer-grained (0.2-0.3 mm average grainsize) and does not have an ophitic texture. Instead the amphibole is more elongate and probably primary; pyroxenes are absent. Quartz and particularly opaques are more abundant; opaques form between 5 and 10% of the rock. Plagioclase is zoned and probably has an average composition around An_{45}. These rocks should strictly be termed magnetite-quartz microdiorites.

A few samples of porphyritic dolerite have been collected. One from grid reference 379951, contains about 15% plagioclase phenocrysts up to 3 mm, and 5% phenocrysts up to 2 mm of possible orthopyroxene completely altered to a mat of fine chlorite; the groundmass has an average grainsize of 0.3 mm. The plagioclase phenocrysts are extremely calcic; they are weakly zoned, having cores of around An_{90} in sharp contact with narrow rims of around An_{40}.

Two other dolerites, from grid references 408958 and 443966, appear to be porphyritic in hand specimen, but thin sections show that they comprise extremely poikilitic greenish brown hornblende up to 6 x 4 mm enclosing abundant groundmass-size plagioclase. As these hornblendes are not phenocrysts in the strict sense the rock cannot really be termed porphyritic.

2. Gabbros

(a) Clinopyroxene gabbro. This is the most abundant gabbro type, being the main constituent of all the larger stocks. Samples are even-grained, but locally grainsize may be anything from 1 to 5 mm; the coarse-grained types such as that from grid reference 364734 are the least common. Most samples have a subophitic texture of elongate euhedral plagioclase laths (An_{75-50}) and equant anhedral grains of partly uralitised colourless clinopyroxene ($2V_z \doteqdot 50^o$). In some samples, such as those from grid references 361723 and 381740, both plagioclase and clinopyroxene are anhedral. Poikilitic brown hornblende (up to 5%) is present in most samples; its pleochroic scheme varies from locality to locality between two extremes of X = pale brown, Y = red-brown, Z = red-brown, $X < Y < Z$, $2V_x = 75\text{-}80^o$, and X = pale yellow-brown, Y = brown, Z = green-brown, $X < Z < Y$, $2V_x = 65^o$. Opaques are common in rocks containing hornblende of the latter type, so this hornblende is probably the more iron-rich. Green hornblende surrounding the clinopyroxene, and quartz, are also present in these more iron-rich rocks. In some samples, such as that from grid reference 468103, euhedral plagioclase crystals are aligned to produce a well-developed cumulate layering.

Where uralitisation has been strong the adjacent plagioclase crystals have more sodic rims than normal, as low as An_{20} in some (e.g., at grid ref. 379186). This suggests that the original clinopyroxene was a subcalcic augite, so that calcium had to be scavenged from the feldspar and added to the augite to form uralite of roughly actinolite composition. Proof that this process plays at least some part in the uralitisation process is evident in sample 72840184, a coarse-grained gabbro from grid reference 374734, in which a zoned 4-mm plagioclase crystal has been broken and the fracture filled with fine-grained actinolite. For 0.2 mm either side of the fracture the plagioclase is strongly depleted in calcium, and there is a sharp boundary between the original and calcium-depleted parts of the plagioclase crystal. Evidently diffusion processes can remove calcium from the outer 0.2 mm of plagioclase crystals. The same sort of diffusion process probably operates when plagioclase is albitised during low-grade metamorphism.

(b) Two-pyroxene gabbro. This rock type cannot be distinguished from clinopyroxene gabbro in the field, but it contains clinopyroxene and up to 10% orthopyroxene. The orthopyroxene is colourless with $2V_x \doteqdot 70\text{-}75^o$ (bronzite), and is somewhat more ophitic to plagioclase than the accompanying clinopyroxene. One two-pyroxene-magnetite gabbro from grid reference 401955 contains pleochroic hypersthene ($2V_x \doteqdot 55^o$), rather than bronzite, with X = pale pink, Y = pale yellow, Z = very pale green. Two-pyroxene gabbro appears to be common in the stock immediately east of Hilltop (grid ref. 384042).

(c) Olivine gabbro. Two samples of olivine gabbro, from grid references 393629 and 363715, contain about 50% subhedral plagioclase (An_{75}, 2 mm) which is subophitic to colourless clinopyroxene (25%, $2V_z \doteq 50^\circ$, 2 mm). Almost all the clinopyroxene has orthopyroxene lamellae exsolved parallel to (100). Rounded olivine (10%) up to 1 mm is widely distributed. The olivine has $2V_x \doteq 80^\circ$ and so contains 60-70% forsterite; it also shows alteration selvedges of iddingsite. The rest of the rock is made up of roughly equal amounts of poikilitic orthopyroxene and red-brown hornblende, both irregularly enclosing the plagioclase, clinopyroxene, and olivine. The orthopyroxene may reach 2 mm, has $2V_x \doteq 70^\circ$, and is faintly pleochroic from pale pink to colourless.

An olivine gabbro from grid reference 391970 is similar in mineralogy and grainsize to those described above, except that the olivine occurs in partly altered patches about 10 mm in diameter composed of 1-mm olivine, plagioclase, and orthopyroxene. The olivine has $2V_x = 85^\circ$ (Fo_{75}), and the orthopyroxene has $2V_x = 62^\circ$ (En_{70}).

(d) Leucogabbro. This rock is of similar grainsize to the other gabbro types, but is characterised by the abundance of plagioclase (70-90%). The plagioclase is euhedral, calcic (An_{75-90}), and only weakly zoned. Most crystals are parallel, forming well-developed cumulate layering, and exhibit complex twinning on albite, Carlsbad, and pericline laws. Interstitial partly uralitised clinopyroxene and brown hornblende are the only other primary minerals, though one banded leucogabbro from grid reference 401051 contains a layer 5 mm thick of plagioclase (85%), opaques (10%), and apatite prisms up to 1 mm long (5%).

One rhythmically banded gabbro from grid reference 399055 contains alternating dark and light bands a few centimetres thick. The dark bands have a sharp base and grade up into the light bands. The only difference between the dark and light bands is in the abundance of uralitised clinopyroxene and interstitial brown hornblende. Aligned plagioclase occupies 90% of the rock in the light anorthositic bands and has a composition of An_{91} (from fig. 2 of Tobi & Kroll, 1975).

(e) Magnetite gabbro. This rock type predominates in two areas (see Field occurrence). It differs from the other gabbros in that hornblende is the main primary mafic mineral, and opaques occupy more then 5% of the rock. The hornblende is commonly zoned with greenish brown cores and green rims, and some crystals enclose partly or completely uralitised pyroxene. The pyroxene is mostly monoclinic, but pleochroic orthopyroxene is also present in some samples (e.g., grid ref. 401955). Weak pinkish pleochroism in the clinopyroxene points to a moderate titanium content. Opaques are subhedral to anhedral, and up to 2 mm in the coarser-grained gabbros. In some samples, such as from grid references 386961 and 396970, opaques form up to 15% of the rock. Partly saussuritised plagioclase is subhedral and is zoned from An_{65} to An_{30}. Quartz is a common interstitial mineral, and in some samples a graphic intergrowth of quartz and sodic plagioclase forms part of the interstices. Apatite and anhedral sphene are common accessories. Most of these rocks should be strictly called hornblende-magnetite gabbros and hornblende-magnetite-quartz gabbros or quartz diorites.

3. Hornblende pyroxenite

Only one ultramafic rock has been found in the Micalong Swamp Basic Igneous Complex - a uralitised hornblende pyroxenite from grid reference 456129. It is composed of subhedral ?clinopyroxene crystals (1-2 mm) completely altered to uralite and granular opaques embedded in extremely poikilitic pale brown hornblende up to 10 mm. Plagioclase is absent. The rock is probably from a cumulate layer in which pyroxene has settled, and hornblende has crystallised as an intercumulus mineral.

4. Tonalites

Tonalites and leucogranodiorites represent the fractionated parts of the Micalong Swamp Basic Igneous Complex. With alkali and silica enrichment the hornblende-magnetite-quartz diorites grade into tonalites by a decrease in mafics and an increase in quartz and sodic feldspar. The quartz and sodic feldspar mostly form graphic intergrowths up to 1.5 mm. The feldspar is optically continuous with adjacent euhedral plagioclase crystals, which are also up to 1.5 mm and are zoned from An_{40} or An_{50} to An_{10}. A single albite twin is present in most of the plagioclase crystals. In some samples the quartz and sodic feldspar have not crystallised together but form separate grains - for example, in samples from grid references 375191 and 371179, which contain about 50% zoned plgioclase (An_{50} to An_{10}) and 35% quartz; some of the quartz grains have a beta-habit. In both the graphic and non-graphic tonalites hornblende (up to 12%) and opaques (up to 6%) make up most of the rest of the rock, but apatite needles up to 2 mm long are common, cutting across all other minerals, and zircon is also present. The hornblende is commonly partly altered to chlorite, epidote, and actinolite, but when fresh is a very dark ferro-hastingsite with X = brown, Y = very dark greenish brown (in some samples almost black), Z = dark green, X < Z < Y, and $2V_x \doteqdot 20^{0}$.

The most fractionated rocks are rare; they are fine, even-grained leucogranodiorites collected from dykes at grid references 451106, 459119, and 388961. Their average grainsize is about 0.5 mm, and quartz, plagioclase, and antiperthite make up about 90% of the rocks. Quartz-feldspar intergrowths are rare. The plagioclase is commonly zoned, with An_{35} cores and albite rims; some crystals have antiperthite rims. Ferrohastingsite, opaques, and biotite (X = pale yellowish brown, Y = Z = dark brownish green) make up the rest of the rock. Chlorite and epidote are common alteration products of the mafic silicates, and apatite and zircon are accessories.

5. Contaminated rocks

A number of gabbros and dolerites contain potassic minerals which do not fit into the differentiation sequence delineated for the Micalong Swamp Basic Igneous Complex. We have concluded that these minerals (biotite and microcline) are contaminants. Biotite is the most common. It occurs as partly chloritised flakes up to 2 mm with X = pale yellow-brown, Y = Z = brown with a reddish tinge. Pleochroic haloes are present but are not abundant. The biotite is of a similar size and colour to that in the adjacent Young Batholith. Samples containing biotite have been collected from grid references 403826, 408829, and 447959. Interstitial perthitic microcline is present as monzonitic plates up to 2 mm in samples from grid references 396838, 401833, and 463112.

Discussion

The great range of rock types from abundant basic to rare acid types indicates a well-developed differentiation suite. In situ gravity settling has resulted in a range of basic types from anorthosites to pyroxenites. Olivine and two-pyroxene gabbros are relatively uncommon. Differentiation of the parent liquid has produced iron-rich intermediate members such as hornblende-magnetite gabbro and hornblende-magnetite-quartz gabbro or quartz diorite. The final products of differentiation are tonalites and leucogranodiorites containing ferrohastingsite. The presence of this amphibole in the tonalites indicates a higher iron-to-magnesium ratio than in the iron-rich intermediate members. Soda and silica enrichment proceeds before potash enrichment, and only in the extremely differentiated leucogranodiorites do readily identifiable potash-bearing minerals appear. The Micalong Swamp Basic Igneous Complex is a classic example of rocks produced by low-pressure fractionation of a low-potassium tholeiitic liquid.

Age and relations

The Micalong Swamp Basic Igneous Complex intrudes the Goobarragandra Volcanics, but its relation to the Young Batholith is less simple. The larger basic stocks are older than the Broken Cart Granodiorite and appear to be older than the Couragago Granodiorite. No basic dykes have been observed in these two granitoids, but dykes are present in a porphyritic phase mapped as part of the Broken Cart Granodiorite at the northern end of Feints Range; this porphyry is probably a separate, slightly older intrusion. The dykes are less abundant in the porphyry than in the adjacent Goobarragandra Volcanics. Dykes must have been intruding the region both before and after the intrusion of the porphyry, but ceased intruding before the main body of Broken Cart Granodiorite reached its final emplacement position. The basic stock at the headwaters of the Yarrangobilly River intrudes and has hornfelsed the I-type Kennedy Range Adamellite, yet another basic stock is intruded by the I-type Coodravale Granodiorite, which rare basic dykes have intruded.

From the above relations, we deduce that the emplacements of the Young Batholith plutons and the Micalong Swamp Basic Igneous Complex are intimately related, but the emplacements cannot be regarded as a single event. The relative ages of the basic stocks and the granitoids is probably reflected by the abundance of basic dykes within them, and the basic dykes were intruded over a considerable time. The presence of meridionally trending basic dykes has important implications for the stress regime in the region over that time.

At grid reference 406235 a vein of Burrinjuck Adamellite intrudes a hornfelsed basic stock. As the Burrinjuck Adamellite is thought to be considerably younger than the Young Batholith, it is probably also younger than all of the Micalong Swamp Basic Igneous Complex.

An attempt was made to date whole-rock samples of the Micalong Swamp Basic Igneous Complex by the Rb/Sr method, but this was unsuccessful because of the low values and limited spread in the Rb content of the samples. Hornblende from a hornblende-magnetite-quartz gabbro from grid reference 463112 was dated by the K/Ar method as 430 $\pm$ 9 m.y., an age slightly older than the stratigraphic constraints indicate.

Thus the Micalong Swamp Basic Igneous Complex is a group of chemically related intrusive rocks, the age of which is Late Silurian.

DEVONIAN SEDIMENTARY UNITS

Devonian sedimentary rocks are restricted to an area in the north of BRINDABELLA, where shallow-marine (Murrumbidgee Group), restricted marine (Kirawin Formation) and fluviatile (Sugarloaf Creek Formation and Hatchery Creek Conglomerate) environments existed. The original extent of these sediments is not known, but they probably never fully covered the thick pile of Mountain Creek Volcanics immediately to the south.

Kirawin Formation

Nomenclature

Best & others (1964) introduced the name 'Kirawin Shale' for a black shale or mudstone which crops out in the Narrangullen area between the Mountain Creek Volcanics and the 'Sugarloaf Creek Tuff'. Previously, rocks of 'Kirawin Shale' were included in the 'Sugarloaf Creek Tuff. Pedder & others (1970) changed the name to Kirawin Formation, but the unit has never been formally described.

Derivation of name

The unit is assumed to have been named after Kirawin homestead (grid ref. 676163).

Type section

Natural exposures of the Kirawin Formation are poor owing to its soft nature. We therefore propose as the type section a road-cut at grid reference 576211 on Yass Road, 1.2 km south of Narrangullen. About 15 m of black mudstone dipping 21° to the northwest is exposed, and is typical of the unit where it is fresh and undeformed.

Distribution

The outcrop of the Kirawin Formation forms an arcuate belt 0.5 to 4 km wide, which stretches for 35 km from the eastern side of Codys Spur north to Sugarloaf Creek, then northeast to Narrangullen, then southeast down the valley of Sawyers Creek to Waratah and Kirawin homesteads. Throughout this area the Kirawin Formation tends to form valleys, since it is soft and easily eroded.

Lithology

The Kirawin Formation is typically a massive to poorly bedded black mudstone. When weathered it is light grey to white, and, since weathering is preferentially along joints, bedding planes, or recent root lines, the rock often has a mottled appearance. Thin sections show that the rock consists of very fine quartz grains, muscovite flakes, and rare feldspar scattered through a carbonaceous clay matrix. The muscovite is considered to be secondary, possibly after illite. At some localities the mudstone is thinly laminated owing to variations in the proportion of quartz present, and in places it contains scattered clasts commonly up to 1 cm and rarely up to 3 cm. These clasts are often weathered, but when fresh enough can be identified as volcanic rock fragments from the Mountain Creek Volcanics; they are particularly well developed between Narrangullen and Sugarloaf Creek.

In the area around Narrangullen, where deformation is slight, the mudstone is uncleaved, but, both to the southwest and southeast, dips within the unit become increasingly steep and cleavage is in places well developed.

Close to the contact with the underlying Mountain Creek Volcanics are several thin impersistent black rhyolite flows similar to the typical black rhyolite in the Mountain Creek Volcanics. Some agglomeratic and tuffaceous beds also occur close to this contact.

Higher in the sequence are a few thin fine-grained arenite beds. These contain an abundance of lithic volcanic fragments together with quartz and feldspar.

Environment of deposition

Fossils are virtually absent from the bulk of the Kirawin Formation, apart from rare worm burrows in cleaved mudstone at grid reference 680158, and unidentified trilobites (probably a new genus) found by ANU students near Brooklyn homestead (P.A. Jell, personal communication 1973). Both occurrences are from near the base of the unit. Black muds are commonly regarded as being deposited in marine, oxygen-depleted, anaerobic environments where the supply of detritus is virtually nil. For the Kirawin Formation a marine environment is suggested by the occurrence of trilobites near the base, but the environment rapidly became anaerobic, since fossils are lacking from higher in the unit. The Kirawin Formation is therefore thought to have been deposited in a restricted marine environment which received little coarse detrital sediment.

The absence of coarse detritus from the basin is a puzzling feature for which we have no explanation. It would be expected that, since a thick subaerial volcanic pile - the Mountain Creek Volcanics - was formed immediately before (and even possibly, in part, at the same time as) the Kirawin Formation was deposited, there would be an abundance of available detritus. Instead, abundant debris from the volcanics occurs in the succeeding unit, the Sugarloaf Creek Formation.

Relations

The Kirawin Formation rests conformably on the Mountain Creek Volcanics, and is overlain conformably by the Sugarloaf Creek Formation; both contacts are gradational. At the lower contact, thin rhyolite and tuff are interbedded with black mudstone over several tens of metres, and the contact has been defined for mapping convenience at the top of the last flow which forms a topographic feature. Similarly the top of the Kirawin Formation is placed at the base of the first arenite to form a topographic feature.

Both the lower and upper boundaries are probably time transgressive, since in the Cavan area the Sugarloaf Creek Formation rests conformably on the Mountain Creek Volcanics and the Kirawin Formation is absent. Presumably this area was outside the restricted marine environment in which black mud was deposited.

Thickness

The thickness of the Kirawin Formation in the Wee Jasper area is about 1000 m. It thins to about 500 m in the Sawyers Creek valley and must rapidly thin to nothing eastward, since it is absent in the Cavan area.

Age

No direct fossil evidence for the age of the Kirawin Formation has been found. Since it lies conformably between the Mountain Creek Volcanics and the Sugarloaf Creek Formation an Early Devonian age is assumed.

Sugarloaf Creek Formation

Nomenclature

Edgell (1949) used the name 'Sugarloaf Creek Tuff' for a thick sequence of what he considered to be tuff and rhyolite underlying the Devonian limestone at Wee Jasper. Joplin & others (1953) published this name, which Pedder & others (1970) changed to Sugarloaf Creek Formation. Since we consider the unit to be entirely composed of lithic arenites with no primary volcanic rocks present, we prefer the name Sugarloaf Creek Formation.

Derivation of name

The unit is named after Sugarloaf Creek, which flows into Burrinjuck Reservoir 6 km north of Wee Jasper.

Type locality

No type locality has previously been designated for the Sugarloaf Creek Formation. We therefore designate the road-cutting on Yass Road, from the base of the unit at grid reference 545138 to the top of the unit at grid reference 536133. This section gives good exposures typical of the formation in the western part of its outcrop. A representative section for the eastern area of outcrop is at a road-cut on Mountain Creek Road at grid reference 677177.

Distribution

The outcrop of the Sugarloaf Creek Formation closely follows that of the Kirawin Formation. It commences about 7 km south of Wee Jasper and extends along the east bank of the Goodradigbee River to the northern edge of the map, in a belt initially about 1 km wide but widening to 4 km north of Sugarloaf Creek. In the north the outcrop swings eastwards for several kilometres, and occupies a broad belt extending into YASS, before narrowing and turning south-southeast to form a prominent ridge parallel to and east of Sawyers Gully. East of Mountain Creek Road, the unit is cut off by the Dingo Dell Fault, but it reappears around Cavan Bluff, where it crops out in several small fault-disrupted outcrops.

Lithology

The Sugarloaf Creek Formation is composed of two contrasting lithologies, both of which are derived by the erosion of volcanic rocks. In the west, coarse, poorly sorted arenite predominates, whereas in the east better sorted arenite, siltstone, and shale make up the unit. The lithologies appear to grade laterally into one another in the area of Narrangullen. The composition of the arenites also gradually changes from west to east: in the west all the debris appears to be derived from the Mountain Creek Volcanics, and quartz is virtually absent, whereas in the east there is an increasing proportion of quartz, much of which may be derived from the extensive Silurian volcanics to the east.

The Sugarloaf Creek Formation west of Narrangullen is typically formed of medium to coarse litharenite which typically forms abundant, though invariably weathered, exposures. The arenite is in massive beds, usually from 1 to 10 m thick, which are often lenticular and may channel into underlying units. Within an individual bed sedimentary structures and graded bedding are absent. Thinner beds up to 1 m thick are not lenticular, at least over 30 to 50 m, and may have cross-bedding within them.

The lenticular beds are poorly sorted and composed of angular to subrounded grains from 0.5 to 3 mm in a fine matrix, which typically forms about 40% of the rock. The grains are composed almost entirely of volcanic rock fragments, including flow-banded rhyolite and fine tuff, which may be correlated with rock types in the Mountain Creek Volcanics. Rare quartz grains are also present. XRD determinations on the matrix have revealed that it is mainly composed of illite and chlorite, with minor quartz and plagioclase. Cross-bedded arenites have a similar mineralogy but are better sorted, with much less clay matrix, and lack angular grains.

In the top 30 to 40 m of the unit, coarse to medium-grained litharenites are replaced by fine-grained litharenite or siltstone in parallel-bedded units up to 0.5 m thick, and with cross-bedding locally. These rocks are moderately well sorted, and have a greater quartz component, though lithic grains still predominate.

East of Narrangullen the Sugarloaf Creek Formation is formed of interbedded arenite and siltstone in parallel bedded units up to 0.5 m thick; cross-bedding is evident in places. The arenite is composed of moderately to well-rounded grains from 0.3 to 1.5 mm, and is mostly fairly well sorted; its clay component is less than that farther west. Volcanic rock fragments continue to be the main component, but quartz is more common and rare grains of potash feldspar are present.

Farther east the proportion of quartz and feldspar grains increases and the amount of rock fragments derived from the Mountain Creek Volcanics decreases, until, around Mountain Creek Road, quartz forms over 50% of the grains, feldspar about 10%, and Mountain Creek Volcanic fragments about 15%. Other rock types apparent as grains include quartzite, siltstone, and shale fragments possibly derived from the Ordovician flysch; volcanic grains derived from the Silurian acid volcanics; and rare composite grains of quartz and potash feldspar derived from a granite.

The available rather limited evidence suggests that the change in composition of the arenites from east to west is a gradational one. Similarly there appears to be a gradual lateral change from the massive lenticular arenites in the west to the thinner parallel-bedded arenites in the east. No massive lenticular arenites are known east of Narrangullen, and the change in facies appears to be accomplished by a gradual increase in the number of thinner parallel-bedded arenites immediately west of Narrangullen.

Environment of deposition

The massive lenticular, poorly sorted arenites in the west appear to have been deposited by a series of mudflows in a subaerial environment. They appear to be similar to mudflow deposits described elsewhere (Crandell, 1971; Walton, 1977); a mudflow mechanism appears to be the only depositional method which would result in a rock with such a high clay content. Although mudflows appear to have been the main depositional process in the Wee Jasper area, normal fluviatile processes also led to the deposition of arenite, especially near the top of the formation. East of Narrangullen, mudflow deposition is not evident, and sedimentation appears to have been in a fluviatile environment.

The available evidence suggests that much of the Sugarloaf Creek Formation was deposited, after volcanism had ceased, in an alluvial fan environment (Bull, 1964) on the sides of the northern stratovolcano formed by the Mountain Creek Volcanics. In the east of the area however, other source rocks besides the Mountain Creek Volcanics contributed to form the arenites in the Sugarloaf Creek Formation, and the influence of the alluvial fans draining off the Mountain Creek Volcanics appears to have been minor.

Thickness

The thickness of the Sugarloaf Creek Formation, ranges from about 1200 m near Wee Jasper to about 200 m near Cavan Bluff.

Age and relations

The Sugarloaf Creek Formation conformably overlies the Kirawin Formation, and the Mountain Creek Volcanics near Cavan, where the Kirawin Formation is absent. The Cavan Limestone conformably overlies the Sugarloaf Creek Formation, the contact being gradational.

The Sugarloaf Creek Formation is apparently unfossiliferous, but, since the base of the Cavan Limestone is considered to be early Pragian, the Sugarloaf Creek Formation is considered to be latest Lochkovian to earliest Pragian.

MURRUMBIDGEE GROUP:

Cavan Limestone, Majurgong Formation, and Taemas Limestone

The Devonian limestones and associated sediments of the Taemas and Wee Jasper areas have long been famous; they were first recognised by Mitchell (1838). Since then, a multitude of different names has been used for the various units, but the nomenclature of Browne (1959) is the one which has gained acceptance in the literature. Because of this wide acceptance of Browne's nomenclature we recommend that the theoretical priority of many earlier names be ignored. A full list of these is given by Pedder & others (1970) and need not be repeated here, although the more important work is summarised below.

Süssmilch (1914) introduced the name 'Murrumbidgee Beds' for the limestones of the area; David (1932) changed the name to 'Murrumbidgee Series'. Subsequently Browne (1959) divided the 'Series' around Taemas and Cavan into the 'Cavan Stage', 'Majurgong Stage', and 'Taemas Stage' (in ascending order), and subdivided the Cavan and Taemas Stages into a number of units which may best be regarded as informal members for nomenclatural purposes. Subsequent changes have included replacing the term 'Stage' with 'Formation' or 'Limestone', and renaming the Murrumbidgee Series the Murrumbidgee Group (Pedder & others, 1970).

The limestones in the Goodradigbee valley near Wee Jasper were called the 'Goodradigbee Group' by Joplin & others (1953), and the 'Goodradigbee Limestone' by Best & others (1964). Brown (1964), following the unpublished nomenclature of Edgell (1949), divided the sequence into the 'Lower Goodradigbee Limestone', 'Cookmundoon Shales' and 'Upper Goodradigbee Limestone'. Subsequent work by Young (1969) and Pedder & others (1970) has clearly demonstrated that the three major subdivisions of Browne (1959) can be applied to the Wee Jasper area; we therefore use Browne's nomenclature for the Wee Jasper sequence.

Cavan Limestone

Browne (1959) gave the name 'Cavan Stage' to the lower limestone unit in the Murrumbidgee Group. Pedder & others (1970) used both the names 'Cavan Formation' and 'Cavan Limestone'; we prefer the name 'Cavan Limestone'. Both Best & others (1964) on the Canberra 1:250 000 geological map, and Cramsie & others (1975) on the YASS map, used the name 'Cavan Bluff Limestone'. However, since Browne (1959) used the name 'Bluff Limestone' for the middle part of her 'Cavan Stage', the term 'Cavan Bluff Limestone' is potentially misleading and should not be used.

No type section has formally been designated, although Browne stated that the unit crops out typically at Clear Hill, 1 km south-southeast of Cavan homestead. We therefore propose that the section on Clear Hill (grid ref. 699231) directly underneath the power transmission line be designated the type locality; Offenburg (1974, p. 55) has tabulated a section at this locality.

The contact with the underlying Sugarloaf Creek Formation is gradational; we have placed the boundary at the first limestone bed. In the Cavan area, about 30 m of thinly bedded impure limestone interbedded with brown and grey shale is overlain by 9 m of algal laminated limestone, followed by 42 m of massive to well-bedded limestone (the 'Bluff Limestone' of Browne). Above the massive to well-bedded limestone, a further 15 m of yellowish limestone with shale interbeds is followed by 7 m of massive limestone, which forms the top of the Cavan Limestone.

The succession is similar in the Wee Jasper area, where, however, shale forms a slightly greater proportion of the sequence.

Fossils are common at many levels in the Cavan Limestone, and several corals described by Hill (1940) have their type locality on Clear Hill (grid ref. 699231). Corals are particularly numerous, and brachiopods and gastropods are also common. Bryozoans, bivalves, crinoids, trilobites, and fish have also been found.

The Cavan Limestone was deposited in shallow water near the shore; mud-cracks, ripple marks, and algal laminations are common, and suggest - perhaps surprisingly as the lithology appears to be so laterally consistent - that a supratidal to shallow subtidal environment prevailed.

The thickness of the unit is 103 m in the Cavan area and 155 m in the Wee Jasper area.

Marjurgong Formation

Browne (1959) gave the name, 'Majurgong Stage' to clastic sediments conformably overlying the 'Cavan Stage', but Pedder (1967) changed the name to Majurgong Formation. The unit is named after Majurgong trig station (grid ref. 639291) in YASS. Cramsie, Pogson, & Baker (1978) have nominated a section 1.5 km north of Taemas homestead (YASS; from grid ref. 650284 to grid ref. 648283) as the type section. A typical section in BRINDABELLA is exposed in a road-cut on Yass Road between grid references 656231 and 659225.

In the Cavan area the Majurgong Formation consists of mainly red and some grey shale, siltstone, and fine-grained sandstone. Rare coarse sandstone forms beds up to 2 m thick, and calcareous beds are locally present, especially near the contact with the underlying Cavan Limestone, where thin impersistent limestone beds make this contact gradational. Ripple marks, fine cross-bedding, and mud-cracks are common. Fossils are rare, being generally limited to Lingula and occasional calcareous beds rich in gastropods. The contact with the overlying Taemas Limestone is marked by the incoming of calcareous bands which become increasingly rich in the brachiopod Spinella yassensis.

A similar lithology is present in the Wee Jasper area, although calcareous beds are apparently absent, and siltstone and fine sandstone are more prominent than in the type area.

The arenites are mainly quartz litharenites containing an abundance of lithic grains. Many of these are apparently derived from the Mountain Creek Volcanics, and the proportion of lithic fragments to quartz is greater in the Wee Jasper area than around Cavan, though quartz grains are always the main component.

The thickness of the Majurgong Formation varies. Browne (1959) quoted a thickness of 123 m, but did not state where this was measured. In the type section, Offenburg (1974) quoted a thickness of 115 m, and stated that it thins to about 60 m farther north and even less to the south. This rather marked thinning southwards into BRINDABELLA may be largely tectonic in origin, since the incompetent Majurgong Formation is situated between two competent but strongly folded limestone units. Pedder & others (1970) gave a thickness of 210-215 m for the Majurgong Formation in the Wee Jasper area, but it is obvious from the work of Young (1969) that they included the lowest member of the Taemas Limestone within the unit, whose real thickness in this area is about 120 m.

The range of sedimentary structures within the Majurgong Formation suggests that it was deposited mainly in shallow water which may have been brackish rather than marine. An estuarine environment is therefore suggested for the Majurgong Formation.

Taemas Limestone

David (1950) introduced the name 'Taemas Series' for what is now known as the Murrumbidgee Group. Browne (1959) restricted the name to the upper limestone sequence, and modified it to the 'Taemas Stage', which she subdivided into seven members. These are, in ascending order, the '*Spirifer yassensis* Limestone', 'Currajong Limestone', 'Bloomfield Limestone', '*Receptaculites* Limestone', 'Warroo Limestone', 'Crinoidal Limestone', and an unnamed uppermost unit of tuff and shale. Browne's choice of names is unfortunate: only two, Bloomfield and Warroo, are permissible as names for members under the Australian Code of Stratigraphic Nomenclature. However, the widespread and entrenched usage of all the names means that to abandon or change them now would cause unnecessary confusion. They may perhaps be regarded as informal subdivisions of the Taemas Limestone.

Cramsie & others (1978) have proposed a section in YASS at Duffys Point (grid ref. 634314 to 651324) as the type section.

The lower four subdivisions of Browne (1959) are exposed in BRINDABELLA near Cavan, but in the Wee Jasper area, where the whole of the unit is present, only the lower three subdivisions can be recognised; the 'Bloomfield Limestone' is succeeded by a different facies.

The '*Spirifer yassensis* Limestone' consists of poorly exposed thin interbeds of pure limestone, shaly limestone, and yellow-brown shale, which are commonly richly fossiliferous; the brachiopod *Spinella yassensis* is characteristic of the lower part. The '*Spirifer yassensis* Limestone' rests conformably on the Majurgong Formation, the contact being gradational over several tens of metres, and is overlain conformably though rather more abruptly by the 'Currajong Limestone'.

The 'Currajong Limestone' is a well-exposed massive to well-bedded fine-grained limestone. In contrast to the underlying member, terrigenous material is virtually absent. Fossils are common and at some localities are partly silicified. The 'Bloomfield Limestone', which conformably overlies the 'Currajong Limestone', marks a return to a similar facies to the '*Spirifer yassensis* Limestone'; it comprises thin-bedded flaggy limestone and mudstone, and beds of more massive limestone.

The three lower subdivisions of the Taemas Limestone, described above, are remarkably similar between Taemas and Wee Jasper; however, the next limestone subdivision in the sequence - the '*Receptaculites* Limestone', which is the youngest one in BRINDABELLA near Taemas - cannot be identified in the Wee Jasper area. The '*Receptaculites* Limestone' is a massive to well-bedded limestone, often fossiliferous, with widespread silicification of many fossils; terrigenous sediment is almost completely lacking.

In the Wee Jasper area a thick sequence of biostromal limestone is developed above the 'Bloomfield Limestone' (Young, 1969). Most of this sequence comprises massive to well-bedded biosparite or biomicrite in which biostromes have developed at many levels. In the uppermost part of the sequence, mudstone and shaly limestone predominate near the contact with the overlying Hatchery Creek Conglomerate.

No detailed analysis of the depositional environment of the Taemas Limestone has yet been published, but the richly fossiliferous nature of the unit, in which corals and brachiopods are particularly abundant, indicates a shallow-marine environment. However, the unit accumulated in water deeper than that in which the Cavan Limestone was deposited, since algal laminations and mud-cracks which are characteristic of the Cavan Limestone are largely absent in the Taemas Limestone.

Browne (1959) estimated the thickness of the Taemas Limestone in the Taemas area as 840 m, and Young (1969) placed the thickness at 970 m in the Wee Jasper area.

Age of the Murrumbidgee Group

The richly fossiliferous limestones of the Murrumbidgee Group have been extensively studied in the past, but much still remains to be documented. The early work of de Koninck (1876) and Hill (1940) suggested a Middle Devonian age. The most recent discussion of the age of the group is by Chatterton (1973), who, primarily from a study of brachiopods and trilobites from the Taemas Limestone, concluded that the base of the group is no older than early Emsian and that the top is most likely of late Emsian or possibly earliest Eifelian in age. This is essentially in agreement with Pedder & others (1970) who stated that the group ranges from the early Pragian to late Zlichovian in age.

Hatchery Creek Conglomerate

The occurrence of a red-bed sequence of presumed Devonian age in the Wee Jasper area was first reported by Edgell (1949). He described a succession of conglomerate, sandstone, red siltstone and shale, and grey shale, and interpreted it as a terrestrial sequence. He deduced a Devonian age for these rocks from their position above limestone to which he assigned an Early to Middle Devonian age, and from his mistaken interpretation that they are intruded by a granite (the Burrinjuck Adamellite) to which he wrongly assigned a Carboniferous age. He applied two names to the sequence in his unpublished work; he divided it into a lower part dominated by conglomerate, and an upper part of mainly red siltstone and some grey siltstone. His names have never been published, and as we do not use his divisions, they remain so.

Joplin & others (1953) named the sequence the Hatchery Creek Conglomerate, which has been used by later authors; yet the unit remained undefined and only poorly described. Subsequent workers have paid little more attention to it, except to suggest a correlation with the Hervey Group farther north (Pedder, 1967; Packham 1969, p. 149; Pedder & others, 1970).

None of these authors reported fossils from the Hatchery Creek Conglomerate, except for unidentifiable wood fragments; their suggestions of the age of the unit were Late Devonian by lithological correlation with the Hervey Group.

Derivation of name

The name Hatchery Creek Conglomerate is derived from Hatchery Creek, which flows into Burrinjuck Reservoir near Burrinjuck Dam (grid ref. 460247).

Type section

No type section for the formation has previously been nominated. Since the exposures are scattered in Hatchery Creek, which is relatively inaccessible, we nominate the section along the Cave Creek road from grid reference 506173 to 491172 as the type section for the Hatchery Creek Conglomerate (Fig. M28). About 1200 m of conglomerate, sandstone, and siltstone typical of the lower part of the formation crop out here in almost continuous exposure.

Distribution

The Hatchery Creek Conglomerate crops out over about 65 km^2 in BRINDABELLA; a further 4 km^2 are covered by thin Tertiary basalt flows, and about 1 km^2 crops out in YASS. The formation occupies a roughly semicircular area west of the Goodradigbee River near Wee Jasper; its outcrop has a north-south length of about 16 km and a maximum width of 7 km.

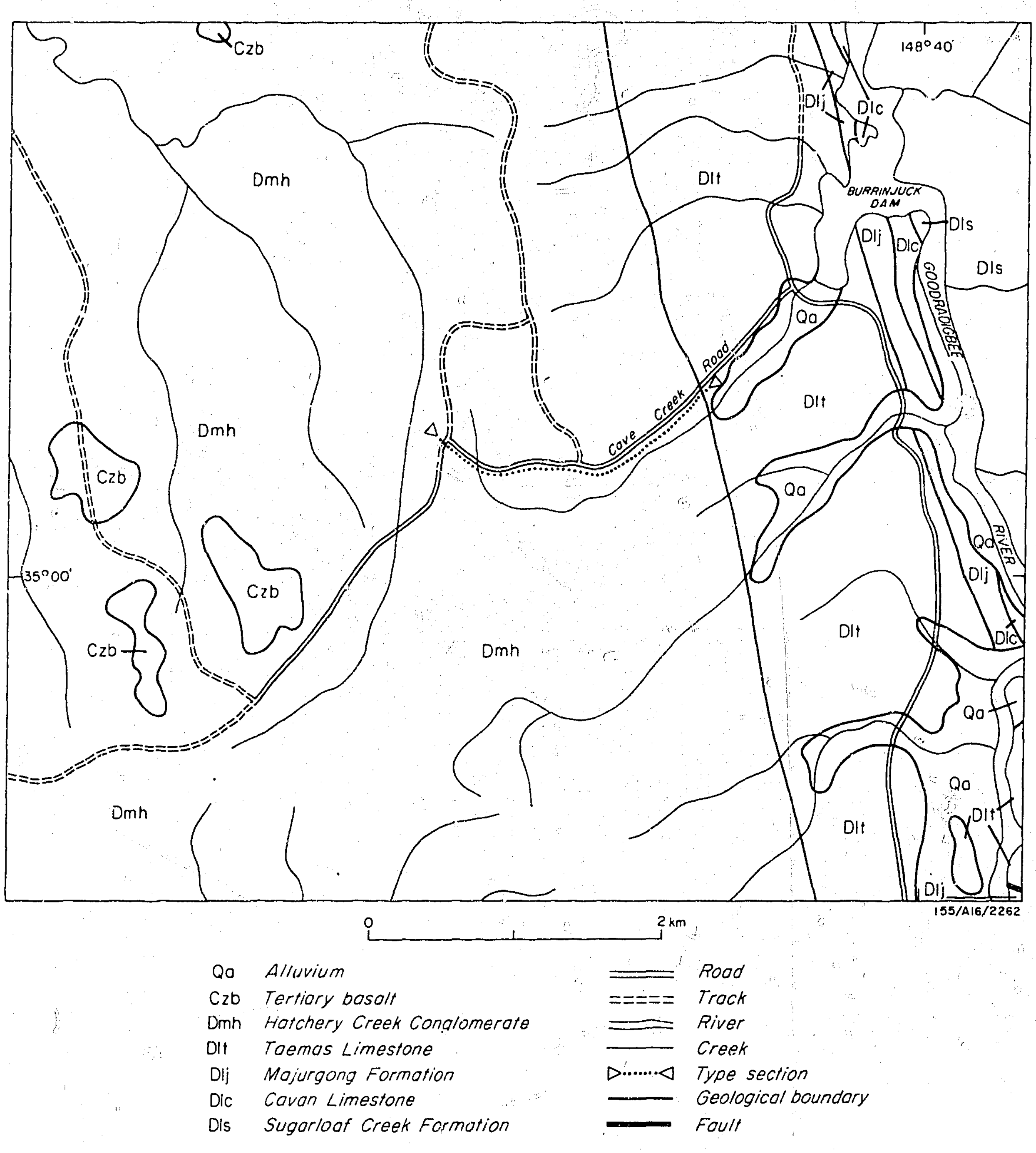


Fig. M28. Type section of the Hatchery Creek Conglomerate

Lithology

The lower part of the Hatchery Creek Conglomerate comprises numerous sedimentary cycles. From the top a complete cycle is:

<u>red silty unit with round whitish mottles</u> - contains root casts which bifurate downwards; in upper part, extensively bioturbated, bedding in places destroyed, and colour bleached around numerous root casts; wood tissue rare

<u>reddish purple sandstone</u> - thin-bedded and usually flat-bedded; local foreset cross-bedding in which foresets dip at about 20^{o} and appear to flatten out towards basal contact

<u>reddish brown basal conglomerate</u> - subrounded to rounded pebbles and cobbles of quartzite, quartz, chert, rhyolite, and minor granitic rock; clay casts and pellets; fines upwards into overlying unit; in scoured-contact with top of preceding cycle

The top beds of many cycles are truncated by erosion, which preceded the next cycle, to the extent that in places one conglomerate bed rests on another of a preceding cycle. Cycles range in thickness from 1 m to as much as 20 m, and individual cycles, as defined by conglomerate beds, rarely extend more than 1 km laterally.

About 1500 m above the base of the Hatchery Creek Congglomerate, the conglomerate portion of each cycle becomes less important - it contains smaller pebbles, and in places is absent. The sequence becomes dominated by fine buff sandstone and red siltstone with root casts. Within this part of the sequence, units of grey sandstone and grey to black mudstone recur at least three times; each unit, which is not more than 30 m thick and is of limited lateral extent, comprises several cycles, of which the sequence is:

<u>black to dark grey massive mudstone</u> - up to 2 m thick; vascular plant remains - stems up to 10 cm long and possible leaf impressions - and rare fish remains at the base; in upper part, grey-white limestone nodules, some of which contain disarticulated microscopic fish plates (R.S. Nicoll, BMR, personal communication 1977); mud-cracks on upper bedding surfaces

fine to medium-grained sandstone - thin; contains small pebbles; fish and plant remains showing little evidence of abrasion in one of the cycles; fish plates are disarticulated, and do not appear to lie parallel to bedding, suggesting sandstone forms one bed

pebbly medium grey coarse sandstone - thin; pebbles small, subangular to subrounded

This sequence of mainly buff sandstone and red siltstone cycles with few conglomerate beds is about 1100 m thick, and is succeeded by another series of cycles which contain a basal conglomerate similar to that in the lower part of the Hatchery Creek Conglomerate. About 300 m of this upper series of cycles is exposed, but its top is faulted out by a major reverse fault with a throw of several thousand metres.

Environment of deposition

The lower part of the Hatchery Creek Conglomerate contains features similar to those of meandering stream deposits (Allen, 1965; Visher, 1965). The coarse basal beds probably indicate a high-energy environment and a steep gradient. The extensive development of soil profiles indicates areas that were quiescent for long periods of time before later deposition. Vegetation developed on these areas and extensively churned the sediments. The red colour of non-marine sediments is generally conceded to indicate deposition in desert-like climates with infrequent flooding.

The upwards transition into finer-grained cycles represents a change to a lower-energy environment, with a shallower gradient. It presumably indicates that the source area was becoming subdued in relief, and that the piedmont slope on which the sediments were deposited was becoming more aggraded.

Within this sequence of finer cycles the grey to black sediments, which at least locally contain fish remains, are thought to represent short-lived episodes of lacustrine deposition. Features that support this hypothesis are the lack of basal scour, minor basal conglomerates, and the thick black mudstones. The mudstone may represent a quiet stage when no coarse material was deposited, and zones containing calcareous concretions indicate some development of soil profiles on the dried-out lake. The unworn fish plates, the unbroken plant remains, and unworn quartz grains in the basal pebbly sandstone indicate little transport of bed load, so the sediments may represent sheet deposition of the traction load in the earliest stages of decreasing high-energy flow; the black mudstone represents deposits from suspension during falling-flow stages. Ripples and sand laminae are not evident, perhaps because the exposures are highly weathered. Mud-cracks on the tops of some beds indicate periods of desiccation. We consider that these lacustrine sediments represent deposition in shallow lakes of limited lateral extent, into which periodic floods brought coarser material. The basin in which the lakes formed may have originated by either wind ablation or by the damming of a shallow valley by the alluvial fan of a tributary stream.

A return to coarse conglomeratic cycles higher in the sequence indicates the return of a high-energy environment, possibly owing to renewed uplift in the source area.

Thickness

The total preserved thickness of the Hatchery Creek Conglomerate is estimated to be 2900 m, but since the western boundary is a major fault this is a minimum value.

Age

Previous workers have inferred a Late Devonian age for the Hatchery Creek Conglomerate, by lithological correlation with the Hervey Group farther north in New South Wales (Pedder, 1967; Packham, 1969; Pedder & others, 1970). Before our work the only fossils known from the unit were unidentified wood fragments, and a fish plate from an unknown locality mentioned by Hills (1958).

During our mapping of the unit, calcareous nodules from one of the grey mudstones in the middle of the formation were collected for possible conodont extraction. Although no conodonts were found, microscopic fish plates were observed. Macroscopic fish remains subsequently collected at the same locality have been described by Young & Gorter (in prep.), who have concluded that the association of thelodontid agnathans, phlyctaeniid euarthrodires, pterichthyodid antiarchs, and osteolepidid rhipidistians suggests an Eifelian (early Middle Devonian) age.

Relations

Pedder & others (1970), who assigned a Late Devonian age to the Hatchery Creek Conglomerate, suggested that it overlies the Taemas Limestone (of latest Early Devonian age) disconformably, since there is no structural discontinuity between the two.

The recent evidence from fish fossils suggests an early Middle Devonian age, indicating that a disconformity - if present - represents a short time duration. The work of Young (1969) supports the presence of a disconformity, since he was able to demonstrate that the thickness of the uppermost unit of the Taemas Limestone varies by up to 130 m, which he suggests is due to erosion. The available evidence therefore suggests that the Taemas Limestone passes disconformably up into the Hatchery Creek Conglomerate.

The upper part of the Hatchery Creek Conglomerate is in faulted-contact with the Burrinjuck Adamellite and Goobarragandra Volcanics, and Tertiary basalt lava flows unconformably overlie the formation.

CAINOZOIC SEDIMENTS AND VOLCANIC ROCKS

Tertiary sediments

Sediments of known or possible Tertiary age crop out at three places in TANTANGARA and one in BRINDABELLA: Miocene sub-basaltic sediments on Bullock Hill; ferruginous gravels of presumed Tertiary age on Cooleman Plain; extensive gravels and sub-basaltic Tertiary sediments in the Yaouk/Shannons Flat area; and gravel and sand on Goodradigbee Hill, northwest of Wee Jasper.

Bullock Hill

The Bullock Hill sediments are part of much more extensive deposits to the west, outside TANTANGARA, which have been described by Andrews (1901), and Gill & Sharp (1957). The only major deposits in the mapped area are at the Six Mile (or Gooandra) diggings (grid ref. 363355) at the southern end of the Bullock Hill basalts. These were briefly mentioned by Andrews (1901, p. 19, 26), who noted their resemblance to the New Chum Hill deposits at Kiandra. He presented a cross-section of the deposits - showing a basal bed of about 5 m of auriferous gravel and coarse sand, followed by about 1 to 2 m of clay, then about 4 m of lignite, and possibly 25 m of sand, sandy gravel, clay, and lignite forming the upper unit. At the present day, little may be seen of the sediments as float and talus from the overlying basalt obscures them on natural hillslopes, and vegetation regrowth or spoil from the diggings obscures them in the workings.

Gill & Sharp (1957, p. 26) gave an age for the sediments, based on work by Cookson (various papers from 1945 to 1954) on the microflora, of late Eocene or possibly early Oligocene. Earlier, Andrews (1901) had assumed a Miocene age, although firm evidence was lacking at that time. However, Wellman (1971) has dated the basalts at Kiandra as 18 to 22 m.y. (Early Miocene). Owen (1975) has been able to confirm an Early Miocene age for the sediments, after re-examining the microflora in the sediments at New Chum Hill, Kiandra.

Cooleman Plain

The gravels on Cooleman Plain occur as thin patches overlying limestone, and are commonly formed of limonite, or hematite pebbles cemented by limonite. At some localities, such as near Blue Waterhole Saddle (grid ref. 520536), the gravels are relatively uncemented, whereas at other localities (e.g., grid ref. 519547) cementation of limonite pebbles by limonite is complete. Some of these massive limonite outcrops have developed gossanous weathered surfaces, and their origin is uncertain: they may be derived from cemented ferruginous gravels, or be true gossans. A puzzling feature of these deposits is that they apparently overlie only limestone.

Small patches of stream gravel are also preserved in the area, on the interfluves between valleys. They appear to be moderately well sorted, are well rounded, and are formed of vein quartz and locally derived igneous rocks.

The age of the deposits on Cooleman Plain is uncertain. From the presence of stream gravels on the interfluves of valleys, they appear to be associated with the planation surface on the limestone. Stevens (1958b) considered this surface to be Devonian in age, but Jennings (1971) has argued for a Late Tertiary age. A Miocene age is suggested for the Cooleman gravels.

Yaouk/Shannons Flat

Extensive areas around Yaouk and Shannons Flat are underlain by Tertiary sediments, which are divided into two groups for the purpose of description: silicified and ferruginised gravels and sandstones apparently associated with the Tertiary basalts in the south and southeast of the area; and gravel, sand, and clay forming high-level river terraces in the Murrumbidgee River valley.

Silicified and ferruginised sand and gravel (silcrete and ferricrete respectively) are common in the Shannons Flat area. They correspond to the 'greybilly' of Browne (1973), who has described many of the deposits both in the Shannons Flat/Adaminaby area and in much of the remainder of eastern New South Wales.

Major outcrops of silcrete are at Adaminaby (grid ref. 592163), Jones Plain (grid ref. 738157), north of Bolaro (grid ref. 666186), and on the Callemondah road (grid ref. 796197). The Callemondah silcrete is on top of a low ridge and is a hard white rock composed of coarse gravel to coarse sand cemented by silica. Its pebbles are well rounded, generally composed of vein quartz, and poorly sorted. It is crudely bedded in places, and its total thickness is about 5 m. Below it, 5 to 10 m of poorly exposed fine white sand and clay rest on Ordovician slate.

The outcrop of silicified sandstone at Jones Plain is similar to that at Callemondah except that it is much finer-grained, most of the deposit being fine to medium sand with some coarse. The rock is well sorted, and cementation by silica is complete, leaving no pore space. Outcrops north of Bolaro and north of Adaminaby are similar in appearance to the Jones Plain occurrence.

Ferruginised sand and gravel, in places cemented to ferricrete, are also common in the area. The main outcrop is on a basalt-topped hill north of the junction of the Shannons Flat/Cooma road and the Callemondah road (grid ref. 787183). The sediments underlie basalt, rest on leached Ordovician slate, and increase in thickness southward from about 30 m to about 45 m. They comprise interbedded slightly lithified coarse sand and fine gravel increasingly strongly cemented by limonite towards the base of the overlying basalt. At this locality, fine-grained sediments are lacking, but at Jones Plain (grid ref. 749159) a silt containing plant fragments has been completely cemented by limonite.

Several theories for the origin of the silcretes of New South Wales have been suggested, and have been summarised by Browne (1973). These usually claim a genetic relation between the silcrete and the overlying basalt. Theories proposed include that the basalt metamorphosed the underlying sediments; that silica released from the weathering of basalt was redeposited in the underlying sediments; and that basalt acted as a caprock to restrict the circulation of groundwater in the underlying sediments. Taylor & Smith (1975) have discussed the origin of silcretes south of TANTANGARA, and have presented the first detailed account of sub-basaltic silcretes. They showed that the cementing silica could not have been derived from the overlying basalt, and suggested that the basalt merely acted as a caprock enabling pore water to migrate slowly through the sediment, dissolving and reprecipitating quartz.

Taylor & Smith did not extend their work to include ferricrete, whose origin still remains a problem; presumably it is derived by a similar process of solution and reprecipitation by pore water, but of iron oxides rather than silica. However, since basalts are relatively rich in iron, the cement of the ferricrete may have been derived from the weathering of basalt. Geochemical work on the ferricrete is needed to resolve this problem.

The age of these deposits is assumed to be the same as that of the overlying basalts - that is, late Miocene.

Clay, sand, and gravel forming extensive river terraces above the Murrumbidgee River in the Yaouk area are unrelated to the sub-basaltic sediments farther east. Several terrace levels are present. The highest (at grid ref. 623300) is represented between Swamp Creek and Dog Plain Creek (grid ref. 625291) by a highly dissected gravel-covered surface about 75 m above the present level of the Murrumbidgee River. A second terrace, 60 m above the river and also highly dissected, is present around Stuartfield homestead, and a third at 50 m is present north of Swamp Creek. The most extensive terrace is at the 40-m level, and covers a large area north and west of the Murrumbidgee River at Yaouk. This level is almost completely undissected by the streams which drain it. Further minor terraces are present at various heights up to 10 m above river level.

All the terraces consist of generally unknown thicknesses of gravel, sand, and clay. The gravels are mostly poorly sorted, though well rounded, and some contain boulders up to 50 cm across. The composition of the boulders appears to remain constant on all terraces, though no quantitative analysis has been done. Granite and vein quartz predominate, and quartzite, slate, sandstone, and rare acid porphyry rocks are also present. All the rock types may be correlated with lithologies in the upstream drainage area of the Murrumbidgee River.

The only sections through the sediments are road-cuttings at grid references 618327 and 633340. Both show a series of interbedded gravels and sands partly cemented by limonite, in beds 0.5 to 2 m thick. At grid reference 618327 a white silty clay is about 20 cm thick.

The Murrumbidgee valley near Yaouk has obviously had a complex history, the details of which are not known. Even the ages of the various terraces are unknown, though the higher levels are probably of Late Tertiary age, whereas the extensive 40-m terrace is probably Pleistocene, as the streams which drain it have barely begun to dissect it; the lower terraces are probably late Pleistocene and Holocene.

Goodradigbee Hill

The only known occurrence of Tertiary sediments in BRINDABELLA is a small area of sub-basaltic gravel and sand less than 10 m thick underlying basalt on Goodradigbee Hill (grid red. 475160).

Tertiary basalt

Tertiary basalt is present in two areas in TANTANGARA. One of them, around Kiandra, forms a discontinuous zone extending from Tabletop Mountain in the southwest along the western edge of the Sheet area as far north as Peppercorn Hill, together with isolated small outcrops in the northwest. The other is in the Alum Creek valley around Shannons Flat.

In BRINDABELLA, basalt is extensive in the northwest quadrant as a series of disconnected outcrops extending from just north of Brindabella Road to the northwestern corner of the Sheet area. A small outcrop in the southwest corner of the Sheet area extends into TANTANGARA.

The Tertiary basalts of the Kiandra area occur as a series of disconnected outcrops forming small summit plateaux and ridges. The main outcrops are on Dunns Hill (southwest of Kiandra), Bullock Hill, and Peppercorn Hill. The basalts on Dunns Hill, Bullock Hill, and New Chum Hill (just west of the map area) were once part of the same flow system (Gill & Sharp, 1957; Moye & others, 1963; Mackenzie, 1968), now dissected by erosion. The relation of the Peppercorn Hill basalt to these Kiandra basalts is not known.

The basalts are poorly exposed in all areas, but boulders of basalt are common as downslope float. Individual flows are impossible to identify in the field, although drilling by SMHA at Eight Mile diggings, between Kiandra and Cabramurra (YARRANGOBILLY), has revealed at least four flows. The basalts range in thickness from 100 m on New Chum Hill to about 20 m on Bullock Hill.

Mackenzie & White (1970) have discussed in detail the petrography and geochemistry of the basalts. Two analyses given in Appendix 2 (Table A19) are similar to theirs. The main rock type is a black fine-grained basalt with common olivine, rare titanaugite phenocrysts, and rare zeolite-filled vesicles. The groundmass is composed of small calcic plagioclase laths, subhedral to euhedral pyroxene, magnetite, rare nepheline and analcime, and interstitial sodic feldspar. The rock types range from alkali basalt to basanite.

Gill & Sharp (1957) considered the basalts at Kiandra to be late Eocene or Oligocene, but K-Ar dating by Wellman & McDougall (1974) has given an age of 18 to 22 m.y. (early Miocene). K-Ar dating on whole-rock samples by AMDEL for BMR has yielded an age of 23.2 ± 0.5 m.y. for the basalt at Peppercorn Hill.

The eruptive source of the Peppercorn Hill basalt is unknown, but the Kiandra basalts are thought to have originated from Tabletop Mountain (Gill & Sharp, 1957; Moye & others, 1963), where jointing is widespread - though irregular in direction - and tuff and breccia are absent. If this is so, then Tabletop Mountain (Fig. M29) is a volcanic plug of massive olivine basalt occupying an area of about 700 m by 400 m. This interpretation is supported by the presence of a large aeromagnetic anomaly over the mountain, a feature absent over recognised basalt flows.

Basalt is fairly common in the Shannons Flat area, the largest outcrop being on an unnamed hill at grid reference 723260, at an altitude of 1400 m. Other outcrops are at grid reference 767260 (altitude 1325 m), on a ridge between grid references 763218 and 772209 (altitude 1100 m), and centred on grid reference 786194 (altitude 1100 m). The present altitudes of e basalts indicate that they flowed from the northwest; the large almost circular area of basalt at grid reference 723260 may have been the source of the flow. Again there is a strong aeromagnetic anomaly over this body, suggesting that it is a volcanic plug.

The basalts in the Shannons Flat area are similar petrographically to those near Kiandra, except that nepheline appears to be absent. Rare subrounded phenocrysts of plagioclase and titanaugite up to 1 mm diameter, and abundant

Fig. M29. Tabletop Mountain - a Tertiary basalt vent - viewed from Four Mile Hill.

(GA/6370)

euhedral to subhedral phenocrysts of olivine up to 0.8 mm diameter, lie in a groundmass of poorly aligned subhedral plagioclase laths up to 0.2 : 0.1 mm, interstitial opaque minerals, titanaugite, and pale brown devitrified glass. A few quartz xenocrysts up to 3 mm diameter are present and are surrounded by reaction rims of euhedral augite with narrow margins of pale blue-green amphibole.

The geographic location of the basalt at Shannons Flat suggests that it might be related to basalts around Cooma, which are part of the Monaro Province of Wellman & McDougall (1974). The nearest dated basalt in this province - one from 35 km southwest of Shannons Flat and 9 km southeast of Eucumbene Dam - gave a late Eocene age of 36 m.y. (Wellman & McDougall, 1974). However, three samples from Shannons Flat dated for BMR by AMDEL gave ages of 15.2 ± 0.3, 18.0 ± 0.4, and 18.2 ± 0.3 m.y. (late Miocene), significantly younger than any sample dated by Wellman & McDougall from the Cooma area. The Shannons Flat basalt, then, may be part of Wellman & McDougall's (1974) late Miocene Snowy Province, from which it is geographically isolated.

The basalts in northwest BRINDABELLA form a discontinuous series of outcrops which gradually decrease in altitude from south to north. The southernmost outcrop covers about 9 km^2 either side of Nottingham Road at grid reference 458963, at an altitude of over 1000 m. Part of this body is probably a plug and the source of the flows farther north, since it reflects an intense aeromagnetic anomaly. Several small outcrops of basalt at an elevation of 860 to 900 m are present south of Yass Road around grid reference 395110, and basalt crops out more extensively at an elevation of 700 to 750 m - north of this road - in the valley of Macphersons Swamp Creek and around Goodradigbee Hill. Farther north still a large outcrop of basalt around Hilltop (grid ref. 421203) ranges in altitude from 800 m at its southern end to 700 m at its northern end, over 6 km away. The base of the flows, therefore, gradually decreases in altitude from the probable source area in the south to the northern outcrops, 30 km away. Only one source area can be postulated, since none of the flows north of the Nottingham Road outcrop has an aeromagnetic anomaly associated with it.

The petrography of these basalts is similar to those around Kiandra. Common olivine and rarer titanaugite phenocrysts are set in a groundmass of calcic plagioclase laths, pyroxene, magnetite, rare nepheline and analcime, and interstitial sodic feldspar. Wass & Irving (1976) have reported various xenoliths from this area; they include wehrlite, chrome-diopside-bearing lherzolite, and megacrysts of anorthoclase, spinel, and clinopyroxene. The basal flow in the Macphersons Swamp Creek valley at grid reference 442146 is a nephelinite with phenocrysts of zoned clinopyroxene in a nepheline-rich groundmass; carbonate-filled vesicles are abundant, and xenoliths of clinopyroxenite and megacrysts of titanomagnetite, anorthoclase, kaerautite, and clinopyroxene are also present.

Wellman & McDougall (1974) dated a basalt from the Macphersons Swamp Creek area as 20.9 ± 0.5 m.y., in close agreement with ages farther south near Kiandra. They accordingly included these basalts in their Snowy Province.

Holocene alluvium

Small deposits of alluvium , many covering less than 100 m^2, are present along most of the streams. More rarely, extensive deposits of alluvium have accumulated, particularly along the Murrumbidgee River at the northern end of Long Plain, Tantangara Dam, Yaouk, Bolaro, and between Uriarra Crossing and Burrinjuck Reservoir. Other rivers which have formed large alluvial deposits include the Eucumbene River at Providence Portal (now covered by Lake Eucumbene); Nungar Creek, particularly on Nungar Plain; Gurrangorambla Creek on Currango Plain; Yaouk Creek at Yaouk; Little River at Adaminaby; the Goodradigbee River at Brindabella and Wee Jasper; Micalong Creek at Micalong Swamp; Tumorrama Creek at Tumorrama Swamp; and Macphersons Swamp Creek where it flows into Burrinjuck Reservoir.

Exploration work for gravel by SMHA in many places in TANTANGARA has revealed that the alluvium invariably consists of several metres of coarse unsorted gravel resting on bedrock and overlain by a surface mantle of organic-rich silt up to 1 m thick. Up to 5 m of gravel was proved by SMHA at Providence Flat on the Eucembene River, and a similar thickness was considered to be present near Tantangara Dam. Most of the other accumulations of alluvium are probably similar, though the Micalong and Tumorrama Swamps appear to have several metres of organic-rich silt with little gravel.

The alluvial gravels on the Murrumbidgee River are presently being worked at two localities in BRINDABELLA (at grid refs. 794988 and 773110), and are intermittently worked in TANTANGARA near Bolaro (grid ref. 666162).

AUSTRALIA 1:100 000 GEOLOGICAL SERIES

TANTANGARA

NEW SOUTH WALES AND AUSTRALIAN CAPITAL TERRITORY

SHEET 8626

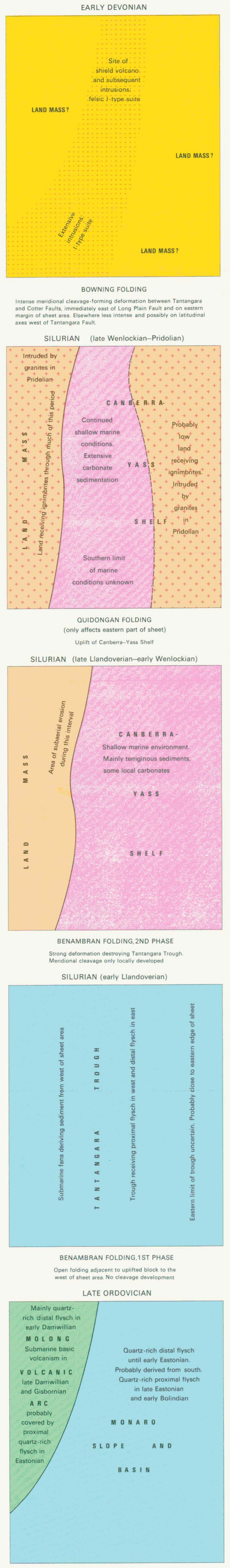
PALAEOGEOGRAPHY AND EVENTS

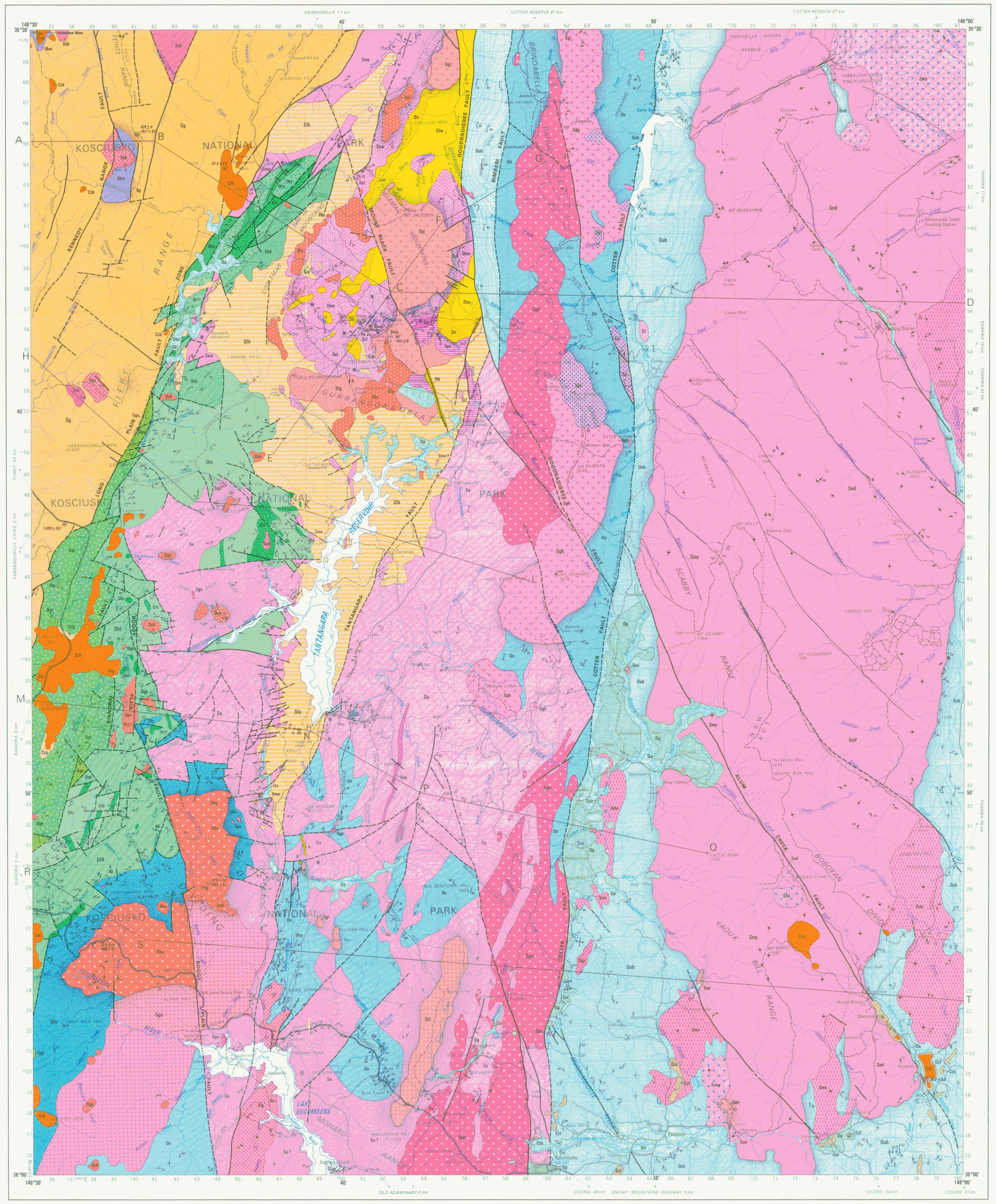
Scale 1:500 000

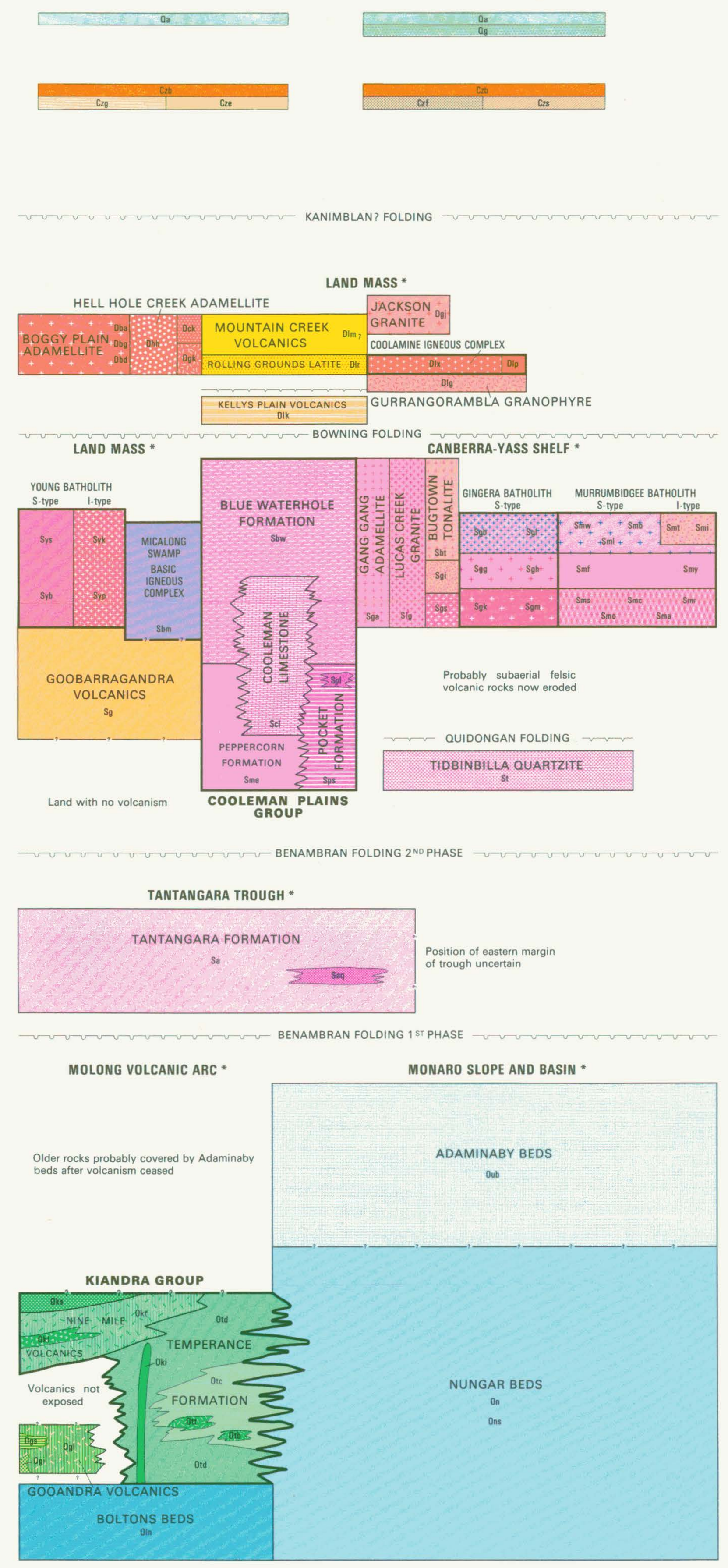
KANIMBLAN? FOLDING

Meridional open folds north of Cooleman Plain. Wrench faulting common

EARLY DEVONIAN







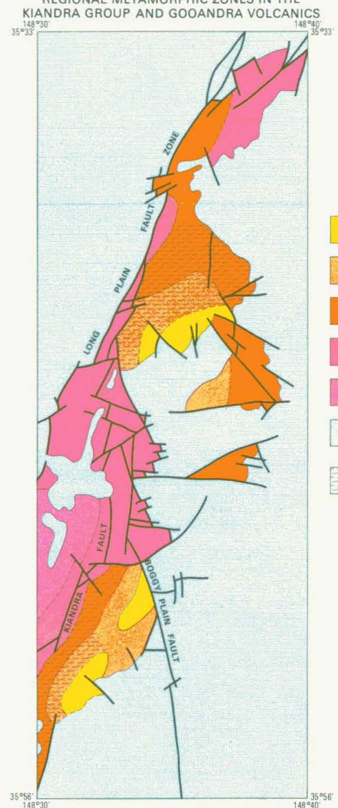
HOLOCENE	QUATERNARY		CAINOZOIC
PLEISTOCENE			
PLIOCENE	TERTIARY		
MIOCENE			
OLIGOCENE			
EOCENE			
Pragian	EARLY DEVONIAN	DEVONIAN	PALAEOZOIC
Lochkovian			
Pridolian	LATE SILURIAN	SILURIAN	
Ludlovian			
Wenlockian			
Llandoverian	EARLY SILURIAN		
Bolindian	LATE ORDOVICIAN	ORDOVICIAN	
Eastonian			
Gisbornian			
Darriwillian	EARLY ORDOVICIAN		

Boggy Plain I-type Suite

Jindabyne I-type Suite

S-type**

REGIONAL METAMORPHIC ZONES IN THE KIANDRA GROUP AND GOOBARRAGANDRA VOLCANICS



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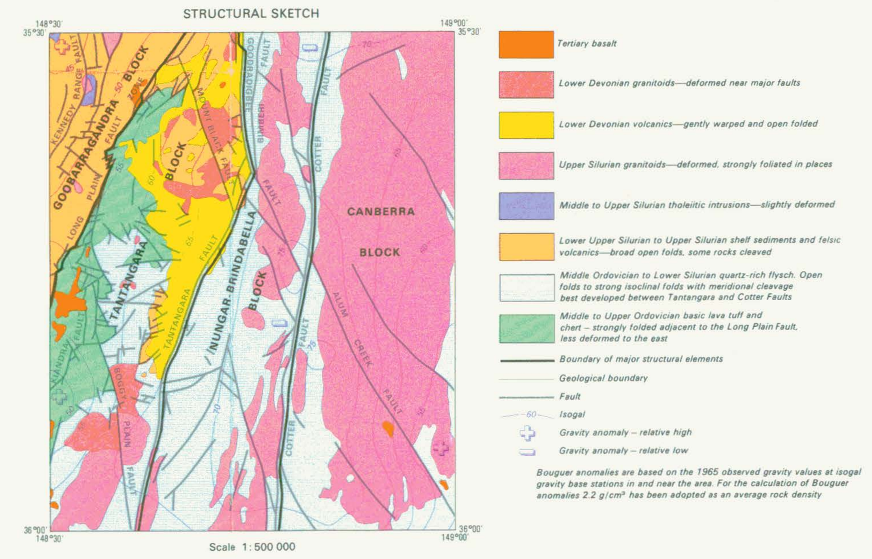
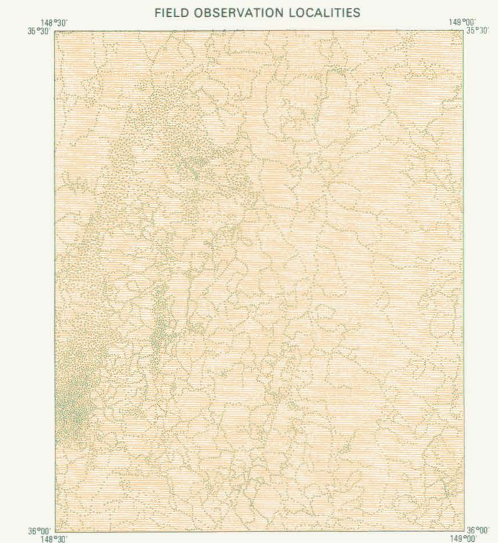
STRUCTURAL SKETCH



Scale 1:500 000

FIELD OBSERVATION LOCALITIES



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UNIVERSAL GRID REFERENCE

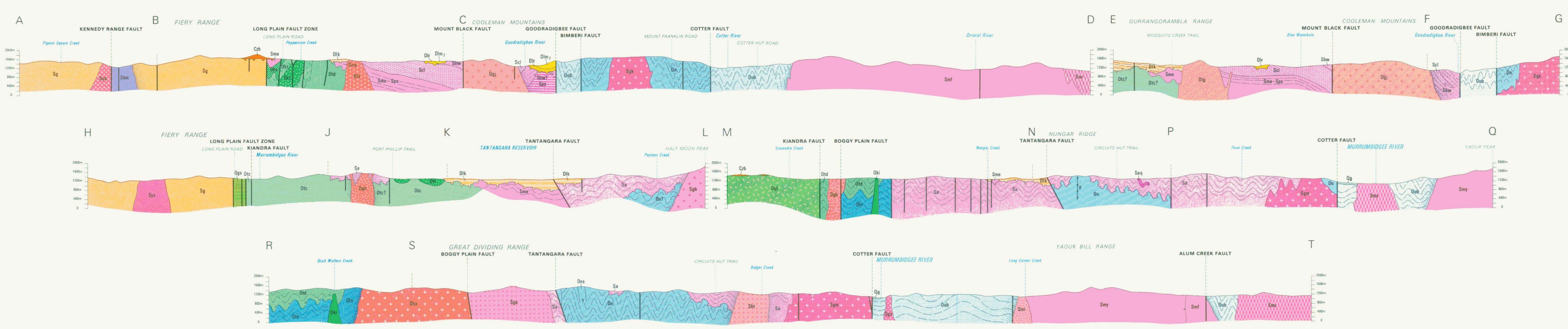
SCALE 1:100 000

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Issued under the authority of the Minister for National Development. Base map compiled and drawn by the Division of National Mapping from aerial Photography at 1:50 000 scale.

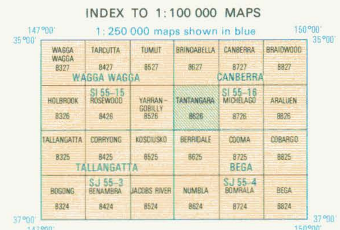
Geology 1971–73 by M. Owen, D. E. Gardner, A. L. Jaques, P. A. Langworthy, D. Wyborn, J. Saltet, P. Jell
Compiled 1973 by M. Owen, D. Wyborn, D. G. Walton, J. M. Mifsud
Gravimetry 1966 by Geophysical Branch, BMR
Total magnetic intensity contours by Geophysical Branch, BMR I 55/BI–8626
Design by Cartography Section, BMR
Drawn by Robert G. Winchester (Exploration) Pty. Limited, Canberra, ACT
Printed by Mercury-Walch, Hobart, Australia
Bibliographic reference: Owen M. and Wyborn D. 1979
TANTANGARA (NSW and ACT) 1:100 000 Geological Map
First edition. Bureau of Mineral Resources, Geology and Geophysics

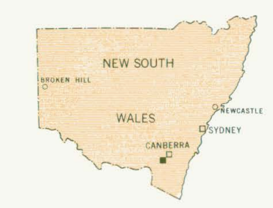
Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT, or the Geological Survey of New South Wales, Sydney

SCHEMATIC SECTIONS



INDEX TO 1:100 000 MAPS





TANTANGARA

SHEET 8626

FIRST EDITION 1979

AUSTRALIA 1:100 000 GEOLOGICAL SERIES

BRINDABELLA

NEW SOUTH WALES AND AUSTRALIAN CAPITAL TERRITORY

SHEET 8627

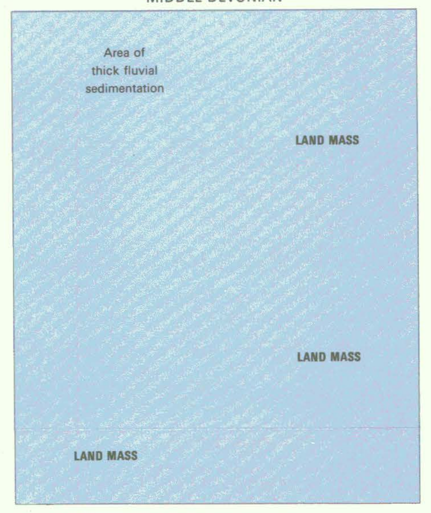
PALAEOGEOGRAPHY AND EVENTS

Scale 1:500 000

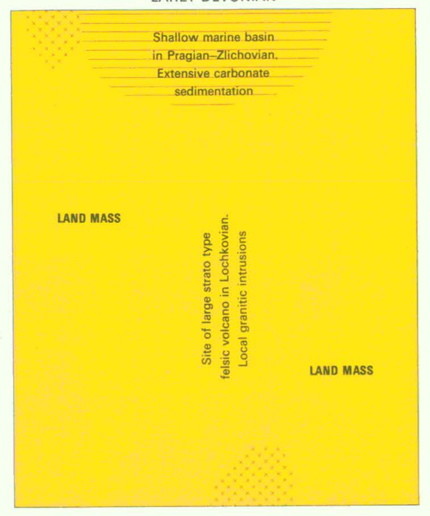
KANIMBLAN? FOLDING

Large NNW trending folds east of Long Plain Fault. Cleavage formed immediately adjacent to fault

MIDDLE DEVONIAN



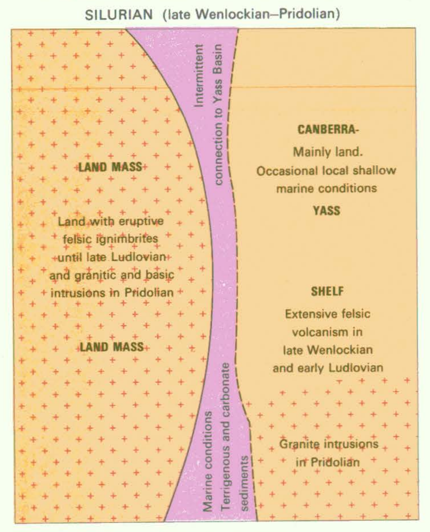
EARLY DEVONIAN



BOWNING FOLDING

Open meridional folds east of Pig Hill Fault and west of Long Plain Fault. Cleavage-forming meridional isoclinal folding between

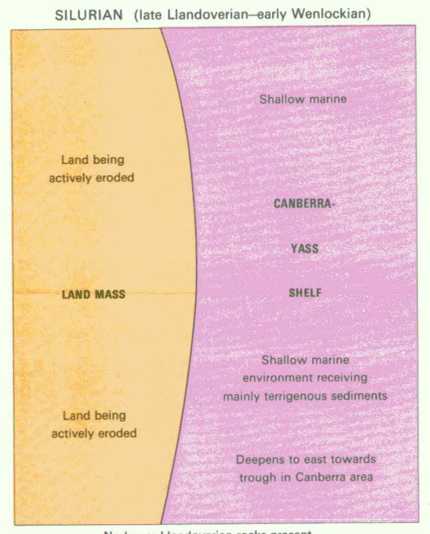
SILURIAN (late Wenlockian–Pridolian)



QUIDONGAN FOLDING

Uplift of Canberra–Yass Shelf

SILURIAN (late Llandoverian–early Wenlockian)

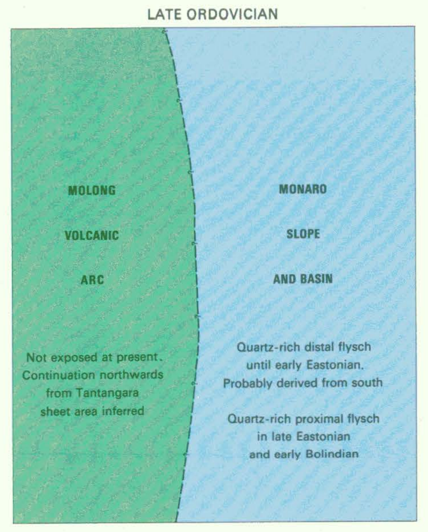


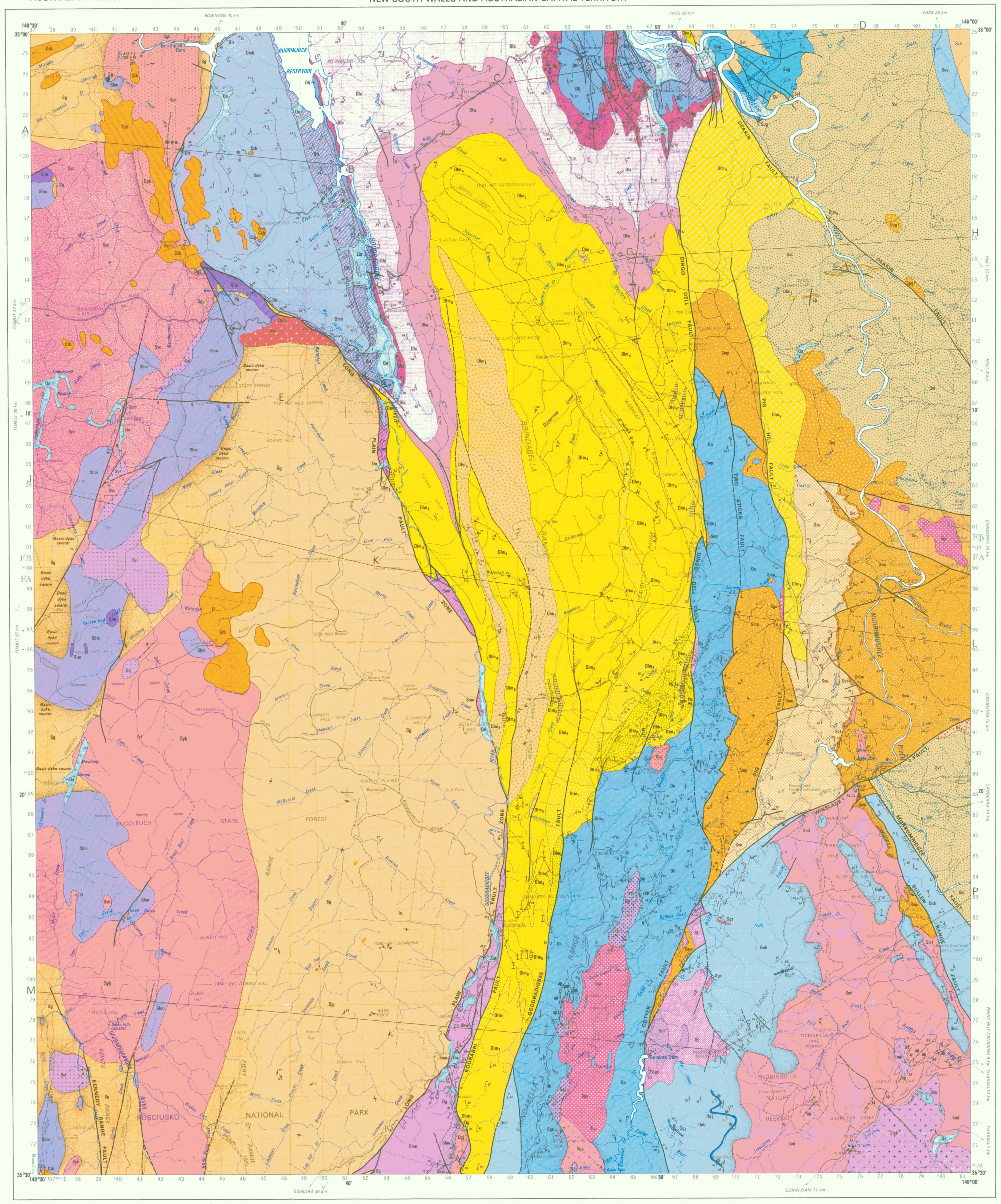
No lower Llandoverian rocks present. Probably removed by subsequent erosion

BENAMBRAN FOLDING 1ST AND 2ND PHASES

Gentle warping to open folds east of Cotter Fault. Folding probably only gentle west of Cotter Fault

LATE ORDOVICIAN





Legend

Symbol	Description
Qa	Gravel, sand, silt and clay: alluvial
Qg	High level river gravel
Czb	Alkali olivine basalt, minor nepheline basanite
Czg	Gravel and sand, locally lithified
Dmh	Conglomerate, sandstone and siltstone
Dlt	Massive to thin-bedded fossiliferous limestone and calcareous shale
Dlj	Brown to red siltstone and shale
Dlc	Medium to thin-bedded limestone and shale
Dls	Lithic arenite, siltstone and shale
Dlw	Black shale and mudstone

INTRUSIVES (Boggy Plain I-type Suite)

Symbol	Description
Dgb	Adamellite, granite, aplite
Dgj	Granite, aplite, adamellite

EXTRUSIVES

Symbol	Description
Dlm_9	Pink, green and purple tuff and ignimbrite, feldspathic sandstone and siltstone
Dlm_8	Siltstone, sandstone
Dlm_7	Interbedded tuff and rhyolite
Dlm_6	Tuff, lapilli tuff, agglomerate, minor reworked tuff and black shale
Dlm_5	Massive and flow-banded grey and dark blue rhyolite lava with minor ignimbrite
Dlm_4	Massive and banded green rhyolite ignimbrite, red plagioclase-bearing green ignimbrite, agglomerate, flow breccia
Dlm_3	Massive pink granophyric rhyolite
Dlm_2	Porphyritic ignimbrite
Dlm_1	Flow-banded dark blue and black rhyolite lava

INTRUSIVES (? I-type)

Symbol	Description
Scg	Granodiorite, tonalite
Spg	Red porphyry with quartz, plagioclase and mafic phenocrysts, rare K-feldspar megacrysts
Sp	Red plagioclase-bearing porphyry dykes

EXTRUSIVES

Symbol	Description
Svu	Dark grey to pink rhyodacite ignimbrite and air-fall tuff
Svt	Fine-grained bedded ashstone
Svl	Dark to light grey porphyritic rhyodacite ignimbrite
Sv_2	Reworked tuff

INTRUSIVES (Coodravale I-type Suite)

Symbol	Description
Syo	Granodiorite, adamellite

INTRUSIVES (S-type **)

MURRUMBIDGEE BATHOLITH

Symbol	Description
Smb	Leucogranite, aplite
Smm	Porphyritic and K-feldspar megacryst-bearing granite
Smf	Adamellite, aplite
Scf	Leucocratic quartz feldspar porphyry

GINGERA BATHOLITH

Symbol	Description
Sgl	Leucogranite, aplite
Sgg	Leuco-adamellite, aplite
Sgo	Granodiorite

YOUNG BATHOLITH

Symbol	Description
Syl	Leucogranite, aplite
Syc	Granodiorite, adamellite
Syb	Granodiorite, porphyritic granodiorite, minor adamellite

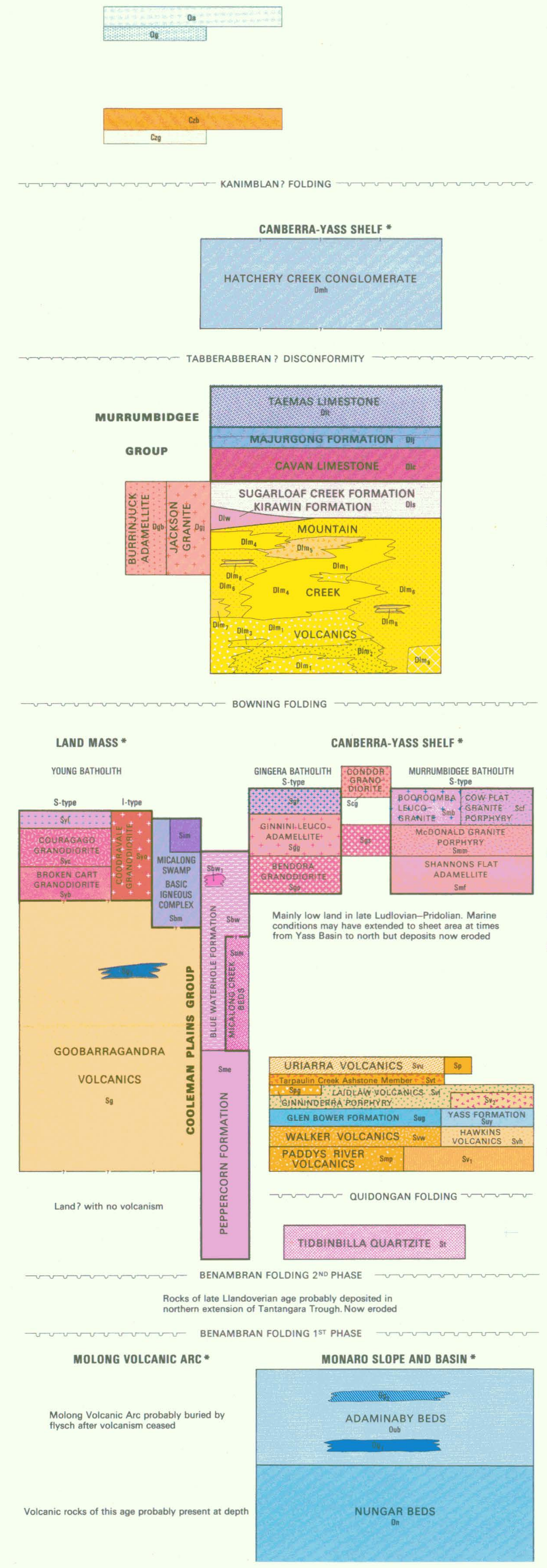
INTRUSIVES

Symbol	Description
Sgs	Quartz-feldspar porphyry, adamellite, granodiorite

EXTRUSIVES

Symbol	Description
Sg	Dacite ignimbrite, agglomerate, tuff, sediments, intrusive porphyry
Sg_1	Marble, calc-silicate hornfels interbedded in Sg
Svw	Green to purple dacite ignimbrite and bedded tuff, minor andesite, volcaniclastic sediment and limestone
Svh	Grey green dacite ignimbrite
Sv_1	Interbedded volcaniclastic sediment, dark grey ignimbrite, agglomerate and air-fall tuff
Smp	Grey green dacite ignimbrite, limestone and shale lenses, minor rhyolite and andesite

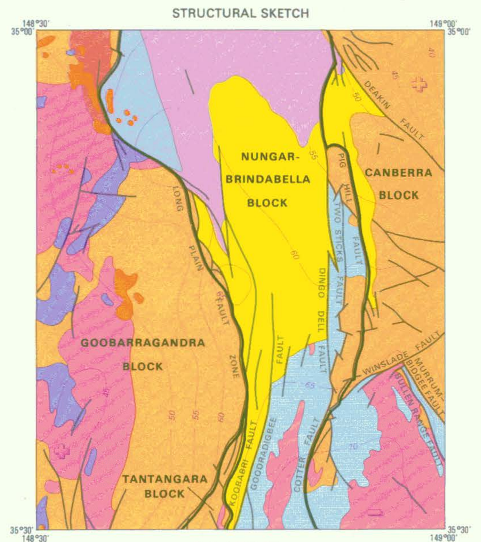
Symbol	Description
Sbm	Gabbro, hornblende magnetite gabbro, dolerite, leucogabbro, gabbro pegmatite, anorthosite, quartz gabbro
Sim	Tonalite, leucogranodiorite
Sum	Recrystallised limestone, marble and interbedded shale
Sbw	Siltstone, cherty siltstone, limestone and hornfels
Sbw_1	Calc-silicate hornfels
Sme	Arenite, siltstone and cleaved shale
Sug	Interbedded limestone, sandstone and red shale, minor conglomerate
Suy	Interbedded shale and siltstone
St	Massive to thin-bedded quartz arenite and quartzite; minor shale. Basal coarse gritstone
Oub	Quartz arenite, siltstone and shale forming a proximal flysch sequence
Og_2	Black graptolitic shale
Og_1	Black graptolitic shale
On	Quartz arenite, siltstone and shale forming distal flysch sequence



* The areas in which the rock units accumulated or to which the comments in black apply are shown in the appropriate palaeogeographical sketches at left

* * I and S-types are distinguished by chemical, mineralogical and field criteria

STRUCTURAL SKETCH



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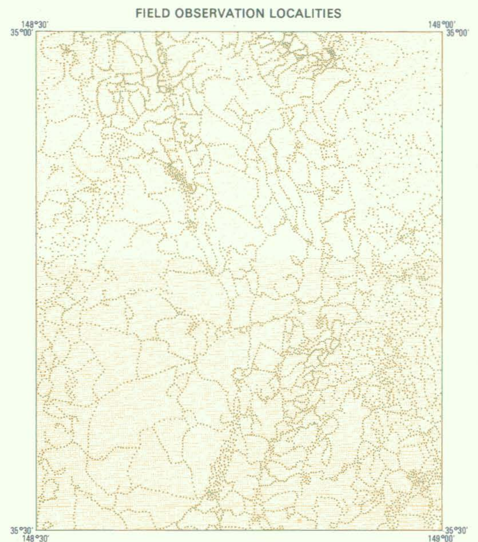
FIELD OBSERVATION LOCALITIES



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Geology 1972–74 by M. Owen, D. Wyborn, J. Saltet
Compiled 1977 by M. Owen, D. Wyborn, P. Blythe
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Total magnetic intensity contours by Geophysical Branch, BMR, I 55/B1–8626
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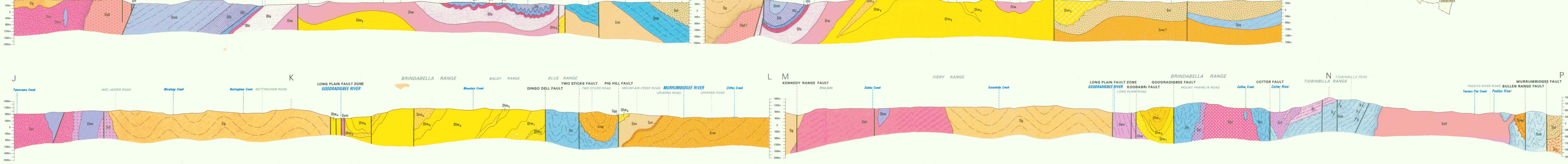
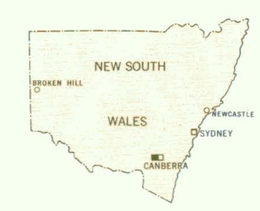
SCHEMATIC SECTIONS

Quaternary sediments omitted





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